

**INTEGRATED SCHEDULING OF PRODUCTION AND  
LOGISTICS OPERATIONS OF A MULTI-PLANT  
MANUFACTURER SERVING A SINGLE CUSTOMER AREA**

A THESIS

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MASTER OF SCIENCE

By  
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July, 2009

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# ABSTRACT

## INTEGRATED SCHEDULING OF PRODUCTION AND LOGISTICS OPERATIONS OF A MULTI-PLANT MANUFACTURER SERVING A SINGLE CUSTOMER AREA

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Increasing market competition forces manufacturers to continuously reduce their leadtimes by minimizing the total time spent in both production and distribution. Some studies in the relevant literature indicate that scheduling production and logistics operations in a coordinated manner leads to improved results. This thesis studies the problem of scheduling production and distribution operations of a manufacturer serving a single customer area from multiple identical production plants dispersed at different geographical locations. The products are transported to the customer area by a single capacitated truck. The setting is inspired by the operations of a leading soft drink manufacturer, and the objective is set in line with their needs as the minimization of the total completion time of the jobs. The completion time of a job is defined as the time it reaches at the customer area. We consider both this general problem and four special cases motivated by common practical applications. We prove that both the main problem and three of its special cases are NP-hard at least in the ordinary sense. We develop mixed integer programming (MIP) models for all these problems and propose a pseudo-polynomial dynamic programming mechanism for the remaining special case. Since the MIP models are able to provide optimal solutions only for small instances in a reasonable amount of time, heuristics are also proposed to solve larger instances. Fast lower bounds are developed to facilitate the performance assessment of these heuristics in medium and large instances. Evidence from extensive computational experimentation suggests that the proposed heuristics are both efficient and effective.

*Keywords:* Multi-plant scheduling, distribution, complexity, integer programming, heuristic

# ÖZET

## TEK MÜŞTERİ BÖLGESİNE HİZMET VEREN ÇOK TESİSLİ BİR İMALATÇININ ÜRETİM ÇİZELGELEME VE LOJİSTİK FAALİYETLERİNİN BÜTÜNLEŞİK PLANLAMASI

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Yükselen pazar rekabeti imalatçıları üretim ve dağıtımda geçen toplam süreyi en küçülterek tedarik sürelerini sürekli olarak azaltmaya zorlamaktadır. İlgili literatürdeki bazı çalışmalar üretim ve dağıtım işlemlerinin bağlantılı bir şekilde çizelgelenmesinin daha iyi sonuçlar verdiğini göstermektedir. Bu tezde farklı coğrafik yerleşimlerdeki özdeş tesislerden tek müşteri bölgesine hizmet veren bir imalatçının üretim ve dağıtım işlemlerinin çizelgelenmesi çalışılmaktadır. Ürünler müşteri bölgesine taşıma kapasitesi belirli bir araç tarafından taşınmaktadır. Problemin tanımı ileri gelen bir alkolsüz içecek imalatçısının çalışmalarından esinlenilmiş ve amaç fonksiyonu onların ihtiyaçlarıyla uyumlu olacak şekilde işlerin bitiş zamanlarının toplamının en küçültülmesi olarak belirlenmiştir. Bir işin bitiş zamanı o işin müşteri bölgesine ulaştığı zaman olarak tanımlanmıştır. Hem genel problem hem de onun pratik uygulamalarda sıklıkla karşılaşılan dört özel durumu ele alınmıştır. Hem esas problemin hem de onun üç özel durumunun NP-zor olduğu kanıtlanmıştır. Tüm bu problemler için karışık tamsayı programlama (KTP) modelleri geliştirilmiş ve geri kalan özel durum için sözde-polinom bir dinamik programlama mekanizması önerilmiştir. KTP modelleri eniyi sonuçları makul sürelerde sadece küçük örnekler için verebildiğinden büyük örnekleri çözebilmek için sezgisel yöntemler önerilmiştir. Sezgisel yöntemlerin orta ve büyük örneklerdeki performans değerlendirmesini kolaylaştırmak amacıyla hızlı alt sınırlar

geliştirilmiştir. Yapılan kapsamlı deneyler önerilen sezgisel yöntemlerin verimli ve etkili olduğunu göstermiştir.

*Anahtar sözcükler:* Çok tesisli çizelgeleme, dağıtım, karmaşıklık, tamsayı programlama, sezgisel yöntemler

To my mother...

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# Chapter 1

## INTRODUCTION

The main focus of scheduling is the allocation of limited resources to tasks over time with the objective of optimizing with respect to one or more performance measures. Recent developments in scheduling have focused on extending various classical models to address real-life problems more closely. In today's competitive business world, as the concept of on-time delivery of jobs has become more crucial for customer satisfaction, effective scheduling of production resources, achieving reduction in inventory levels and shortening lead times have gained much criticality.

Many studies in scheduling literature have concentrated on how to effectively schedule production operations within the confines of a single production facility. However, from the perspective of minimizing the total cost in a supply chain, companies usually acknowledge that the cost of a product is not only determined with the amount of factory resources used to convert the raw material into a finished product, but also with the amount of resources used to deliver the product to the customer. Hence, concentrating only on scheduling of production operations within plants may not be sufficient to obtain the desired low levels in the production and logistics costs of the supply chain. From another perspective to increase customer satisfaction, the order lead times should also be minimized. This requires the time spent both in the production of the product and in its distribution to be minimized

The importance of the coordination between production and distribution operations have been studied in Chandra and Fisher (1994), Ertogral et al. (1998), and Fumero and

Vercellis (1999). It has been shown that integrated scheduling of production and distribution operations perform substantially better than unsynchronized scheduling of these operations. Hence, it is important for the companies to recognize that a reduction in total cost of the supply chain and an increase in customer satisfaction can be realized through integrated scheduling of production and distribution operations.

In the relevant literature there have been various studies that concentrate on the integration of production and distribution operations. However, most of those studies have considered a single production plant with different machine configurations. To the best of our knowledge, there are only two studies in the relevant literature that try to address the problem with decentralized plant locations, the studies of Chen and Pundoor (2006) and Li and Ou (2007). In these works, the products have a very short selling season, and are transported from the plants to a warehouse via a third-party carrier and it is assumed that a transporter would be available at each facility whenever one is required. However, as experienced by a leading soft drink manufacturer in Turkey, third-party carriers may cause high distribution costs and long lead times. Because of increasing demand the prices of the trucks supplied by these third-party carriers are increasing while the availability of the trucks is decreasing. Therefore, aforementioned soft drink manufacturer has considered building its own fleet.

In order to address the problems faced by the soft drink manufacturer, in this thesis, we study the problem of integrated scheduling of production and distribution operations of a manufacturer with multiple production plants at different locations serving a single customer area via a single capacitated truck. Assuming that a truck is assigned to each warehouse and that truck is used to transport the products from the plants to that warehouse, our work can also be used to find a good solution for a larger system with decentralized plants and multiple warehouses.

As in the problem studied in Qi (2008), in order to satisfy unexpected customer demand on time, some companies may choose outsourcing from other plants at different

locations. Assuming that the outsourcing company has a single capacitated truck, proposed methods in this thesis can be used to address the problem of outsourcing.

The rest of this thesis is organized as follows. The next chapter gives a summary of the relevant literature in the area of integrated scheduling of production and distribution operations. Chapter 3 gives a precise explanation of the problem setting and necessary notations. In Chapter 4, dynamic programming algorithms for the problem where the assignments of the jobs to the plants are known are provided. In addition to that, heuristic and exact algorithms and lower bound generation methods for the three special cases and the original problem are explained in detail. Following that, in Chapter 5, the experimental design to test the performance of the proposed methods and the numerical results obtained in the generated test problems are given. A general conclusion of the study is presented in Chapter 6.

# Chapter 2

## LITERATURE REVIEW

There are many studies in the literature which consider the integration of production and distribution operations. We study the problem with  $m$  identical plants at different locations serving a single customer area. We consider a single truck with finite capacity to transport the jobs from the plants to the customer area. To give the related literature, we will first review the papers according to their fleet types in the Section 2.1. Then in Section 2.2, we will continue with the review of the literature based on the machine configuration and customer area properties.

### 2.1. Studies with Different Fleet Types

The fleet types considered in the scheduling literature can mainly be grouped based on two aspects: the number of trucks in the fleet and the capacity of the trucks. Most of the studies up to date assume a fleet consisting of infinitely many trucks, a few of which integrate a capacity constraint for the trucks.

The first papers in scheduling research that focuses on problems where the completion time of a job is defined as the time the job reaches the customer, mainly consider a fleet of infinitely many trucks. They do not consider a capacity constraint for the trucks. Although this assumption of infinite capacity simplifies the problem, it is not realistic. Potts (1980), Hall and Shmoys (1989), Zdrzalka (1991, 1995) and Woeginger (1994, 1998) are the

first ones to use this assumption. They assume that whenever a job finishes its production, there is always a truck available to immediately deliver the job to the customer in  $q_j$  time where  $q_j$  denotes the time required to transport job  $j$  from the machine/plant to the customer. Hence the time a job reaches the customer is the process completion time of that job at the plant plus the transportation time of that job.

In the studies of Cheng et al. (1996), Cheng and Gordon (1994), Cheng et al. (1997) and Wang and Cheng (2000), the delivery time of a batch is defined as the completion time of the last job in that batch. Here, the transportation is assumed to be instantaneous. However, the objective functions to minimize contain a term for delivery cost and delivery cost depends on the number of deliveries made to transport all the jobs from the plant to the customer. Hall and Potts (2003) make the same instantaneous transportation assumption in their paper that studies scheduling problems in a supply chain where a supplier makes deliveries to several manufacturers. Also these manufacturers make deliveries to customers. Again in the study of Qi (2006), the transportation from the facility to the customer is assumed to be instantaneous. However, for the transportation between facilities at different locations, infinitely many trucks are used and a transshipment time is required.

The study of Hall and Potts (2005) also investigates the condition where there are infinitely many trucks. However, they also consider the case when there is only one truck. They combine these two different truck constraints by defining a parameter  $T$  which denotes the minimum time between any two consecutive deliveries. If there are a sufficient number of trucks,  $T$  is defined as the time it takes to load a truck; else if there is a single truck, it is defined as the travel time to and from the customers plus the loading time.

The papers of Pundoor and Chen (2005) and Chen and Vairaktarakis (2005) consider the case with a fleet of infinitely many trucks. However, their fleet choice is more realistic when compared with the aforementioned ones since they take the capacity constraint into account. In Chen and Vairaktarakis (2005), it is assumed that distribution operations are



carried out by third-party carriers and thus an unlimited number of vehicles are available. But due to limited vehicle capacity, each truck can carry up to a certain number of jobs. The same third-party carrier assumption with vehicle capacities also holds in the study of Li and Vairaktarakis (2007).

Chang and Lee (2004) study a more difficult problem by considering a single and capacitated truck. They define the completion time of a sequence as the time when the vehicle finishes delivering the last batch to the customer site(s) and returns to the machine(s). The reason for this definition is that to have a cyclic pattern they have to wait for the truck to return to the machine. An interesting point to mention about their study is that they assume each job might occupy a different amount of physical space in the truck. Li et al. (2005) also incorporate the same single and capacitated truck idea in their study. However, their capacity constraint is defined so that the truck can also behave as uncapacitated. They define the capacity of the truck to be  $K$  and they add that  $K$  can also be equal to the number of jobs, i.e.  $n$ , which means an unlimited capacity.

Although it may seem that third-party carrier assumption is reasonable, it should also be taken into account that to decrease transportation cost, many manufacturing companies prefer to build their own fleet. Since the number of trucks in such a fleet will be limited, the assumption of infinitely many trucks becomes unreasonable. It is also for sure that for a more realistic assumption, each truck will have a capacity constraint. From this perspective, Lee and Chen (2001) can be considered as a milestone in the literature relevant to the integration of production and distribution. They study two classes of transportation: within the facility and from the facility to the customer. For both transportation classes, they consider various types of fleet. The types of fleet they assume in their study can be listed as follows:

- Single truck which can carry only one job at a time
- Single truck which can carry more than one but fewer than  $n$  jobs
- Single truck which can carry  $n/2$  jobs

- Multiple but limited number of trucks, each can carry more than one but fewer than  $n$  jobs

Although single truck case has been studied before, Lee and Chen (2001) is the first to consider multiple trucks.

As mentioned in Chapter 1 for the soft drink manufacturer, using third-party carriers may cause high distribution costs and long leadtimes. To reduce the distribution costs and leadtimes, it is a reasonable alternative for the companies to have their own fleet instead of using third-party carriers. It is logical for large companies to assign a truck to each of their warehouses and each warehouse would be responsible from using its own truck to have their products delivered to them from the plants. In this context, in our problem, having a single truck with a finite capacity is realistic. Also, for a small company which uses outsourcing from plants at different locations, having a single capacitated truck to gather the products from other plants is logical.

## **2.2. Studies with Different Machine Configuration and Customer Area Properties**

In the literature relevant to simultaneous scheduling of production and distribution, there have been various studies considering different types of machine configurations and different structures for the customer location, e.g.. a single customer area or multiple customer areas. For the machine configuration part, there are many papers that study single machine, parallel machines or a series of flow shop machines. So it would be beneficial to group the relevant literature according to their combinations of machine configuration and customer area. In such a case, four main groups may occur:

- Single machine and single customer area

- Single machine and multiple customer areas
- Multiple machines and single customer area
- Multiple machines and multiple customer areas

We will review the studies in each group in the same order as they are stated above.

### **2.2.1. Single Machine and Single Customer Area**

Most of the papers, especially the earliest ones, in the relevant literature consider this case in their studies. The reason for this is that single machine scheduling is relatively easier than multiple machine scheduling. Also sending the jobs to a single customer area eliminates routing issues and hence the problem becomes easier. Some of the papers in this area consider batching, which means that each batch will consist of a pre-specified amount of jobs. We will first review the studies which do not consider a batch concept as defined above.

The first paper that considers the scheduling of the production on a single machine and delivery of the finished products to a single customer is the study of Potts (1980). In his paper, Potts tries to find a sequence for the jobs, each of which has a release date ( $r_i$ ), a nonnegative processing time ( $p_i$ ) and a delivery time ( $q_i$ ). The objective is to minimize the time by which all jobs are delivered. One of the interesting points in this study is the *symmetric form* of the original problem created by defining due dates for each job  $i$  by assigning  $d_i = K - q_i$  where  $K$  is a constant. This forms a modified problem in which due dates replace the delivery times. Hence, minimizing the makespan in the symmetric form is equivalent to minimizing maximum lateness with respect to the due dates. This problem was shown to be NP-hard by Lenstra et al. (1977) and Potts develops a heuristic that is guaranteed to produce a solution within 50% of the optimum.

Hall and Shmoys (1989) also consider release times, processing times and delivery times for the jobs. With a similar modification of the problem as in Potts (1980), they convert the makespan problem into a maximum lateness problem. They denote the problem as  $1|r_j|L_{\max}$  using the notation of Graham et al. (1979) and they provide a polynomial time approximation scheme for this problem. For the special case, where  $r_j = 0$ , they use the Jackson's Rule to solve the problem optimally in polynomial time. They also investigate the case where precedence constraints between jobs are involved. They provide a  $(4/3)$ -approximation algorithm for  $1|r_j, prec|L_{\max}$ . Hall and Shmoys (1992) give a detailed explanation of their  $(4/3)$ -approximation scheme and provide two polynomial approximation schemes for the problem  $1|r_j|L_{\max}$ . Woeginger (1994) considers similar job properties but with the exception that he does not take release times into account. For the single machine case, Woeginger modifies the problem as in Potts (1980) and transforms it into  $1||L_{\max}$ . It is stated that sequencing the jobs in non-increasing delivery times, i.e. sequencing the jobs according to *earliest due date* rule, yields an optimum schedule in  $O(n \log n)$  time. The author also claims that no algorithm that is asymptotically faster than  $O(n \log n)$  can construct an optimum schedule for this problem.

Lee and Chen (2001) consider two different objectives in their study: minimizing the time by which the last job reaches the customer and minimizing the total flow time. The main importance of their study is that they assume a limited number of trucks with finite capacity and hence there is not a delivery time assigned to each job. In fact the delivery time for each job is determined by the distance of the machine to the customer. For the objective of minimizing the makespan, the paper shows that this single machine problem with multiple trucks can easily be converted to a parallel machine problem where each truck is treated as a machine. The modified problem is denoted as  $Pv|r_j, p_j \equiv p|C_{\max}$  where  $v$  is the number of trucks,  $p$  is the time to travel from the machine to the customer and turn back to the machine. It is stated that this problem can be solved optimally in polynomial time. For the total flow

time case, a polynomial time dynamic programming algorithm is presented. Later Li et al. (2005) present a more efficient dynamic programming algorithm for this case. Chang and Lee (2004) consider a similar problem but with a single truck condition. It is shown that minimizing the makespan subject to these constraints is NP-hard in the strong sense. The authors provide a heuristic for the problem which produces solutions with an error bound of  $5/3$ .

Hall and Potts (2005) again study the single plant and single customer area setting with finitely many capacitated trucks, but also in order to minimize the number of trips required to deliver all the jobs, the authors include the transportation cost into their objective functions. Their study considers a constraint  $T$ , which denotes the minimum time interval between two consecutive deliveries which was explained in more detail in Section 2.1. For the problems  $1|T|Dy + \sum C_j$ ,  $1|T|Dy + L_{\max}$ , and  $1|T|Dy + \sum U_j$ , where  $D$  denotes the delivery cost for each trip and  $y$  denotes the number of trips, polynomial time algorithms are provided to find an optimal schedule whereas for the problems  $1|T|Dy + \sum w_j U_j$  and  $1|Dy + \sum T_j$  pseudopolynomial algorithms are presented. The study also shows that recognition versions of problems  $1|Dy + \sum w_j C_j$  and  $1|T|Dy + \sum w_j C_j$  are unary NP-complete. Chen and Vairaktarakis (2005) also incorporate distribution cost into their objective functions but differently from Hall and Potts (2005) infinitely many capacitated trucks are considered. The objective is to minimize total distribution cost and mean (or maximum) delivery time simultaneously and polynomial time algorithms are provided for these problems.

In Li and Ou's (2005) work, a single capacitated truck is used to carry unprocessed jobs from the warehouse to the plant and processed jobs from the plant to the warehouse. The study aims to minimize the makespan and polynomial time algorithms for some special cases and a heuristic for the general problem are proposed.

Although Qi (2006) considers two machines at different locations, since each machine serves to its own customer area, it is more suitable to review this study in this section. The reason for the authors to mention the locations of the plants is that whenever the demand in one of the processing facilities, named *facility 1*, exceeds its capacity the other facility's, named *facility 2*, capacity may be used and the jobs processed there should be transferred to *facility 1* again. Then the jobs are delivered from *facility 1* to its customer. Both batch transshipment and item transshipment are considered under different objective functions and algorithms (mostly dynamic programming) are developed for them.

The notion of batching starts with Zdrzalka (1991). In this study, a unit setup time associated with switching from jobs in one batch to those in another is inserted. Three polynomial time heuristics so as to minimize the time by which the last batch reaches the customer are proposed. Zdrzalka (1995) generalizes the problem to sequence independent setup times and provides two approximation algorithms with the worst-case performance ratio of  $3/2$ . In Woeginger (1998), a polynomial-time approximation scheme is provided for the problem in Zdrzalka (1995). In addition to that, it is shown that finding a polynomial-time approximation algorithm with constant worst-case ratio is not possible for a variant of the problem where sequence-dependent setup times are involved. Setup times are involved also in the study of Cheng et al. (1997). The authors assume that there is a constant setup time between two consecutive batches. The objective is to find a number  $B$  of batches and a sequence so as to minimize the sum of the total weighted job earliness and mean batch delivery time. They prove that the problem is NP-hard in the strong sense. It is stated that even for the case where the number of batches has a fixed upper bound, the problem is NP-hard in the ordinary sense and a dynamic programming algorithm which solves this problem in pseudopolynomial time is provided. For this upper bound case, it is shown that the complexity does not change even if the setup times are equal to zero. Also the authors prove when  $B$  has a fixed lower bound the problem remains strongly NP-hard. For the special cases where all the weights are equal or all the processing times are equal, polynomial time algorithms are derived. Finally, a heuristic approach is presented for the general problem.

Cheng and Gordon (1994) again consider the batching concept on a single machine scheduling environment. The objective is to minimize the total distribution cost that mainly depends on the number of batch deliveries. The authors provide a dynamic programming approach which yields two pseudopolynomial algorithms when the number of batches has a fixed upper bound. In this study the authors also consider a special case where the processing times of the jobs in the same batch are assumed to be equal. A polynomial algorithm for this special case is presented.

### **2.2.2. Single Machine and Multiple Customer Areas**

There are not many studies that fall into this category. The main reason for this is that routing decisions may be involved when there are multiple customers at different locations.. Also the properties of the batches are again determined according to these routing decisions. Although we consider identical plants at different locations and a single customer area in our study, this case has considerable importance for our research. In order to get an intuition for our study, it is possible to think the reverse of this multiple customer areas case.

Considering multiple customer areas is a relatively new concept and the study of Chang and Lee (2004) is among the first papers in this area. Two customer areas are considered and the finished products are delivered with a single and capacitated vehicle allowing milkrun. The distances from the machine to each customer are prespecified. The objective is to minimize the time by which all the jobs reach their customers. All jobs delivered in one shipment are called as a batch and it is stated that if the assignment of the jobs to the batches is known, the problem can easily be converted to a two-machine flow shop problem with the objective of minimizing the makespan where the vehicle is seen as the second machine. For this special case Johnson's rule solves the problem optimally. However, the original problem is shown to be NP-hard in the strong sense. A heuristic is provided that yields solutions with a worst case error bound of  $7/4$ .

Pundoor and Chen (2005) consider the case with  $m$  customers positioned at different locations. It is assumed that only direct shipping from the supplier to the customer is used, i.e. no milkrun. Therefore, only the jobs associated to the same customer can be delivered together in a shipment. A combined objective function which considers both the maximum tardiness and the total distribution cost is used. It is shown that for arbitrary number of customers, the problem is NP-hard even for the special case where the processing times and due dates are agreeable (i.e. if  $p_i \leq p_j$  then  $d_i \leq d_j$ ). A fast heuristic which is capable to generate near optimal solutions is provided. One of the most important properties of this study is that they have showed that using the integrated production-distribution approach is more advantageous when compared to the approach of optimizing production and distribution sequentially with little or no integration.

The study of Chen and Vairaktarakis (2005) is important as it considers all the machine configuration and customer area cases. In this section, we will only review the single machine and multiple customer case. They allow milkrun in their study and determine the distances of the customers to the processing facility according to the milkrun routes. Their objective is to minimize total distribution cost and mean (or maximum) delivery time simultaneously and they provide efficient dynamic programming algorithms to solve these problems optimally.

Li et al. (2005) is one of the studies we base our research on. This study considers  $m$  customers at different locations and aims to minimize the total flow time. First, the problem is proven to be NP-hard in the strong sense. For the case where milkrun is allowed, first a pseudopolynomial dynamic programming algorithm for two-customers is provided and then generalized to multiple customers. Another dynamic programming algorithm for the case with only direct shipments is presented. The authors conclude that the computational complexity is lowered when the deliveries are restricted to direct shipments.



### **2.2.3. Multiple Machines and Single Customer Area**

This is the second most widely studied case after single machine and single customer area. In this section, we consider mainly two types of problems. The first type is with a single production plant that has different machine configurations such as parallel machines, flow shops, and job shops. The second type considers multiple production plants dispersed at different geographic points where each plant can be viewed as a single machine. The problem studied in this thesis is among the second type. In our research we consider  $m$  identical machines at different locations and a single customer area. Delivery to the customer can be made from all of the plants via a single truck with a certain capacity. To the best of our knowledge, no one has studied this problem before. In our problem only direct shipments are allowed. Most of the studies in the relevant literature consider direct shipments. The studies that consider milkruns will be mentioned both in this and the following section.

Most of the work issuing multiple machines and a single customer area address the problems where the machines are located at the same location, i.e. parallel or flow-shop machines. The studies with parallel machines can be regarded as special cases of our problem where the distances between the machines are negligible and products of different machines can be transported on the same shipment.

Hall and Shmoys (1989) consider two multiple machine problems in their study. In the first one, their objective is to minimize maximum lateness of jobs with respect to release dates and delivery times in a parallel machine environment. They provide a polynomial approximation scheme for the case without precedence constraints and a 2-approximation algorithm for the case considering precedence. A two-machine flow shop environment is considered for the second problem. They have specified the special case where all release dates equal zero and stated that Johnson's rule solves the problem optimally. Then as in the parallel machine case, they provide a polynomial approximation scheme for the general problem. Woeginger (1994) showed that even for the case without release dates the problem

is NP-hard when the objective is to minimize the makespan. Two heuristics with the best one having a worst-case performance guarantee of  $2 - 2/(m+1)$  are provided.

In the study of Wang and Cheng (2000), it is shown that parallel machines problem with the objective of minimizing total flow time and delivery cost is NP-hard in the strong sense and a dynamic programming algorithm is provided to solve it. Also polynomial time algorithms to solve the special cases where the job assignments to machines are given or the processing times are equal. Chen and Vairaktarakis (2005) has the objective of minimizing mean/maximum delivery time and total distribution cost and proves the problems to be NP-hard. The study also provides polynomial algorithms for the special cases where they consider only the total distribution cost.

As in the single machine and single customer case, Hall and Potts (2005) consider a constraint  $T$  that denotes the minimum time interval between two consecutive deliveries. It is shown that the recognition versions of the problems  $P2 \mid \mid Dy + \sum C_j$  and  $P2 \mid T \mid Dy + \sum C_j$  are binary NP-complete ( $Dy$  denotes the delivery cost). Pseudopolynomial algorithms are provided for the problems  $P2 \mid \mid Dy + L_{\max}$ ,  $P2 \mid T \mid Dy + L_{\max}$ ,  $P2 \mid \mid Dy + \sum w_j U_j$  and  $P2 \mid T \mid Dy + \sum w_j U_j$ . Chang and Lee (2004) also study the two parallel machines problem but with a single and capacitated truck and with the objective of minimizing the makespan. A heuristic with a worst-case performance ratio bound of 2 is presented in this study.

Lee and Chen (2001) study a two-machine flow shop environment with delivering products to a single customer area with the objective of minimizing the makespan. This study is different in the way that it considers both the transportation inside a manufacturing facility (type-1 transportation) and the transportation between the facility and the customer (type-2 transportation). It is shown that type-1 transportation problems, where there exists a single truck that can carry only one job at a time or more than three jobs, are strongly NP-hard. A dynamic programming algorithm that solves the problem in polynomial time is provided for

the case where the processing times of all jobs are equal for the same machine. For type-2 transportation where jobs are first processed on a two-machine flow shop, then delivered to the customer by a single truck, the problem is shown to be strongly NP-hard when the truck can carry only one or more than four jobs at a time and they provide a heuristic for this problem.

Although most of the studies in the literature discussed in this section consider the problems with multiple machines at the same plant, there are also a few papers that address the problems with plants at different locations. These studies are very important for our research since they use the same machine and customer settings with our problem. However, since all of these studies consider infinitely many trucks, our research remains to be the first study in this machine and customer setting that takes the truck availability into account. Chen and Pundoor (2006) deserve particular attention since this is the first study to consider decentralized machines in this context. The authors define a problem where the products are produced on plants at different locations, and transported to a single warehouse assuming that there is a truck available at each plant at any time. Assigning a certain cost for each delivery trip, the aim of the study is to minimize four different objective functions in this problem setting:

- Problem 1: Minimizing a weighted sum of the total lead time and total cost
- Problem 2: Minimizing the total cost subject to the constraint that the total lead time is no longer than a given threshold
- Problem 3: Minimizing a weighted sum of the maximum lead time and total cost
- Problem 4: Minimizing the total cost subject to the constraint that the maximum lead time is no longer than a given threshold

All these four problems are shown to be NP-hard, and heuristics for those problems are developed in their study. Also, polynomial time exact algorithms are presented for some special cases. Li and Ou (2007) study a similar problem to the one in Chen and Pundoor

(2006); with the distinction of considering jobs with multiple tasks where each task of a job must be processed by a specific machine.

Both Chen and Pundoor (2006)'s and Li and Ou (2007)'s works are designed for time-sensitive products that have a large variety, a short life cycle, and are sold in a very short selling season. In this setting, using third-party carriers and hence assuming infinitely many trucks is logical. However, the work in our study is generally designed for companies using their own fleet or for small companies that might require outsourcing. Therefore, assuming infinitely many trucks would not be a logical assumption in our setting. On the other hand, having a single truck and taking truck availability into account is a more realistic assumption for our research setting.

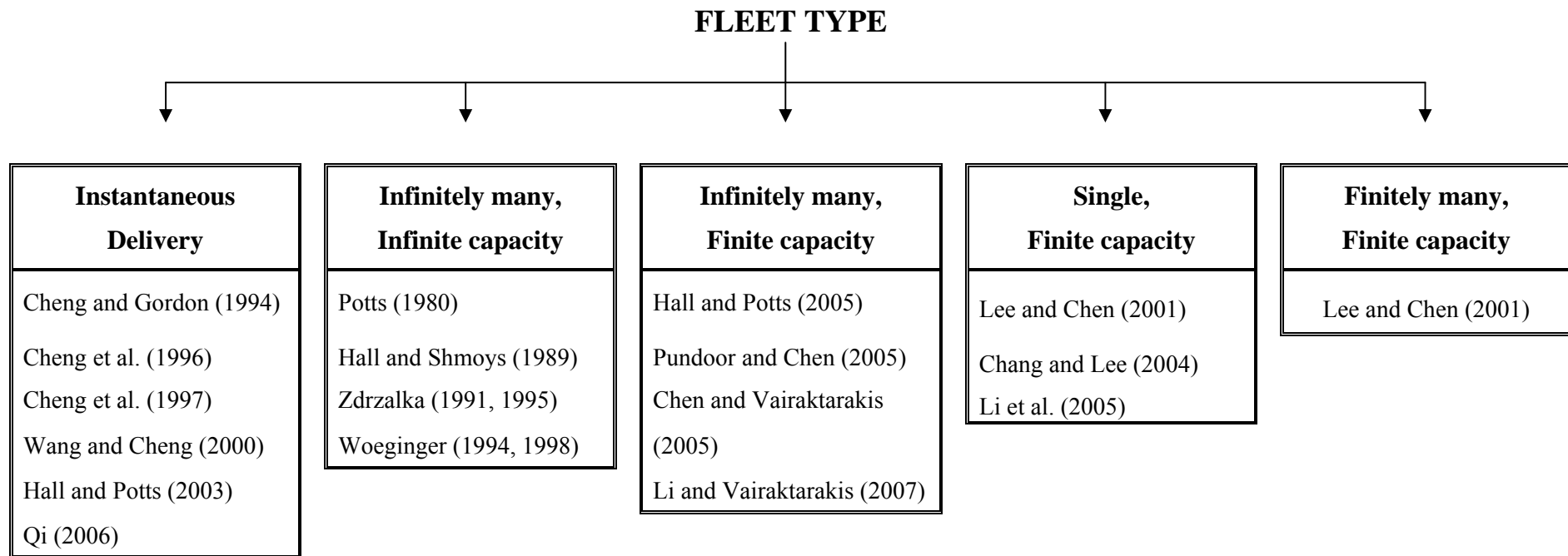
#### **2.2.4. Multiple Machines and Multiple Customer Areas**

As the number of multi-facility companies increase, the need for the realistic models that consider multiple machines also increase. When it is assumed that shipments to the customers are made directly from the facilities without using a warehouse, it is reasonable to consider multiple customer areas. One of the studies that consider this case is the paper of Chen and Vairaktarakis (2005). They consider parallel machines to process the jobs and delivery of the products to the customers at different locations allowing milkrun. The problems under the objective of minimizing total distribution cost and mean/maximum delivery time are shown to be NP-hard and heuristics are provided for these problems.

The second and to our knowledge the last paper that considers this case is Li and Vairaktarakis (2007). The authors study an integrated production and distribution scheduling system where the jobs are processed on two flow shop machines which are located at the same facility and their output bundled together for delivery. The objective is to minimize the total delivery cost and the customers' waiting costs that depend on the arrival times of the

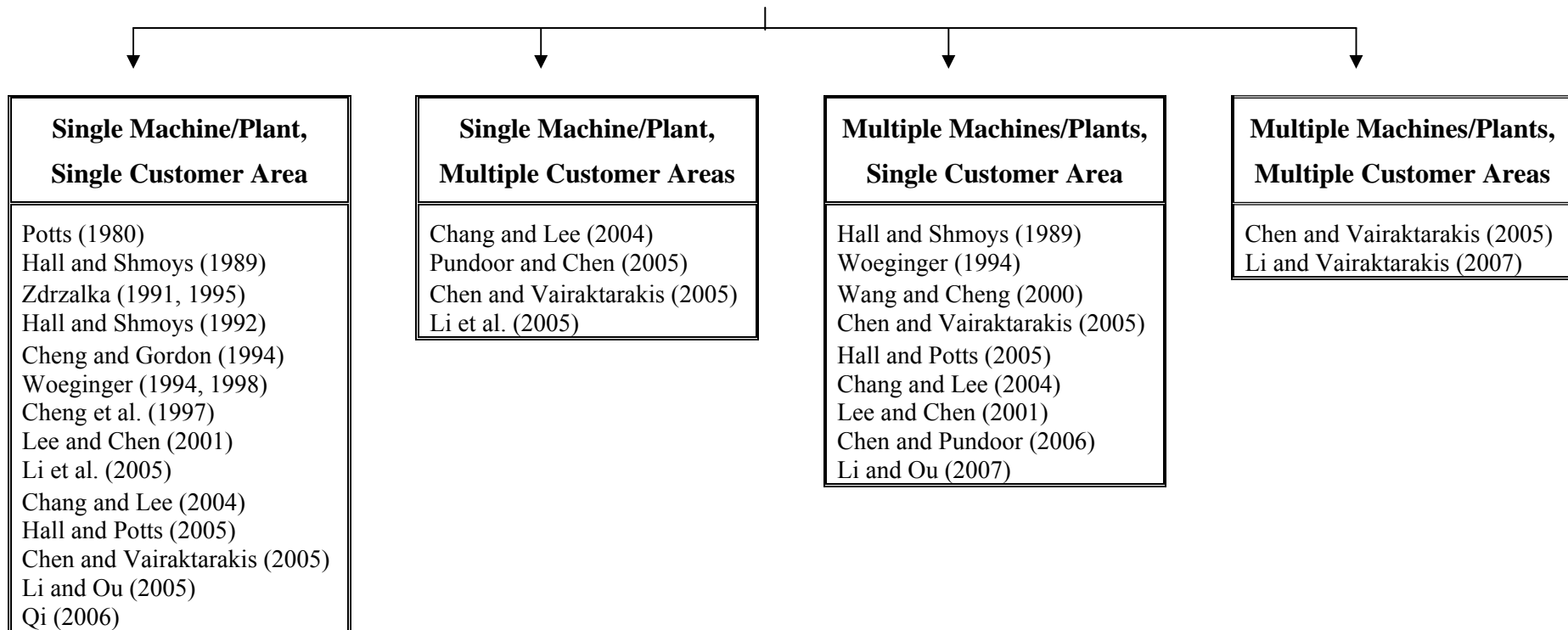
jobs at the customers. Both direct shipments and milkruns are considered. A polynomial time approximation scheme is provided for the special case with the objective of minimizing total flow time. For the original problem, heuristics with constant worst-case error bounds are presented.

Figures 2.1 and 2.2 show the classification for the literature presented in this chapter.



**Figure 2.1:** Literature classification for fleet type

## MACHINE/PLANT CONFIGURATION AND CUSTOMER AREA PROPERTIES



**Figure 2.2:** Literature classification for machine/plant configuration and customer area properties

# Chapter 3

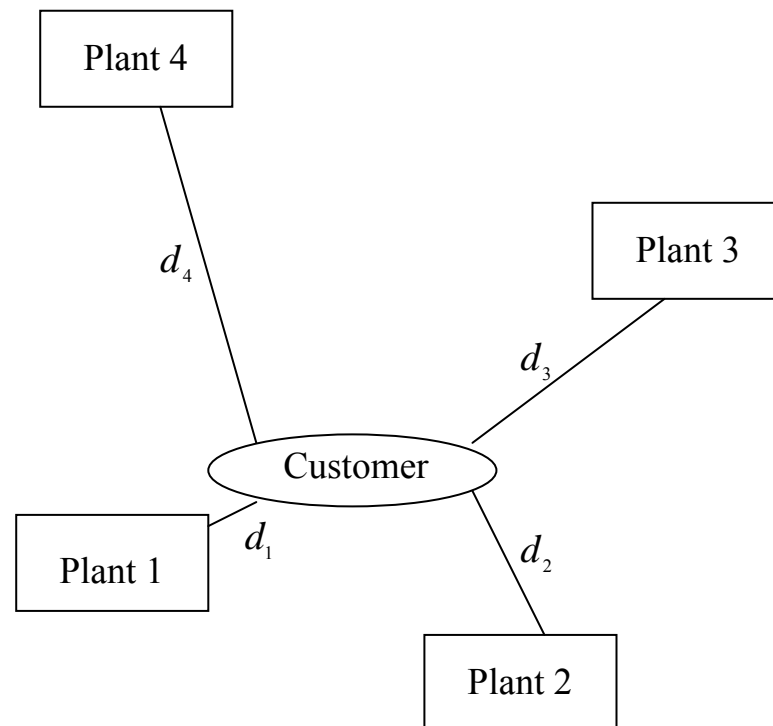
## PROBLEM DESCRIPTION AND NOTATION

In this thesis, we work on a problem that considers simultaneous scheduling of production and transportation operations of a multi-plant manufacturer. The plants are located at different geographical points. The products produced in these plants are distributed to a single customer area using a single capacitated truck. Here the customer area may denote a single warehouse as well as multiple customers that are in close proximity to each other.

Consider a set of  $n$  jobs,  $N = \{1, 2, \dots, n\}$ , each of which is to be processed in exactly one of the  $m$  plants,  $M = \{1, 2, \dots, m\}$ , positioned at different locations. We assume that plants are identical (there is a dedicated production line in each plant for the customer area), and every plant can process all jobs. It takes  $p_j$  units of processing time to produce job  $j$ ,  $j \in N$ , on any of the plants. Job  $j$  is denoted as  $J_j$ . Each job needs to be processed on only one of the plants without interruption. Preemption is not allowed. Each finished job should be transported from the plant on which it is produced to the customer. A job cannot be transported unless it has completed its processing in the plant. The distance of plant  $i$ ,  $i \in M$ , to the customer is denoted as  $d_i$  and given in time units. Hence, in other words, it takes the transporter  $d_i$  units of time to go from plant  $i$  to the customer. It is assumed that the travel time from a plant to the customer is equal to the travel time from the customer to that plant. Distribution of finished jobs from the plants to the customer is done by a single



truck which can carry up to  $K$  jobs. Loading and unloading times are assumed to be negligible. Only direct shipments are allowed. To the best of our knowledge, in practice, companies with multiple plants try to allocate those plants so that they will be able to serve as many warehouses as possible. Since they do not require the plants to be in close proximity of each other, it can be assumed that those plants may be distant to each other. Therefore, our assumption of direct shipments is reasonable. Initially, the truck is assumed to be located at the customer area and for convenience each shipment (i.e. each visit of the truck to a plant) will be called a *trip*. A simple representation of plant locations and their distances to the customer area can be seen in Figure 3.1 for an example with 4 plants.



**Figure 3.1:** A representation of plant locations and distances to the customer area

Without loss of generality, throughout this thesis, the plants are named according to their distances to the customer area. The plant with the smallest distance is called Plant 1, the one with second smallest distance is called Plant 2, and so on. Again without loss of generality, jobs are named according to their processing times. The job with the smallest

processing time is referred to as job 1, the one with second smallest processing time is called job 2, and so on. Hence,  $d_1 \leq d_2 \leq \dots \leq d_m$  and  $p_1 \leq p_2 \leq \dots \leq p_n$ .

For job  $j$ , produced on plant  $i$ , to be transported from that plant to the customer at time  $t$ , there are two conditions to be satisfied:

- Job  $j$  needs to have completed its processing on or before time  $t$ ,
- The truck should arrive at plant  $i$  on or before time  $t$  and should still be there at time  $t$ .

As common in the relevant literature on integrated scheduling of production and distribution operations, the completion time of job  $j$  is determined as the time that job reaches the customer. In our study, the objective is to minimize the total completion time of all jobs. A solution constitutes the following:

- Assignment of the jobs to the plants
- Scheduling of production of jobs at each plant
- The route and schedule of the truck
- Assignment of the jobs to the *trips*

Suppose that jobs are assigned to a plant set  $M'$ ,  $M' \subseteq M$ . The route of the truck is the order truck visits the plants in  $M'$ . For example, if the truck visits first Plant 2, then Plant 1, and then Plant 2 again, the route of the truck is Plant 2 – Plant 1 – Plant 2. Determining the schedule of the truck means determining the time truck leaves each plant on its route.

In this study, we consider a single planning horizon and we aim to send the jobs to the customer as soon as possible within this planning horizon. Viewing the customer area as a warehouse, the length of this planning horizon depends on the demand amount of the warehouse.

In Chen (2008),  $MP$  notation is used for multiple decentralized plants. Denoting the completion time of job  $j \in N$  as  $C_j$ , and using the three-field notation as in Lee and Chen (2001), our problem can be denoted as  $MP \rightarrow 1 | v=1, K \geq 1 | \sum C_j$ . Here  $MP \rightarrow 1$  means from multiple plants to a single customer area, and  $v=1, K \geq 1$  means using a single truck with a capacity of  $K$ . The following theorem holds for our problem.

**Theorem 1.** *There exists an optimal schedule that satisfies the following conditions for each plant:*

- (i) *If  $J_i$  is processed earlier than  $J_k$ , then  $J_i$  leaves the plant no later than  $J_k$ .*
- (ii) *Jobs are processed in non-decreasing order of processing times in each plant.*
- (iii) *There exists no idle time between job processing in any given plant.*
- (iv) *The transporter either leaves the plant immediately as it arrives or at the completion time of a job.*

*Proof:*

(i) Suppose that there exists an optimal schedule in which  $J_i$  is processed earlier than  $J_k$  but leaves the plant after  $J_k$ . While having the same transportation schedule, if we interchange the processing positions of these jobs at the plant such that  $J_k$  is processed earlier than  $J_i$ , the total completion time will not change. If we apply the same interchange procedure to all necessary job pairs, we will have a transportation sequence which is the same with the processing sequence.

(ii) Consider an optimal schedule where jobs are not processed in non-decreasing order of processing times (SPT order). Then there exists at least two adjacent jobs  $J_i$  and  $J_k$  where  $J_i$  is processed before  $J_k$  and  $p_i > p_k$ . If  $J_i$  and  $J_k$  are transported on the same trip, then interchanging the processing positions of these jobs at the plant will not increase total completion time. However, if  $J_i$  and  $J_k$  are not transported on the same trip, interchanging

the positions of these jobs may decrease the total completion time by decreasing the start times of the trips on which these jobs are transported.

(iii) If there exists idle time between job processing, we can move the jobs succeeding the idle period earlier without increasing the total completion time.

(iv) Suppose the vehicle leaves the plant neither as soon as it arrives there nor at the completion time of processing of a job. Then we can move subsequent trips earlier to either the arrival time of the truck at the plant or to the process completion time of the most recently loaded job and in this way decrease the total completion time. ■

The following section aims to more precisely convey the parameters given in a problem instance as well as the structure of a desirable solution by considering a numerical instance.

### 3.1. Sample Problem

Suppose that we have 10 jobs to be processed at a subset of 3 plants, and to be transported with a truck that carries at most 4 jobs in a trip. First, the plants are sorted in non-increasing order of their distances to the customer and reindexed, and the same procedure is applied for the jobs with respect to their processing times. After sorting, the distances of the plants can be listed as  $d = \{d_1, d_2, d_3\} = \{26, 30, 37\}$  whereas the processing times of the jobs can be listed as  $p = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}\} = \{6, 6, 10, 11, 22, 25, 27, 29, 33, 34\}$ . As can be seen in Figure 3.2, the optimal solution to this problem assigns jobs  $\{J_1, J_2, J_3, J_4, J_6, J_9, J_{10}\}$  to Plant 1, and the rest to Plant 2. As have been stated in Theorem 1, the jobs are processed according to SPT rule at each plant.

*Trip 1:* At time 0, the truck leaves the customer and goes to Plant 1 and arrives at that plant at time  $d_1 = 26$ . Jobs  $\{J_1, J_2, J_3, J_4\}$  are transported on the first trip and since  $p_1 + p_2 + p_3 + p_4 = 33 > 26 = d_1$ , truck waits for the completion of the processing of  $J_4$ , and leaves the plant at time 33. Truck arrives at the customer at time  $33 + 26 = 59$ . Hence the completion time for jobs  $\{J_1, J_2, J_3, J_4\}$  is 59.

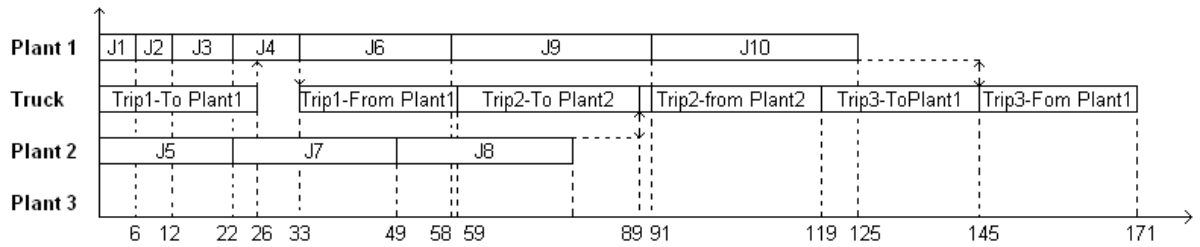
*Trip 2:* On the second trip truck goes to *Plant2*, and arrives there at time  $59 + 30 = 89$ . It takes jobs  $\{J_5, J_7, J_8\}$  and since  $p_5 + p_7 + p_8 = 78 < 89$ , the truck will leave Plant 2 as soon as it arrives and will turn back to the customer at time  $89 + 30 = 119$ . This means that the completion time for jobs  $\{J_5, J_7, J_8\}$  is 119.

*Trip 3:* Truck makes the third trip to Plant 1 again and it arrives at Plant 1 at time  $119 + 26 = 145$ . Since  $p_1 + p_2 + p_3 + p_4 + p_6 + p_9 + p_{10} = 125 < 145$ , truck leaves Plant 1 as soon as it arrives there and transports jobs  $\{J_6, J_9, J_{10}\}$ . The truck turns back to the customer at time  $145 + 26 = 171$  and hence the completion time for jobs  $\{J_6, J_9, J_{10}\}$  is 171.

Instead of summing individual completion times of the jobs, it is possible to calculate the total completion time by summing the contributions of each trip, where the contribution of a trip is calculated by the multiplication of the number of jobs transported on that trip and the arrival time of the truck to the customer at the end of that trip. Therefore, total completion time can also be shown as  $\sum C_j = 4 \cdot 56 + 3 \cdot 119 + 3 \cdot 171 = 1106$ . Here the coefficients  $\{4, 3, 3\}$  are the number of jobs transported on and the multipliers  $\{56, 119, 171\}$  are the completion times of trip 1, trip 2 and trip 3, respectively.

It should be noted that, in the optimal solution of this sample problem, Plant 3 is not used and all the jobs are produced on Plant 1 and Plant 2. The reason for this situation is that Plant 3 is further than other plants and since it is possible to produce all the jobs in closer plants, it is not logical to use Plant 3. However, this may not be the case for each instance.

Especially for the instances which have larger processing times when compared to this problem, it may be better to produce also in Plant 3.



**Figure 3.2:** Gantt chart for the optimal solution of sample problem with 10 jobs and 3 plants

# Chapter 4

## METHODOLOGY

In Chapter 3, the problem studied in this thesis was defined. In this chapter, we present the constructive heuristics and exact methods to solve this problem. To facilitate the assessment of heuristics, we develop fast lower bounds. In order to be able to provide a good understanding of the methods proposed we will follow a path from simpler cases referred to as special cases, to the main problem. The first special case we investigate will be the problem where we assume the assignments of the jobs to the plants are given. A dynamic programming algorithm will be presented for this problem. Then we will study the problem where we have the constraint of sending the truck fully loaded in its all trips, which we prefer to name as *Fully Loaded Trips Problem*. A special case of this problem, where it is known that last trip will be partially loaded, will be explained and the methods to generate exact solutions, heuristic methods to obtain near optimal solutions for both problems will be presented. Since these problems are NP-hard, for which proofs will be provided, it is hard to obtain exact solutions in a reasonable amount of time. Therefore, we have also generated lower bounds to measure the efficiency of our heuristic methods. The main problem, referred to as *General Problem*, occurs when we do not have the fully loaded trucks constraint. Exact solution methods, heuristic algorithms and lower bounds will be presented for both this main problem and its special case, where the truck leaves the plants it visits on each trip as soon as it arrives there.

## 4.1. Job Assignments Given Problem

In this problem, we assume that the assignments of the jobs to the plants are given so that we know which job will be processed on which plant. Therefore, the only question we need to answer is which route the truck should follow and which jobs it should take from the plant it visits. The truck leaves the plant either as soon as it arrives there or at the completion time of the last job transported on that trip. Hence, if which jobs to be transported on a trip is determined, then it can be determined whether the truck leaves the plant immediately or not. This case is mostly applicable when there are eligibility conditions so that each job can be produced only on a certain plant set.

In some cases, the distances of the plants to the customer may be equal or close to each other. Then for such problems, it is possible to assume that the distances of each plant to the customer are equal. In such a case, the following dynamic programming algorithm may be applied.

### 4.1.1. Plants at Equal Distances

First, we need to give some relevant notation:

- $n_i$ : number of jobs assigned to plant  $i$ ,  $i = 1, \dots, m$  such that  $\sum_{i=1}^m n_i = n$
- $C_j^i$ : the completion time of the  $j^{\text{th}}$  job at plant  $i$
- $d$ : the distance from a plant to the customer

The truck will leave the customer at time 0 and will go to a plant. Since all plants have the same  $d$  distance to the customer, the truck will be at some plant at time  $d$ . As stated in Theorem 1(iv), it will leave the plant either immediately or will wait until the completion of all jobs transported on that trip. Then it will return to the customer in  $d$  units of time. It will leave the customer again as soon as it arrives to the customer and start a new



trip. Therefore, there can only be a finite number of time points the truck can depart from the customer, i.e. the time points a trip can start. Let  $T$  be the set of possible departure times of the truck from the customer. Then each departure time  $t$ ,  $t \in T$ , can be obtained using the following formula:

$$(C_{j_1}^1 + a_1 \cdot d) + (C_{j_2}^2 + a_2 \cdot d) + \dots + (C_{j_m}^m + a_m \cdot d) + q \cdot 2 \cdot d$$

where  $C_0^i = 0$  for  $i = 1, \dots, m$ ;  $j_i = 0, 1, \dots, n_i$  for  $i = 1, \dots, m$ ;  $a_i = 0, 1$  for  $i = 1, \dots, m$  and  $q_i = 0, 1, 2, \dots, n$  for  $i = 1, \dots, m$ .

Let  $f(i_1, i_2, \dots, i_m, t)$  denote the minimum possible total completion time of the jobs  $\{J_{i_1}, J_{i_1+1}, \dots, J_{n_1}\}, \{J_{i_2}, J_{i_2+1}, \dots, J_{n_2}\}, \dots, \{J_{i_m}, J_{i_m+1}, \dots, J_{n_m}\}$  given that the truck departs the customer at time  $t$  to complete the transportation of those jobs, where  $t \in T$ ,  $i_1 = 1, \dots, n_1$ ,  $i_2 = 1, \dots, n_2$ , ...,  $i_m = 1, \dots, n_m$ . In other words, since some of these jobs have been already transported to the customer in the previous trips, the transportation of the jobs  $\{J_{i_1}, J_{i_1+1}, \dots, J_{n_1}\}, \{J_{i_2}, J_{i_2+1}, \dots, J_{n_2}\}, \dots, \{J_{i_m}, J_{i_m+1}, \dots, J_{n_m}\}$  will be completed once the trip with starting time  $t$  is over.

If we denote  $h_i$  to be the number of jobs transported from plant  $i$  to the customer on the trip starting at time  $t$ , we can write the recursive function as follows:

$$f(i_1, i_2, \dots, i_m, t) = \min \left\{ \begin{array}{l} \min_{0 \leq h_1 \leq \min(n_1 - i_1 + 1, K)} \{h_1 \cdot A_1 + f(i_1 + h_1, i_2, \dots, i_m, A_1)\}, \\ \min_{0 \leq h_2 \leq \min(n_2 - i_2 + 1, K)} \{h_2 \cdot A_2 + f(i_1, i_2 + h_2, \dots, i_m, A_2)\}, \\ \cdot \\ \cdot \\ \min_{0 \leq h_m \leq \min(n_m - i_m + 1, K)} \{h_m \cdot A_m + f(i_1 + h_1, i_2, \dots, i_m, A_m)\} \end{array} \right\}$$

where  $A_k = \left[ \max(t + d, C_{i_k + h_k - 1}^k) + d \right]$  for  $k = 1, \dots, m$ . The boundary condition is  $f(n_1 + 1, n_2 + 1, \dots, n_m + 1, t) = 0$  for all  $t \in T$ , such that  $t \geq \sum_{j=1}^n p_j + m \cdot d$ , and the objective is  $f(1, 1, \dots, 1, 0)$ .

**Lemma 4.1:** The overall complexity of the dynamic programming for the problem with known job assignments and plants at equal distances to the customer is  $O(2^m n^{2m+2})$ .

*Proof:* Using the formula  $(C_{j_1}^1 + a_1 \cdot d) + (C_{j_2}^2 + a_2 \cdot d) + \dots + (C_{j_m}^m + a_m \cdot d) + q \cdot 2 \cdot d$  we can obtain each departure time. Each  $j_i$  can have  $(n_i + 1)$ , each  $a_i$  can have two and  $q$  can have  $(n_i + 1)$  different values. Hence there are  $(n_1 + 1) \cdot 2 \cdot (n_2 + 1) \cdot 2 \cdot \dots \cdot (n_m + 1) \cdot 2 \cdot (n + 1)$  possible departure times. Therefore,  $|T| = O(2^m n^{m+1})$ . In the recursive formulation, the number of possible  $(i_1, i_2, \dots, i_m, t)$  combinations is  $|T| \cdot \prod_{i=1}^m (n_i + 1)$ , meaning there are  $O(n^m |T|) = O(2^m n^{2m+1})$  states to evaluate. When  $m$  is fixed, it takes  $O(n)$  time to evaluate each  $f(i_1, i_2, \dots, i_m, t)$  and hence the overall complexity is  $O(2^m n^{2m+2})$ . Since in real life  $m$  does not grow exponentially and usually is a small number, this algorithm works in polynomial time when  $m$  is fixed.

#### 4.1.2. Plants at Different Distances

In this case, we will assume that plants do not have the same distances to the customer. Let  $d_i$  be the distance from plant  $i$  to the customer where  $i = 1, \dots, m$ . The set of the possible departure times of the truck from the customer can be found using the following formula:

$$(C_{j_1}^1 + a_1 \cdot d_1) + (C_{j_2}^2 + a_2 \cdot d_2) + \dots + (C_{j_m}^m + a_m \cdot d_m) + q_1 \cdot 2 \cdot d_1 + q_2 \cdot 2 \cdot d_2 + \dots + q_m \cdot 2 \cdot d_m$$

where  $a_i, j_i, C_{j_i}^i$  are as described in the previous case and  $q_i = 0, 1, 2, \dots, n_i$  for  $i = 1, \dots, m$ .

The recursive function generated for the problem in the previous section, i.e. the problem with equal distance plants, can be used for this problem with a slight modification of  $A_k$  values such that  $A_k = \left[ \max(t + d_k, C_{i_k + h_k - 1}^k) + d_k \right]$  for  $k = 1, \dots, m$ . The boundary condition and the objective are the same as in the equal distance problem in Section 4.1.1.

**Lemma 4.2:** The overall complexity of the dynamic programming algorithm for the problem with known job assignments and plants at different distances to the customer is  $O(2^m n^{3m+1})$ .

*Proof:* There are  $(n_1 + 1) \cdot 2 \cdot (n_2 + 1) \cdot 2 \cdot \dots \cdot (n_m + 1) \cdot 2 \cdot (n_1 + 1) \cdot (n_2 + 1) \cdot \dots \cdot (n_m + 1)$  possible departure times. Hence,  $|T| = O(2^m n^{2m})$ . In the recursive function, the number of possible  $(i_1, i_2, \dots, i_m, t)$  combinations is  $|T| \cdot \prod_{i=1}^m (n_i + 1)$  and therefore there are  $O(n^m |T|) = O(2^m n^{3m})$  states to evaluate. It takes  $O(n)$  time to evaluate each state. Therefore, overall complexity is  $O(2^m n^{3m+1})$ . When  $m$  is fixed, this problem can be solved in polynomial time.

## 4.2. Fully Loaded Trips Problem

One of our motivations in studying the problem of  $MP \rightarrow 1|v=1, K \geq 1|\sum C_j$  is that it is a problem faced by the soft drink manufacturer mentioned in Chapter 1. This manufacturer is producing physically sensitive products and wants to transport them with less damage. For example, glass bottles may be broken when scattered around in the truck and the cans may be damaged when shaken. The easiest solution preferred by this soft drink manufacturer in the transportation of these products is sending the trucks full so that the damage to the products will be minimized. Also, companies feel they utilize truck capacity better when they send the trucks fully loaded. Hence, we found it beneficial to study the special case of our problem where we have the constraint of sending the truck fully loaded, i.e. loading  $K$  jobs, in all trips. However, since the number of jobs may not be divisible by the capacity of the truck, we may end up with a partially loaded trip. Here, the truck being partially loaded means that it would transport fewer than  $K$  jobs on that trip. In the main problem, we are required to answer how many jobs will be transported on a trip and which jobs will constitute the jobs being transported. In fully loaded trips problem, instead of answering how many jobs to be transported on each trip, we need to determine which trip will be partially loaded.

Last Trip Partial Problem, is a special case of fully loaded trips problem. In this problem, as the name implies, the only partially loaded trip will be the last one. Clearly, a partially loaded trip will be required only if the number of jobs,  $n$ , is not divisible by the truck capacity  $K$ .

Before continuing with the solution methods for the problem having the last trip partial, we will first prove that the problem with fully loaded trips, except one if a partially loaded trip is required, is NP-hard in the ordinary sense in Theorem 2. In Corollary 2 it will be shown that Last Trip Partial Problem is also NP-hard in ordinary sense.

### 4.2.1. NP-Hardness Proofs for the Fully Loaded Trips Problem and Its Special Case Last Trip Partial Problem

In this section, to provide clarity, we denote the problem with fully loaded trips, and one partial trip if needed, as  $MP \rightarrow 1 | v=1, K \geq 1, FullTrips | \sum C_j$ . Its special case where the last trip is partial, if a partially loaded trip is required, is denoted as  $MP \rightarrow 1 | v=1, K \geq 1, LastPartial | \sum C_j$ . To prove the NP-hardness of the problems in this chapter, we use well known PARTITION problem defined as follows:

Given a finite set  $A$  and a size  $s(a) \in \mathbb{Z}^+$  for each  $a \in A$ , is there a subset  $A' \subseteq A$  such that  $\sum_{a \in A'} s(a) = \sum_{a \in A-A'} s(a)$ ?

**Theorem 2:** Problem  $2P \rightarrow 1 | v=1, K \geq 1, FullTrips | \sum C_j$  is NP-hard.

*Proof:* Given an instance of the PARTITION problem,  $A = \{a_1, a_2, \dots, a_{2h}\}$ , we construct the following instance of our problem.

Number of jobs  $n = 4h$ , and jobs set  $N = H \cup \{2h+1\} \cup \{2h+2, 2h+3, \dots, 4h\}$  where  $H = \{1, 2, \dots, 2h\}$

Number of plants  $m = 2$

Truck capacity  $K = 2h$

Processing times  $p_j = s(a_j)$  for  $j \in H$ ,  $p_{2h+1} = \sum_{j \in H} p_j = 2B$ ,

$p_j = 0$  for  $j = \{2h+2, 2h+3, \dots, 4h\}$

$$\text{Plant distances } d_1 = d_2 = d = \frac{\sum_{j \in H} p_j}{2} = B$$

$$\text{Threshold on total completion time } C = 12Bh$$

→ If there is a solution to the PARTITION instance, we show that there is a schedule for the above constructed instance with a total completion time of no more than  $C$ . Let  $G$  be a subset of  $H$  that solves the PARTITION instance. Since  $|H| = 2h$ ,  $|G| < K$ . Produce  $K - |G|$  of the jobs with zero processing time and all jobs in  $G$  on Plant 1. Schedule these jobs in non-decreasing order of processing times (SPT order) on Plant 1, as stated in Theorem 1(ii). Assign the rest of the jobs to Plant 2 and schedule them in SPT order. Hence,

the  $K$  jobs assigned to Plant 1 will complete their processing at time  $B = \frac{\sum_{j \in H} p_j}{2}$  and the other  $K$  jobs, assigned to Plant 2, will complete their processing at time

$$3B = \sum_{j \in H} p_j + \frac{\sum_{j \in H} p_j}{2}. \text{ Truck will leave the customer at time } 0 \text{ and will arrive at Plant 1 at}$$

time  $d$ . Since  $d = B$ , it will take all  $K$  jobs assigned to that plant and will return to the customer at time  $2d$ . Then truck will leave the customer and arrive to Plant 2 at time  $3d = 3B$ . Again since all  $K$  jobs have already been processed, truck will take them and arrive at the customer at time  $4d$ . Hence, total completion time will be  $2Kd + 4Kd = 6Kd = 12Bh$ .

← If there exists a schedule with total completion time of no more than  $C$ , then there must be a solution to PARTITION instance. Since there are  $2K$  jobs, it is for sure that there will be two trips. Consider two cases:

Case 1: Both trips visit the same plant. In this case all of the jobs will be processed at one of the plants in SPT order. Truck arrives at the plant at time  $d$  and up to that time all of  $K-1$  jobs with zero processing time will have been processed. Then depending on,

$p = \min_{j \in H} p_j$ , truck will leave plant at time  $d' \geq d$ . It will arrive at the customer at time  $d' + d$  and will go back to the plant at time  $d' + 2d$ . Since the completion time of all jobs is  $2 \sum_{j \in H} p_j = 4B = 4d$  and  $d' < 2d$ , truck will leave plant at time  $4d$  and will arrive at the customer at time  $5d$ . Hence, total completion time is going to be  $K(d' + d) + 5Kd \geq 7BK > C$ . Since total completion time of this case is greater than  $C$ , the truck should not visit the same plant in both trips.

Case 2: One of the trips is to Plant 1 while the other is to Plant 2. Since Case 1 is shown to yield a total completion time greater than  $C$ , this case is the only possible case. Assuming without loss of generality that the first trip is to Plant 1, one of the questions is on which plant  $J_{2h+1}$ , i.e. the job with processing time of  $2d$ , will be produced. If  $J_{2h+1}$  is produced at Plant 1, at best, the jobs with zero processing time will be produced there and the truck will leave Plant 1 at time  $2d$ , arriving at the customer at time  $3d$ . On its second trip, truck will arrive at Plant 2 at time  $4d$  and will return to the customer at time  $5d$ . Hence, total completion time will be at least  $3Kd + 5Kd = 8BK > C$ . Therefore,  $J_{2h+1}$  will be assigned to the plant to which second trip is made.

Assuming without loss of generality that the first trip is to Plant 1, let  $M$  denote the set of jobs that are assigned to Plant 1 such that  $M \subseteq H$ . Even if the truck leaves the plant as soon as it arrives there on each trip, total completion time will be  $C$ . Since we want to obtain a schedule with total completion time of no more than  $C$ , it is required that  $K$  jobs are produced on each plant on or before the time truck arrives at that plant. Hence, we require  $\sum_{j \in M} p_j \leq d = B$  and  $\sum_{j \in H \setminus M} p_j + p_{2h+1} \leq 3d$ . The latter can be re-expressed as  $\sum_{j \in H \setminus M} p_j \leq d = B$ . Since  $\sum_{j \in H} p_j = 2B$ , we have  $\sum_{j \in M} p_j = \sum_{j \in H \setminus M} p_j = B$ . Therefore, we have a solution to the PARTITION instance if there exists a schedule with a total completion time of no more than  $C$ . ■

The following corollary immediately follows.

**Corollary 1:**  $MP \rightarrow 1 | v = 1, K \geq 1, FullTrips | \sum C_j$  is NP-hard.

**Corollary 2:** Problem  $2P \rightarrow 1 | v = 1, K \geq 1, LastPartial | \sum C_j$  is NP-hard.

*Proof:* Since Theorem 2 does not involve a partial trip the proof is valid also for this special case.

The problem  $MP \rightarrow 1 | v = 1, K \geq 1, LastPartial | \sum C_j$  is also NP-hard since the problem  $2P \rightarrow 1 | v = 1, K \geq 1, LastPartial | \sum C_j$  is shown to be NP-hard.

#### 4.2.2. Last Trip Partial Problem

In this section we consider a problem that involves the constraint that the only partially loaded trip, when required, can be the last one. The need to decide which trip will be partially loaded increases the complexity of the problem. Thus, this constraint makes the problem easier. Managers in real life may also find it intuitive to send more jobs on the earlier trips and fewer jobs on the last trip when they wish to minimize the total completion time. With this motivation, an exact method to solve this problem will be given in the next section. Since the problem is NP-hard, it will be difficult to obtain optimum solutions in a reasonable amount of time and hence fast heuristic algorithms will also be proposed. Finally, a lower bound will be derived to facilitate the quality assessment of the heuristic algorithms.



#### 4.2.2.1. Exact Solution Method for Last Trip Partial Problem

##### Parameters:

$n$  : number of jobs

$p_j$  : processing time of job  $j$ , for  $j = 1, 2, \dots, n$

$d_i$  : distance between plant  $i$  and the customer, for  $i = 1, 2, \dots, m$

$K$  : truck capacity

$q'$  : number of trips required to transport all jobs,  $q' = \left\lceil \frac{n}{K} \right\rceil$

$q$  : number of fully loaded trips required,  $q = \left\lfloor \frac{n}{K} \right\rfloor$

Note that if a partially loaded trip is not required, it will be that  $q' = q$ , otherwise  $q' = q + 1$ .

##### Assumptions:

We assume without loss of generality that jobs are indexed in non-decreasing order of their processing times. That is,  $p_1 \leq p_2 \leq \dots \leq p_n$ .

##### Decision Variables:

$$X_{ij} = \begin{cases} 1, & \text{if job } j \text{ is assigned to plant } i \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n$$

$$Y_{jk} = \begin{cases} 1, & \text{if job } j \text{ is transported on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } j = 1, 2, \dots, n \text{ and } k = 1, 2, \dots, q'$$

$$W_{ik} = \begin{cases} 1, & \text{if plant } i \text{ is visited on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } k = 1, 2, \dots, q'$$

$C_j$  = process completion time of job  $j$  at the plant it is assigned to,  $j = 1, 2, \dots, n$

$Q_k$  = time truck reaches the customer at the end of the  $k^{\text{th}}$  trip,  $k = 1, 2, \dots, q'$

### Mixed Integer Programming Model (MIP-1)

$$(1) \quad \text{minimize} \quad K \cdot \sum_{k=1}^q Q_k + (n - q \cdot K) \cdot Q_{q'}$$

*subject to*

$$(2) \quad \sum_{i=1}^m X_{ij} = 1, \quad j = 1, 2, \dots, n$$

$$(3) \quad \sum_{k=1}^{q'} Y_{jk} = 1, \quad j = 1, 2, \dots, n$$

$$(4) \quad \sum_{j=1}^n Y_{jk} = K, \quad k = 1, \dots, q$$

$$(5) \quad \sum_{j=1}^n Y_{j(q+1)} = n - q \cdot K$$

$$(6) \quad W_{ik} \geq X_{ij} + Y_{jk} - 1, \quad i = 1, \dots, m, \quad j = 1, \dots, n, \quad k = 1, \dots, q'$$

$$(7) \quad \sum_{i=1}^m W_{ik} = 1, \quad k = 1, \dots, q'$$

$$(8) \quad \sum_{l=1}^j (X_{il} \cdot p_l) \leq C_j + (1 - X_{ij}) \cdot M_1, \quad i = 1, \dots, m, \quad j = 1, \dots, n$$

$$(9) \quad Q_1 \geq 2 \cdot \sum_{i=1}^m (W_{i1} \cdot d_i)$$

$$(10) \quad Q_k \geq Q_{k-1} + 2 \cdot \sum_{i=1}^m (W_{ik} \cdot d_i), \quad k = 2, \dots, q'$$

$$(11) \quad (M_1 + d_i) \cdot (2 - X_{ij} - Y_{jk}) + Q_k \geq C_j + d_i, \quad i = 1, \dots, m, \quad j = 1, \dots, n, \quad k = 1, \dots, q'$$

$$(12) \quad C_j \text{ is nonnegative real number,} \quad j = 1, \dots, n$$

$$(13) \quad Q_k \text{ is nonnegative real number,} \quad k = 1, \dots, q'$$

$$(14) \quad X_{ij} \in \{0, 1\}, \quad i = 1, \dots, m, \quad j = 1, \dots, n$$

$$(15) \quad Y_{jk} \in \{0, 1\}, \quad j = 1, \dots, n, \quad k = 1, \dots, q'$$

$$(16) \quad W_{ik} \in \{0, 1\}, \quad i = 1, \dots, m, \quad k = 1, \dots, q'$$

Since only the last truck will be partially loaded, the critical information in determining the objective value is the times the truck arrives at the customer after each trip. The objective function shown in (1) formulates the total completion time as a function of these truck arrival times. Constraint set (2) ensures that each job is assigned to exactly one plant. Similarly, constraint set (3) ensures the assignment of each job to exactly one trip. Constraint set (4) enforces the condition that  $K$  jobs be transported on the first  $q$  trips and constraint (5) forces  $(n - qK)$  jobs to be assigned on the last trip. In constraint (5) if  $q'$  was used instead of  $(q + 1)$ , when no partially loaded trip is required, this constraint would try to assign 0 jobs to the last trip. Hence our model would not work since all jobs would not be transported. Constraint set (6) implies that if job  $j$  is transported on trip  $k$ , then the plant at which job  $j$  is produced should be visited on trip  $k$ . Constraint set (7) ensures that on each trip only one plant is visited therefore only direct shipments from each plant to the customer are permissible. Constraint set (8) requires a thorough explanation. According to Theorem

1(ii), all jobs assigned to each given plant are processed in SPT order. Since jobs are indexed in SPT order, the only jobs that affect the completion time of job  $j$  are the jobs with smaller indices at the same plant. Therefore, the completion time of job  $j$  is the summation of the processing times of these jobs and that of job  $j$ .  $M_1$  in constraint set (8) is a large integer and its value is determined to be the sum of processing times of all jobs, i.e.  $M_1 = \sum_{j=1}^n p_j$ .

Constraint (9) states that the truck cannot leave the plant it visits on its first trip before arriving there. Constraint set (10) ensures the same condition as in constraint (9) but for the trips other than the first one. In constraint set (11), instead of the term  $(2 - X_{ij} - Y_{jk})$ , we can use  $(1 - W_{ik})$ . This constraint set ensures that on any trip, if job  $j$  is transported on that trip, the truck cannot leave the plant job  $j$  is processed at before the completion of that job. Here, if a job is not transported on the  $k^{th}$  trip, the constraint becomes redundant. However, for each job transported on the  $k^{th}$  trip, this constraint must be satisfied.

#### 4.2.2.2. Heuristic Methods for Last Trip Partial Problem

Preliminary computations indicate that the MIP model developed for the problem with last trip partially loaded is not able to provide results in a reasonable amount of time. Thus, we develop two fast heuristic methods to obtain near optimal solutions for this problem. Although the name of this problem is Last Partial Case, our heuristics are designed to handle situations where the number of jobs is divisible by the truck capacity, i.e. no partially loaded trip is required. Therefore, whenever we use the term  $(n - qK)$  in order to represent the number of jobs in the partially loaded trip, it should be kept in mind that its value may be zero when a partially loaded trip is not required.

**Heuristic 1 (LPH1):**

There are two main principles supporting the mechanism of this procedure. We believe that the algorithm will present better intuitive appeal after a description of these two principles.

Principle 1 (Batch the Jobs): One of the main ideas underlying Heuristic 1 is that on each plant assigned jobs will be processed in SPT order. Therefore, all jobs are sorted in SPT order and then grouped into full batches of  $K$  jobs, and the partial batch with  $(n - qK)$  jobs. A grouping example with a partially loaded trip is as shown below.

$$\underbrace{J_1, J_2, \dots, J_K}_{\text{Batch1}}, \underbrace{J_{K+1}, J_{K+2}, \dots, J_{2K}}_{\text{Batch2}}, \dots, \underbrace{J_{qK+1}, J_{qK+2}, \dots, J_n}_{\text{Batch}(q+1)}$$

In Heuristic 1, first Batch 1 will be assigned to a plant and that plant will be visited on the first trip. Then Batch 2 will be assigned to a plant and transported on the second trip and this will continue until all the batches are assigned to a plant and transported.

For ease of notation, as mentioned in Chapter 3,  $p_i$  will be used to denote the processing time of  $J_i$ .

Principle 2 (Choose Potential Plants): Initially none of the batches is assigned to any plant. We need to choose a plant to assign Batch 1. The processing of the jobs in Batch 1 takes  $\sum_{j=1}^K p_j$  time. If Batch 1 is assigned to Plant 1, the first trip will end at time

$\max\left(\sum_{j=1}^K p_j, d_1\right) + d_1$ . If it is assigned to a farther plant  $i$ , the first trip will end at time

$\max\left(\sum_{j=1}^K p_j, d_i\right) + d_i$ . Since  $d_i \geq d_1$ ,  $\max\left(\sum_{j=1}^K p_j, d_i\right) + d_i \geq \max\left(\sum_{j=1}^K p_j, d_1\right) + d_1$ . Therefore, to

minimize the completion time of the first trip, the truck should visit Plant 1 on the first trip. For the second trip, we know that Batch 1 is assigned to Plant 1 and no batches have been assigned yet to farther plants. With a similar calculation to the one made for the first trip, it is obvious that among the plants in the set {Plant 2, Plant 3, ..., Plant  $m$  }, it is better to assign Batch 2 to Plant 2. Therefore, instead of thinking every plant as an alternative, only Plant 1 and Plant 2 are considered as alternatives for assigning Batch 2. To choose one of them, the completion time of the second trip is calculated for both alternatives. The alternative that gives a smaller trip completion time is chosen to assign Batch 2. Here, the calculation of trip completion times can be shown as follows: if Batch 2 is assigned to Plant 1, the completion

time of the second trip is  $\max\left(\sum_{j=1}^{2K} p_j, \max\left(\sum_{j=1}^K p_j, d_1\right) + 2d_1\right) + d_1$ . The latter term in the

maximum is the time truck arrives at Plant 1 after the first trip. If Batch 2 is assigned to Plant

2, the completion time of the second trip is  $\max\left(\sum_{j=K+1}^{2K} p_j, \max\left(\sum_{j=1}^K p_j, d_1\right) + d_1 + d_2\right) + d_2$ .

Suppose that Plant 2 was chosen. Then for the third trip, among plant set {Plant 3, ..., Plant  $m$  }, Plant 3 will be chosen as a potential plant. And between Plants 1 and 2, Plant 1 will be chosen since the sum of the processing times of the jobs already assigned to Plant 1 is smaller than that of those assigned to Plant 2. Hence, the potential plants for the third trip will be Plants 1 and 3. The plant having the smaller trip completion time will be chosen and this procedure will continue until all batches are assigned to some plant. So we can generalize this procedure as follows:

To assign Batch  $k$ , among the plants having the same number of batches that have already been assigned to them, the plant having the smallest distance will be chosen and marked as a potential plant. Among all potential plants, the plant giving the smallest possible trip completion time is chosen to assign Batch  $k$ .

Having clarified main ideas used, Heuristic 1 can be outlined as follows:

Step 0) Index jobs in non-decreasing order of processing times and plants in non-decreasing order of distances to the customer area. Set total completion time to 0. Go to step 1.

Step 1) Assign the first batch and make the first trip to Plant 1. Update the total completion time. If all jobs are assigned to a plant, stop. Otherwise, go to Step 2.

Step 2) Determine the potential plants. Go to step 3.

Step 3) For the first unassigned batch, calculate possible trip completion times of the potential plants. Go to step 4.

Step 4) Choose the plant with the smallest possible trip completion time. Go to step 5.

Step 5) Assign the first unassigned batch to this plant. Update the total completion time. If there exists any unassigned batch, go to Step 2. Otherwise, stop and return the total completion time.

As can be seen in the pseudocode given in Appendix B.1, Heuristic 1 runs in  $O(m^2n + mn^2)$  time. This is polynomial when  $m$  is fixed.

Batching the jobs before determining the route of the truck as in Heuristic 1 makes the solution methodology easy to apply in real life. However, we had the intuition that having the flexibility of rearranging the batches, as opposed to the fixed batches in Heuristic 1, may provide us with better results in terms of total completion time. Therefore, we develop another heuristic called Heuristic 2.

### **Heuristic 2 (LPH2):**

In this method, fixed batches do not exist. Assuming trip  $k$  visits plant  $i$ , and it is required to transport  $K$  jobs, if we can produce  $K$  jobs on plant  $i$  until the truck arrives there, we choose the batch with largest processing time to be assigned to that plant. The

procedure that chooses the batch with largest processing time is called *batch sliding*. The intuition of *batch sliding* comes from the two-dimensional bin packing problem. Each trip in our problem is similar to a bin. First dimension is the number of jobs that needs to be transported on that trip and the second dimension is the available processing time of the plant to which the trip is made. The available processing time of a plant is the time at which the truck arrives at that plant less the time the last job at that plant completes its processing. The main idea here is to use the jobs that can fill as much of the second dimension as possible while using the first dimension completely. This means, among the batches that can fill the first dimension and without exceeding the second dimension, we should choose the batch with the largest processing time, where the processing time of a batch is the sum of the processing times of the jobs in that batch. Since *batch sliding* is also used in some of the methods for other cases, we first illustrate it on an example and then give a step-by-step algorithm.

Example 4.1:

Suppose on the first trip the truck visits Plant  $i$  and  $K = 2$ . The distance of Plant  $i$  to the customer is  $d_i = 24$ . We have a total of 10 jobs with processing times  $p = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}\} = \{5, 6, 8, 8, 10, 11, 14, 14, 15, 15\}$ . Truck arrives at Plant  $i$  at time 24.

- Choose the two jobs with smallest processing times. We can show this batch choice as  $\{\boxed{5}, \boxed{6}, 8, 8, 10, 11, 14, 14, 15, 15\}$ . Since  $5 + 6 = 11 < 24$ , we can produce two jobs until the truck arrives there. Therefore, we can apply *batch sliding*.

- Sliding the batch one step we will have  $\{5, \boxed{6}, \boxed{8}, 8, 10, 11, 14, 14, 15, 15\}$  and since  $6 + 8 = 14 < 24$ , we will continue sliding until we find the two-size batch with largest processing time that does not violate 24 unit limit.



- For this trip our batch choice will be  $\{5, 6, 8, 8, \boxed{10}, \boxed{11}, 14, 14, 15, 15\}$  with a processing time of 21. This batch will be assigned to and transported from Plant  $i$ .

Now suppose that we have the following conditions: the truck will visit a plant with an available processing time of 23 and  $K = 2$ . The job set is  $\{5, 6, 8, 8, 10, 11, 14, 14, 15, 15\}$  where the jobs with processing times 10 and 11 are already assigned to some plant.

- Choose the two jobs with the smallest processing times, shown as  $\{\boxed{5}, \boxed{6}, 8, 8, 10, 11, 14, 14, 15, 15\}$ . Since  $5 + 6 = 11 < 23$ , we can produce two jobs until the truck arrives there. Therefore, we can apply *batch sliding*.

- Sliding the batch as in the previous example we will obtain the following batch choice  $\{5, 6, 8, \boxed{8}, 10, 11, \boxed{14}, 14, 15, 15\}$  with a processing time of  $8 + 14 = 22$ .

Algorithm Batch Sliding can be summarized as follows:

Step 0) Set  $j = 1$ . Go to step 1.

Step 1) Calculate the sum of processing times of the first  $K$  unassigned jobs starting with the job at  $j^{\text{th}}$  position. Go to step 2.

Step 2) If the sum in step 1 is less than or equal to the available processing time of the plant, increment  $j$  and go to step 1. Otherwise, stop and return the batch starting with the job at  $(j-1)^{\text{th}}$  position.

We can outline Heuristic 2 as follows:

Step 0) Index jobs in non-decreasing order of processing times and plants in non-decreasing order of distances to the customer area. Set total completion time to 0. Set  $i = 1$ ,  $k = 0$  and  $q = \left\lfloor \frac{n}{K} \right\rfloor$ . Go to step 1.

Step 1) Calculate the sum of processing times of the first  $K$  unassigned jobs. If the sum is less than or equal to the available processing time of plant 1, apply Algorithm Batch Sliding and go to step 6. Otherwise, go to step 2.

Step 2) Assign the first  $K$  unassigned jobs to plant 1, update total completion time and increment  $k$ . If  $k < q$ , go to step 3. Otherwise, go to step 7.

Step 3) Calculate the sum of processing times of the first  $K$  unassigned jobs. If the sum is less than or equal to the available processing time of plant  $i$ , apply Algorithm Batch Sliding and go to step 6. Otherwise, go to step 4.

Step 4) If  $i < m$ , increment  $i$  and go to step 1. Otherwise, go to step 5.

Step 5) Calculate possible trip completion times with respect to the sum of processing times found in step 1. Choose the plant with smallest trip completion time and assign the first  $K$  unassigned jobs to that plant. Update total completion time, set  $i = 1$  and increment  $k$ . If  $k < q$ , go to step 3. Otherwise, go to step 7.

Step 6) Assign the batch found by the Batch Sliding Algorithm applied in step 1 to plant  $i$ , set  $i = 1$ , update total completion time and increment  $k$ . If  $k < q$ , go to step 3. Otherwise, go to step 7.

Step 7) If a partially loaded trip is not required, return the total completion time and stop. Otherwise, go to step 8.

Step 8) Calculate the sum of processing times of all unassigned jobs. Calculate possible trip completion times with respect to this sum. Choose the plant with smallest trip

completion time and assign all unassigned jobs to that plant. Update and return the total completion time, and stop.

The pseudocodes of the batch sliding algorithm and Heuristic 2 are given in Appendix B.2. Batch sliding algorithm runs in  $O(n^2)$  time and Heuristic 2 runs in  $O(mn^3)$  time.

#### 4.2.2.3. Lower Bound for Last Trip Partial Problem (Lower Bound 1)

Although the MIP model presented in Section 4.2.2.1 may give optimal solutions in a reasonable amount of time for small instances, obtaining a result for larger instances requires long CPU times. Therefore, in order to be able to measure the performance of our heuristic methods even with large instances, we develop a lower bound, named as Lower Bound 1. The calculation of the lower bound for this case is mainly based on two parts: the time truck arrives at the customer after a trip and the number of jobs transported in that trip. In this case, the second part is known so the problem here is to determine the first part. Since we do not know the route of the truck, in order to be able to calculate a valid lower bound, all plants are assumed to have the same distance  $d$  to the customer, where  $d = \min_i d_i$ . On the first trip, truck will arrive at a plant at time  $d$  and will leave the plant either as soon as it arrives or at the completion time of the  $K^{\text{th}}$  job. Therefore, we can say the truck leaves the plant on its first trip at time  $\max\left(\sum_{j=1}^K p_j, d\right)$ . On the second trip, the truck visits another plant and to find a valid lower bound, we assume that when it arrives at the plant on its second trip, there are  $K$  jobs already produced.

If the plants have the same distance to the customer, the truck visits a different plant in each one of the first  $m$  trips. So in the  $(m+1)^{\text{th}}$  trip, it makes a second visit to a plant, meaning that some jobs have already been assigned to and produced at that plant. Since we

know that only the last trip may be partially loaded, there will be at least  $K$  jobs already assigned to the plant to which the  $(m+1)^{th}$  trip is made. Therefore, if not completed already until the truck arrives at that plant, the truck has to wait for the completion of  $2K^{th}$  job. Hence, for the  $1^{st}$ ,  $(m+1)^{th}$ ,  $(2m+1)^{th}$ , ...and so on trips, the departure time of the truck from the plant should be recalculated according to the jobs that have already been assigned to that plant. To clarify, we can divide the trips into *rounds* and since there are  $m$  plants, there will be  $m$  trips in each *round*. The first  $m$  trips will be in *round1*, the second  $m$  trips will be in *round2*, and so on. Since  $\left\lceil \frac{n}{K} \right\rceil$  trips are required to transport all jobs, there will be  $\left\lceil \left\lceil \frac{n}{K} \right\rceil / m \right\rceil$  rounds. In Table 4.1, for each trip on the first three rounds, the calculation of the arrival time of that trip to the customer is given.

**Table 4.1:** Sample calculation of completion times of the trips for Lower Bound 1

|               | <b>Trip 1</b>   | <b>Trip 2</b> | <b>...</b> | <b>Trip <math>m</math></b> |
|---------------|---|---------------|------------|----------------------------|
| <b>Round1</b> | $L_1 + d = \max\left(\sum_{j=1}^K p_j, d\right) + d$          | $L_1 + 3d$    | ...        | $B_1 = L_1 + (2m-1)d$      |
| <b>Round2</b> | $L_2 + d = \max\left(\sum_{j=1}^{2K} p_j, B_1 + d\right) + d$ | $L_2 + 3d$    | ...        | $B_2 = L_2 + (2m-1)d$      |
| <b>Round3</b> | $L_3 + d = \max\left(\sum_{j=1}^{3K} p_j, B_2 + d\right) + d$ | $L_3 + 3d$    | ...        | $B_3 = L_3 + (2m-1)d$      |

As can be seen in Table 4.1, the completion time of a trip is composed of two terms:  $L_v$ , where  $v = 1, 2, \dots, \left\lceil \left\lfloor \frac{n}{K} \right\rfloor / m \right\rceil$ , and  $rd$ , where  $r = 1, 2, \dots, 2m - 1$ . The term  $L_v$  will be called *LeaveTime*, and the term  $rd$  will be called *TravelTime*.

Keeping the calculation procedures shown in Table 4.1 in mind, the algorithm of Lower Bound 1 can be outlined as follows:

Step 0) Index jobs in non-decreasing order of processing times and plants in non-decreasing order of distances to the customer area. Set total completion time to 0,  $k = 1$  and  $LeaveTime = 0$ . Set  $q = \left\lfloor \frac{n}{K} \right\rfloor$  and  $q' = \left\lceil \frac{n}{K} \right\rceil$

Step 1) Calculate *TravelTime* for each trip.

Step 2) If  $k \in \{1, m + 1, 2m + 1, \dots\}$ , go to step 3. Otherwise, go to step 4.

Step 3) Update *LeaveTime* and go to step 4.

Step 4) Calculate completion time of the trip by summing *LeaveTime* computed in step 3 and *TravelTime* of that trip. Increment  $k$ . If  $k \leq q'$ , go to step 2. Otherwise, go to step 5.

Step 5) If a partially loaded trip is not required, go to step 6. Otherwise, go to step 7.

Step 6) Sum the completion times of each trip and multiply it with  $K$ . Set the total completion time to this value. Return the total completion time and stop.

Step 7) Sum the completion times of the first  $q$  trips and multiply it with  $K$ . Multiply the completion time of the  $(q')^{th}$  trip with  $(n - qK)$  and add to this sum. Set the total completion time to the value found. Return the total completion time and stop.

The pseudocode of the algorithm of Lower Bound 1 is given in Appendix A.1. This algorithm runs in  $O(n^2 + mn)$  time.

We also generated a two-stage lower bound where the plants are at the same location (with the distance of the closest plant) and parallel. The jobs are first assigned to the plants in SPT order and then transferred to the customer. However, this lower bound was outperformed by Lower Bound 1 in our preliminary tests.

### 4.2.3. Exact Solution Method for Fully Loaded Trips Problem

In this problem it is not known which trip will be partially loaded; hence, the number of jobs transported in each trip is a variable. Therefore, trying to calculate the total completion time by multiplying the completion time of each trip with the number of jobs transported on that trip would cause nonlinearity. Thus, the total completion time will be calculated by summing up the completion times of all jobs, where the completion time of a job is defined as the time it reaches at the customer.

Parameters:

$$d_{\max} : \max_i d_i$$

Assumptions:

We assume without loss of generality that jobs are indexed in non-decreasing order of their processing times. That is,  $p_1 \leq p_2 \leq \dots \leq p_n$ .

Decision Variables:

$$X_{ij} = \begin{cases} 1, & \text{if job } j \text{ is assigned to plant } i \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n$$

$$Y_{jk} = \begin{cases} 1, & \text{if job } j \text{ is transported on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } j = 1, 2, \dots, n \text{ and } k = 1, 2, \dots, q'$$

$$W_{ik} = \begin{cases} 1, & \text{if plant } i \text{ is visited on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } k = 1, 2, \dots, q'$$

$$F_k = \begin{cases} 1, & \text{if the truck is fully loaded on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } k = 1, 2, \dots, q'$$

$C_j$  = process completion time of job  $j$  at the plant it is assigned to,  $j = 1, 2, \dots, n$

$Q_k$  = time truck reaches the customer at the end of the  $k^{\text{th}}$  trip,  $k = 1, 2, \dots, q'$

$T_j$  = completion time of job  $j$ , i.e. the time that job reaches the customer,  $j = 1, 2, \dots, n$

Mixed Integer Programming Model (MIP-2)

$$(17) \quad \text{minimize} \quad \sum_{j=1}^n T_j$$

*subject to*

(2), (3), (6) – (16)

$$(18) \quad T_j \geq Q_k - M_k(1 - Y_{jk}), \quad j = 1, \dots, n, \quad k = 1, \dots, q'$$

$$(19) \quad \sum_{j=1}^n Y_{jk} \leq K, \quad k = 1, \dots, q'$$

$$(20) \quad K - \sum_{j=1}^n Y_{jk} \leq [1 - F_k] \cdot K, \quad k = 1, \dots, q'$$

$$(21) \quad \sum_{k=1}^{q'} F_k = q' - 1$$

$$(22) \quad T_j \text{ is nonnegative real number}, \quad j = 1, \dots, n$$

$$(23) \quad F_k \in \{0, 1\}, \quad k = 1, \dots, q'$$

Constraint set (18) ensures that if job  $j$  is transported on trip  $k$ , its completion time cannot be smaller than the completion time of trip  $k$ , i.e. the time the truck reaches at the customer at the end of the  $k^{\text{th}}$  trip.  $M_k$  in constraint set (18) is a large integer and its value is determined to be  $k \cdot \left( \sum_{j=1}^n p_j + 2d_{\max} \right)$ , for  $k = 1, \dots, q'$ . Constraint set (19) implies that on each trip, at most  $K$  jobs can be transported. Constraint set (20) and constraint (21) work together. When there is a partially loaded trip, its  $F_k$  value is forced to be 0 by constraint set (20), while constraint (21) ensures that there can be exactly one partially loaded trip. If a partially loaded trip is not required, constraint (21) will again assign the value of 0 to one of the  $F_k$  values. However, since having an  $F_k$  value equal to 0 in constraint set (20), does not prevent the trip from being fully loaded, we will still have all trips fully loaded.



#### 4.2.4. Heuristic Methods for Fully Loaded Trips Problem

The two heuristic methods proposed for this problem are generalizations of the heuristics developed for the problem with the constraint that the partial trip, if required, will be the last one.

##### Heuristic 3 (FTH1):

This method is a generalization of Heuristic 1. The main idea is to calculate the total completion times of  $q'$  alternatives, where  $q' = \left\lceil \frac{n}{K} \right\rceil$  and  $k^{\text{th}}$  alternative assumes that  $k^{\text{th}}$  trip is partially loaded. Among these alternatives, the one yielding the smallest total completion time is chosen. The completion time of each alternative can be calculated by using a slightly modified version of Heuristic 1. A detailed pseudocode of Heuristic 3 is given in Appendix B.3. This heuristic runs in  $O(mn^3)$  time which is polynomial when  $m$  is fixed.

In this method the two principles introduced for Heuristic 1, batching the jobs and choosing the potential plants, are used. Below is an example showing how to batch the jobs for different alternatives supposing that a partially loaded trip is required.

$$\begin{aligned}
 1^{\text{st}} \text{ Trip Partial: } & \underbrace{J_1, J_2, \dots, J_{n-qK}}_{\text{Batch1 (size } n-qK)} , \underbrace{J_{n-qK+1}, J_{n-qK+2}, \dots, J_{n-qK+K}}_{\text{Batch2}} , \dots , \underbrace{J_{n-K+1}, J_{n-K+2}, \dots, J_n}_{\text{Batch } q'} \\
 2^{\text{nd}} \text{ Trip Partial: } & \underbrace{J_1, J_2, \dots, J_K}_{\text{Batch1}} , \underbrace{J_{K+1}, J_{K+2}, \dots, J_{n-qK+K}}_{\text{Batch2 (size } n-qK)} , \dots , \underbrace{J_{n-K+1}, J_{n-K+2}, \dots, J_n}_{\text{Batch } q'} \\
 \dots & \\
 (q')^{\text{th}} \text{ Trip Partial: } & \underbrace{J_1, J_2, \dots, J_K}_{\text{Batch1}} , \underbrace{J_{K+1}, J_{K+2}, \dots, J_{2K}}_{\text{Batch2}} , \dots , \underbrace{J_{qK+1}, J_{qK+2}, \dots, J_n}_{\text{Batch } q' \text{ (size } n-qK)}
 \end{aligned}$$

#### **Heuristic 4 (FTH2):**

This heuristic is a generalization of Heuristic 2. The batch sliding mechanism introduced for Heuristic 2 is also implemented in Heuristic 4. As in Heuristic 3,  $q'$  alternatives are compared to each other and the one with the smallest total completion time is chosen. The completion time of each alternative can be calculated by using a slightly modified version of Heuristic 2. This algorithm runs in  $O(mn^4)$  time and its pseudocode can be found in Appendix B.4.

#### **4.2.5. Lower Bounds for Fully Loaded Trips Problem (Lower Bounds 2, 3 and 4)**

In order to be able to assess the performance of proposed heuristics in large instances, we develop two fast lower bounds, referred to as Lower Bound 2 and Lower Bound 3. In our preliminary studies, we tried solving the MIP model developed for this problem with equal distances  $d$ , where  $d = \min_i d_i$ , in order to obtain a lower bound. However, even with small instances, it takes considerable amount of CPU time to obtain optimal solutions.

#### **Lower Bound 2:**

In this problem at most one trip is partially loaded. It is required to have a total of  $q'$  trips, where  $q' = \left\lceil \frac{n}{K} \right\rceil$ , to transport all jobs.  $q$  of these trips will be fully loaded, where  $q = \left\lfloor \frac{n}{K} \right\rfloor$ . The number of jobs to be carried on the partial trip is  $(n - qK)$ .

The total completion time of a trip consists of two elements: the number of jobs transported in that trip and the time the truck arrives at the customer at the end of that trip.

Number of jobs transported on the trips: We consider as if whenever the truck arrives at a plant, there will be  $K$  jobs already produced at that plant. Hence, for the first  $q$  trips we suppose that  $K$  jobs are transported on that trip and  $(n - qK)$  jobs are transported on the last trip.

Trip completion times: This method simplifies the problem by setting the distance from each plant to the customer equal to the smallest such distance. Denote this identical distance between a plant and the customer location by  $d$ . While determining the number of jobs transported on the trips we supposed that the first trip will carry  $K$  jobs. However, in reality, the first trip may be the one that is partially loaded. Hence, in our lower bound calculations, if we state that the truck waits for the completion time of the  $K^{th}$  job in the first trip, the lower bound obtained would not be valid. In order to alleviate this issue and obtain a valid lower bound, we suppose that the truck leaves the plant visited in the first trip either as soon as it arrives or at the completion time of the  $(n - qK)^{th}$  job. Trip completion times and the number of jobs carried on those trips can be calculated as shown in Table 4.2.

Hence, if a partially loaded trip is not required, the lower bound is obtained using the following formula:

$$K \cdot [A + d] + K \cdot [A + 3d] + \dots + K \cdot \left[ A + \left( 2 \cdot \frac{n}{K} - 1 \right) d \right] = n \cdot A + K \cdot d \cdot q^2$$

where  $A = \max \left( \sum_{j=1}^K p_j, d \right)$ .

If a partially loaded trip is required, the lower bound can be found using the following formula:

$$\begin{aligned} & K \cdot [B + d] + K \cdot [B + 3d] + \dots + K \cdot [B + (2q - 1)d] + (n - qK) \cdot [B + (2q + 1)d] \\ & = n \cdot B + K \cdot d \cdot q^2 + (n - q \cdot K) \cdot (2q + 1) \cdot d \quad \text{where } B = \max \left( \sum_{j=1}^{n-qK} p_j, d \right). \end{aligned}$$

**Table 4.2 :** Trip Completion Times and Number of Jobs Carried in Lower Bound 2

|           | <b>Partially Loaded Trip Not Required</b>          |                        | <b>Partially Loaded Trip Required</b>                   |                        |
|-----------|--|------------------------|---|------------------------|
|           | Trip Arrival Time                                  | Number of Jobs Carried | Trip Arrival Time                                       | Number of Jobs Carried |
| Trip 1    | $A + d = \max\left(\sum_{j=1}^K p_j, d\right) + d$ | $K$                    | $B + d = \max\left(\sum_{j=1}^{n-qK} p_j, d\right) + d$ | $K$                    |
| Trip2     | $A + 3d$   | $K$                    | $B + 3d$  | $K$                    |
| ⋮         | ⋮  | ⋮                      | ⋮   | ⋮                      |
| Trip $q$  | $A + (2q - 1)d$                                    | $K$                    | $B + (2q - 1)d$   | $K$                    |
| Trip $q'$ | ---  | ---                    | $B + (2q + 1)d$   | $n - qK$               |

Lower Bound 2 may be very loose when the processing times of the jobs are large so that the truck may not be filled (at the time it arrives at a plant) in all trips. To address this situation, we develop Lower Bound 3 as an alternative procedure.

**Lower Bound 3:**

Once again, the total completion time of a trip is mainly based on two parts: the time the truck arrives at the customer at the end of that trip and the number of jobs transported in that trip.

Number of jobs transported on the trips: To obtain a valid lower bound, we consider as if the truck carries  $K$  jobs in its first  $q$  trips and  $(n - qK)$  jobs on the last trip as explained in Lower Bound 2.

Trip completion times: Here, in the calculation of trip completion times, we follow the same updating mechanism used in the first trips of the rounds in Lower Bound 1. We assume the plants have the same distance  $d$ , where  $d = \min_i d_i$ , to the customer area. Since the plants have the same distance, the truck visits a different plant in each one of the first  $m$  trips. So in the  $(m+1)^{th}$  trip, it makes a second visit to a plant, meaning that some jobs have already been assigned to and produced at that plant. There will be at least  $(n - qK)$  jobs already assigned to the plant to which the  $(m+1)^{th}$  trip is made. Therefore, if not completed already until the truck arrives at that plant, the truck has to wait for the completion of the  $(n - qK + K)^{th}$  job. Hence, for the  $1^{st}$ ,  $(m+1)^{th}$ ,  $(2m+1)^{th}$ , ...and so on trips, the departure time of the truck from the plant should be recalculated according to the jobs that have already been assigned to that plant.

In Table 4.3, the completion times of all the trips until the end of round 3 are given. The completion times of the trips for other rounds can be calculated by following the procedure shown in this table.

**Table 4.3 :** Trip Completion Times for Lower Bound 3

|               | <b>Trip 1</b>  | <b>Trip 2</b> | <b>...</b> | <b>Trip <math>m</math></b> |
|---------------|--|---------------|------------|----------------------------|
| <b>Round1</b> | $L_1 + d = \max\left(\sum_{j=1}^{n-qK} p_j, d\right) + d$          | $L_1 + 3d$    |            | $B_1 = L_1 + (2m-1)d$      |
| <b>Round2</b> | $L_2 + d = \max\left(\sum_{j=1}^{n-qK+K} p_j, B_1 + d\right) + d$  | $L_2 + 3d$    |            | $B_2 = L_2 + (2m-1)d$      |
| <b>Round3</b> | $L_3 + d = \max\left(\sum_{j=1}^{n-qK+2K} p_j, B_2 + d\right) + d$ | $L_3 + 3d$    |            | $B_3 = L_3 + (2m-1)d$      |

Lower Bound 3 uses the same step-by-step procedure with Lower Bound 1. However, in step 3, updating *LeaveTime* is done according to the calculation methods shown in Table 4.3, instead of Table 4.1. The pseudocode of the algorithm of Lower Bound 3 is given in Appendix A.2. This algorithm runs in  $O(mn + n^2)$  time.

In Lower Bound 3, as mentioned above, the departure time of the first trip from the plant is  $\max\left(\sum_{j=1}^{n-qK} p_j, d\right)$ . Hence, as  $(n - qK)$  gets smaller, the departure time of the first trip may get smaller. Especially for the problems considering jobs with large processing times, this may cause the lower bound to be loose. To overcome this problem we develop an alternative lower bound procedure.

#### **Lower Bound 4:**

In this lower bound generation method, our aim is to eliminate the partially loaded trip. In order to do this, from the job set, we delete the last  $(n - qK)$  jobs. Then we apply exactly the same procedure as the one used in Lower Bound 3. But since we deleted the last  $(n - qK)$  jobs, there will occur only fully loaded trips and the first trip leaves the plant at

$$\text{time } \max\left(\sum_{j=1}^K p_j, d\right).$$

### **4.3. General Problem**

In the previous problems, we considered a constraint such that the truck will have a full load in all trips, except one. The problem considered in this section is more general in the sense that it does not involve any such constraint. As explained in Section 4.2, fully loaded trips constraint may be preferred by the companies producing physically sensitive products.

The solution to this more general problem may be applied by the companies that produce less sensitive products with more durable packages so that product would not be harmed when shaken or scattered around in the truck.

In most applications, when the truck arrives at a plant, it takes the products ready for delivery and turns back to the customer. This is due to the dispatcher's false belief that doing so would result in a better completion time performance on the average. In order to address this common practical application, we study the problem where the truck leaves the plant immediately. Before continuing with the proposed methods to solve this problem, we will first prove in Theorem 4 that the main problem defined in Chapter 3 is at least NP-hard in the ordinary sense. In Corollary 2, it will be shown that the problem with no wait constraint is at least NP-hard in the ordinary sense.

### 4.3.1. NP-Hardness Proofs for the General Problem and the Problem with No Wait Constraint

Lee and Chen (2001), show that the problem  $P2 \rightarrow 1|v=1, K \geq 1|\sum C_j$  is NP-hard. Although this problem is different from ours, their proof shows that our problem is NP-hard. However, we believe that our proof is more intuitive and easier to understand in the context of the main problem studied in this thesis.

**Theorem 3:** Problem  $2P \rightarrow 1|v=1, K \geq 1|\sum C_j$  is NP-hard.

*Proof:* Given an instance of the PARTITION problem, we construct the following instance of our problem.

Number of jobs  $n = 4h$ , and jobs set  $N = H \cup \{2h+1\} \cup \{2h+2, 2h+3, \dots, 4h\}$  where  $H = \{1, 2, \dots, 2h\}$

Number of plants  $m = 2$

Truck capacity  $K = 2h$

Processing times  $p_j = s(a_j)$  for  $j \in H$ ,  $p_{2h+1} = \sum_{j \in H} p_j = 2B$ ,

$$p_j = 0 \text{ for } j = \{2h+2, 2h+3, \dots, 4h\}$$

Plant distances  $d_1 = d_2 = d = \frac{\sum_{j \in H} p_j}{2} = B$

Threshold on total completion time  $C = 12Bh$

We first prove that the total completion time will always be greater than  $C$  if more than two trips are used. It is obvious that at least two trips are required to transport all jobs. If exactly two trips are used,  $K$  jobs will be transported in each trip. Assume that in the first trip, instead of sending  $K$  jobs,  $K - X_1$  jobs were sent, and in the second trip,  $K - X_2$  jobs were sent, where  $X_1 + X_2 > 0$  and  $X_1, X_2 \in \mathbb{Z}$ . Assuming  $Y_1$  jobs were transported in the third trip,  $Y_2$  jobs in the fourth trip, and  $Y_Q$  jobs in the  $(Q+2)^{nd}$  trip, such that

$\sum_{l=1}^Q Y_l = X_1 + X_2$  and  $Y_{l_1} \geq Y_{l_2}$  for every  $l_1 < l_2$  (i.e. on later trips fewer jobs will be sent), we

will obtain a total completion time as follows:

$$\begin{aligned} \sum C_j &\geq 2(K - X_1)d + 4(K - X_2)d + 6Y_1d + 8Y_2d + \dots + 2Y_Q(Q+2)d \\ &\geq 6Kd - 2dX_1 - 4dX_2 + 6d(Y_1 + Y_2 + \dots + Y_Q) \\ &= 6dK + 4dX_1 + 2dX_2 > C \end{aligned}$$

Since using more than two trips results in a total completion time greater than  $C$ , exactly two trips must be used to transport all the jobs. Therefore, proof of Theorem 2 can be used to prove the NP-hardness of this problem. ■

The following corollary immediately follows.



**Corollary 3:** The problem  $MP \rightarrow 1 | v=1, K \geq 1 | \sum C_j$  is NP-hard.

*Proof:* Since  $2P \rightarrow 1 | v=1, K \geq 1 | \sum C_j$  is NP-hard,  $MP \rightarrow 1 | v=1, K \geq 1 | \sum C_j$  is also NP-hard.

In this section, along with the general problem, we consider one of its special cases, the problem with no wait constraint. This problem can be denoted as  $MP \rightarrow 1 | v=1, K \geq 1, NoWait | \sum C_j$ .

**Corollary 4:** Problem  $2P \rightarrow 1 | v=1, K \geq 1, NoWait | \sum C_j$  with no wait constraint is NP-hard.

*Proof:*

Since the truck does not wait in Theorem 4, it is easy to see that the proof of Theorem 4 is also valid for this problem.

### 4.3.2. The Problem with No Wait Constraint

As mentioned before, in this problem, we have the no wait constraint such that when the truck arrives at a plant, it takes the jobs already produced there without violating the capacity constraint and leaves the plant as soon as it arrives there.

#### 4.3.2.1. Exact Solution Method for the Problem with No Wait Constraint

In this problem, since we do not know how many trips are necessary to transport all jobs, we try to cover the worst case, i.e. the case each job is transported on separate trips, by having  $n$  trips. Therefore, we have  $k = 1, 2, \dots, n$  trips.

Assumptions:

We assume without loss of generality that jobs are indexed in non-decreasing order of their processing times. That is,  $p_1 \leq p_2 \leq \dots \leq p_n$ .

Decision Variables:

$$X_{ij} = \begin{cases} 1, & \text{if job } j \text{ is assigned to plant } i \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n$$

$$Y_{jk} = \begin{cases} 1, & \text{if job } j \text{ is transported on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } j = 1, 2, \dots, n \text{ and } k = 1, 2, \dots, n$$

$$W_{ik} = \begin{cases} 1, & \text{if plant } i \text{ is visited on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } k = 1, 2, \dots, n$$

$C_j$  = process completion time of job  $j$  at the plant it is assigned to,  $j = 1, 2, \dots, n$

$T_j$  = time job  $j$  reaches the customer,  $j = 1, 2, \dots, n$

$Q_k$  = time truck reaches the customer at the end of the  $k^{\text{th}}$  trip,  $k = 1, 2, \dots, n$

Mixed Integer Programming Model (MIP-3)

$$(17) \quad \text{minimize} \quad \sum_{j=1}^n T_j$$

*subject to*

(2), (3), (8), (12), (14), (22)

$$(18.2) \quad T_j \geq Q_k - M_k(1 - Y_{jk}), \quad j = 1, \dots, n, \quad k = 1, \dots, n$$

$$(19.2) \quad \sum_{j=1}^n Y_{jk} \leq K, \quad k = 1, \dots, n$$

$$(6.2) \quad W_{ik} \geq X_{ij} + Y_{jk} - 1, \quad i = 1, \dots, m, \quad j = 1, \dots, n, \quad k = 1, \dots, n$$

$$(7.2) \quad \sum_{i=1}^m W_{ik} \leq 1, \quad k = 1, \dots, n$$

$$(9.2) \quad Q_1 = 2 \cdot \sum_{i=1}^m (W_{i1} \cdot d_i)$$

$$(10.2) \quad Q_k \geq Q_{k-1} + 2 \cdot \sum_{i=1}^m (W_{ik} \cdot d_i), \quad k = 2, \dots, n$$

$$(11.2) \quad (M_1 + d_i) \cdot (2 - X_{ij} - Y_{jk}) + Q_{k-1} + \sum_{v=1}^m (W_{vk} \cdot d_v) \geq C_j, \quad i = 1, \dots, m, \quad j = 1, \dots, n, \\ k = 1, \dots, n$$

$$(13.2) \quad Q_k \text{ is nonnegative real number}, \quad k = 1, \dots, n$$

$$(15.2) \quad Y_{jk} \in \{0, 1\}, \quad j = 1, \dots, n, \quad k = 1, \dots, n$$

$$(16.2) \quad W_{ik} \in \{0, 1\}, \quad i = 1, \dots, m, \quad k = 1, \dots, n$$

Most of the constraints of the form (a.2) are the modifications of the constraints of the form (a) with a difference in just the condition for the trip number,  $k$ . In constraint set (7.2), the equality form of constraint set (7) is changed into an inequality since we have  $W_{ik} = 0$  for the trips that may not be used. Conversely in constraint (9.2), the inequality form of constraint (9) is changed into equality because we know that the truck does not wait at the plant and leaves immediately as it arrives there. Since in this constraint only the first trip is considered, the trip is completed at time  $2d_i$ , if the truck visits plant  $i$ . The model will still be valid if the inequality in constraint set (10.2) is changed into equality. Although not

intuitive, preliminary tests indicated that having equality in this constraint results in larger CPU times. Thus, we use inequality. Constraint set (11.2) ensures that if a job is going to be transported in a trip, it should complete its processing on or before the truck arrives at the plant at which it is processed.

In addition to the above constraints, we also have the following valid inequality:

$$\sum_{i=1}^m W_{ik} \leq \sum_{i=1}^m W_{i(k-1)}, \quad k = 2, \dots, n$$

This inequality implies that if trip  $k$  is not used, then trip  $k+1$  will not be used. Actually, this inequality adds a cut to our model.

#### 4.3.2.2. Heuristic Methods for the Problem with No Wait Constraint

Our preliminary tests show that it is not possible to obtain optimal solutions in a reasonable amount of time using the MIP model presented in Section 4.3.2.1. Therefore, we develop two heuristic methods to generate near optimal solutions for this problem.

##### **Heuristic 5 (NWH1):**

Since our objective is to minimize the total completion time, we want to transport more jobs in the beginning of the schedule. However, it is important not to increase the completion times of the trips excessively while trying to increase the number of jobs transported. For example, by visiting a farther plant in a trip, it is possible to transport more jobs in that and subsequent trips, but this may also increase the completion times of these trips. Therefore, there is a tradeoff between the number of jobs transported and the completion times of the trips. The main idea of this method arises from the desire to balance this tradeoff.

First, we define the gain of going to a farther plant as the additional number of jobs that can be transported by going to that farther plant instead of a closer plant. The number of jobs to be transported from a plant is determined by taking the minimum of the number of jobs that can be produced in the available processing time of that plant and the capacity of the truck. As mentioned in Heuristic 2 in Section 4.2.2.2, the available processing time of a plant is the time at which the truck arrives at that plant minus the time the last job assigned to that plant completes its processing.

Secondly, we define the loss as the delay in the completion time of the trip by going to a farther plant instead of going to the closest plant. Although the gain is subject to change depending on the processing times of the jobs that have not been transported yet, the loss is constant for each plant. We can calculate the loss of going to plant  $i$  instead of the closest plant as  $2(d_i - d)$ , where  $d = \min_i d_i$ .

In this method, we try to balance the tradeoff between gain and loss, by visiting a farther plant only if the gain of this trip justifies the loss. The gain-loss justification mechanism depends on two conditions:

1. The gain, denoted as  $g$ , should be larger than the loss divided by  $\bar{p}$ , where  $\bar{p} = \frac{1}{n} \cdot \sum_{j=1}^n p_j$ . In mathematical representation that is,  $g > \frac{2(d_i - d)}{\bar{p}}$ .
2. The gain should be greater than or equal to 1.

If both of the above conditions are satisfied, then Heuristic 5 lets the truck visit a farther plant instead of the closest one.

In the first condition, the ratio  $\frac{2(d_i - d)}{\bar{p}}$  is determined as a result of preliminary experiments. We expressed the ratio as  $\frac{a \cdot 2(d_i - d)}{4 \cdot \bar{p}}$ , and tested its performance on some test

problems for different  $a$  values, where  $a = 1, 2, \dots, 8$ .  $a = 4$  is found to perform better than the others from the perspective of minimizing the total completion time.

In this method, in each trip of the truck, the unassigned jobs with smallest processing times will be assigned to a plant and transported. This means, the batch sliding mechanism explained in Heuristic 2 is not implemented.

Following the discussions above, Heuristic 5 can be summarized as follows:

Step 0) Index jobs in non-decreasing order of processing times and plants in non-decreasing order of distances to the customer area. Set total completion time to 0,  $numSent = 0$ . Calculate  $\bar{p}$ . For each plant  $i$ , set  $numJobs[i] = 0$ .

Step 1) Set  $i = 1$  and calculate the number of jobs that can be produced in the available processing time of plant  $i$ . If the value found is greater than or equal to  $K$ , set  $numJobs[i] = K$  and go to step 2. Otherwise, go to step 3.

Step 2) Assign the first  $numJobs[i]$  unassigned jobs to plant  $i$ . Increase  $numSent$  by  $numJobs[i]$ . Update the total completion time. If  $numSent < n$ , go to step 1. Otherwise, return the total completion time and stop.

Step 3) Increment  $i$  and calculate the number of jobs that can be produced in the available processing time of plant  $i$ . If the value found is greater than or equal to  $K$ , set  $numJobs[i] = K$  and go to step 4. Otherwise, go to step 4 without changing the value of  $numJobs[i]$ .

Step 4) If  $numJobs[i]$  satisfies *gain-loss justification* conditions, go to step 2. Otherwise, go to step 5.

Step 5) If  $i < m$ , go to step 3. Otherwise, set  $i = 1$  and go to step 2.

Heuristic 5 runs in  $O(mn^2)$  time and its detailed pseudocode can be found in Appendix B.5.

### **Heuristic 6 (NWH2):**

In this method, we employ the batch sliding mechanism introduced in Heuristic 2. The main idea is as follows: when the truck makes a visit to a plant, the number of jobs it can produce in the available processing time of that plant, called  $numJobs$ , is calculated. Then, procedure batch sliding is applied to select the batch with largest processing time among the batches having  $numJobs$  jobs. The difference between Heuristic 5 and this heuristic is in step 2. In this method, in step 2, instead of directly assigning the first  $numJobs[i]$  unassigned jobs to Plant  $i$ , the batch determined as a result of batch sliding is assigned to plant  $i$ . The pseudocode of this algorithm is given in Appendix B.6. This algorithm runs in  $O(mn^3)$  time.

### **4.3.2.3. Lower Bound for the Problem with No Wait Constraint (Lower Bound 5)**

As mentioned before, in this problem we assume that the truck will leave the plant immediately after it arrives there and take the jobs ready there. Therefore, the departure time of the truck from a plant is determined if the arrival time of it to that plant is known. However, the arrival time of the truck to a plant depends on the route of the truck and the route is not known.

In this method, the total completion time is again composed of two parts: trip completion times and the number of jobs transported on each trip. Since the route of the truck is not known, to find a valid lower bound, we will treat as if the  $k^{th}$  trip is completed at time

$k \cdot 2d$ , where  $d = \min_i d_i$ . Determining the completion time of each trip, the problem now is to find out how many jobs will be transported on each trip.

Since we set the trip completion times to their respective minimums, in order to find a valid lower bound, we should set the number of jobs to be transported on each trip to their respective maximums. That means, maximum number of jobs are transported in minimum time. For this purpose, this method tries to determine at most how many jobs can be loaded to the truck in each trip and hence how many trips would the truck make in order to transport all jobs.

Although explained in Section 4.2.2.3, it is better to remind the concept of *rounds*. The trips are grouped into *rounds* and since there are  $m$  plants, there exist  $m$  trips in each *round*. In other words, a *round* is completed when each plant is visited once.

On the first trip of the first round, the maximum number of jobs would be transported if the farthestmost plant is visited. Since it takes the truck  $d_m$  units of time to go there, at most

$l_1$  jobs can be produced until the arrival of the truck, where  $\sum_{j=1}^{l_1} p_j \leq d_m < \sum_{j=1}^{l_1+1} p_j$ . In order not

to violate capacity constraints, at most  $\min(l_1, K)$  jobs can be transported. Then on the second trip, we can transport the greatest number of jobs from Plant  $m-1$ . The truck arrives there at time  $2d_m + d_{m-1}$ . At most  $l_2$  jobs can be produced until the arrival of the truck, where

$\sum_{j=1}^{l_2} p_j \leq 2d_m + d_{m-1} < \sum_{j=1}^{l_2+1} p_j$ , and at most  $\min(l_2, K)$  number of jobs are transported.

Calculation goes on like this until the  $m^{\text{th}}$  trip. On the  $m^{\text{th}}$  trip, the truck arrives at the plant at time  $t = 2d_m + 2d_{m-1} + \dots + 2d_2 + d_1$  and at most  $l_m$  jobs can be produced until that time,

where  $\sum_{j=1}^{l_m} p_j \leq t < \sum_{j=1}^{l_m+1} p_j$ .



On the second round, i.e. the round starting with  $(m+1)^{th}$  trip, on each plant visited, there will be some jobs already assigned to and produced at that plant. Since our policy is to calculate the maximum number of jobs that can be transported on each trip, we want to find the maximum number of jobs that can be produced on each plant until the truck arrives there. Therefore, for each plant, we suppose the minimum number of jobs have already been produced there. For the trips between  $(m+1)^{th}$  and  $(2m)^{th}$ , this minimum number of jobs is equal to  $l_{\min}$ , where  $\sum_{j=1}^{l_{\min}} p_j \leq d_1 < \sum_{j=1}^{l_{\min}+1} p_j$ . However, among these produced jobs,  $\min(l_{\min}, K)$  number of jobs have been already transported. Then, for the  $(m+1)^{th}$  trip, to transport the maximum number of jobs, the truck goes again to the farthestmost plant. It arrives there at time  $(2d_m + 2d_{m-1} + \dots + 2d_2 + 2d_1) + d_m$ . Hence, on that plant, at most  $l_{m+1}$  jobs can be produced, where  $\sum_{j=1}^{l_{m+1}} p_j \leq (2d_m + 2d_{m-1} + \dots + 2d_2 + 2d_1) + d_m < \sum_{j=1}^{l_{m+1}+1} p_j$ . However, at least  $\min(l_{\min}, K)$  of them have been already transported. So there are  $(l_{m+1} - \min(l_{\min}, K))$  jobs produced and ready for transportation, and  $\min(l_{m+1} - \min(l_{\min}, K), K)$  of them are transported on this trip. The calculations are similar for the following trips including the  $(2m)^{th}$  trip.

On the first trip of the third round, i.e.  $(2m+1)^{th}$  trip, the value of  $l_{\min}$  is updated. Now, we suppose that we have already made two trips to the closest plant, therefore, on the second trip to that plant, the truck arrives there at the earliest at time  $3d_1$ . Hence, for the trips between the  $(2m+1)^{th}$  and the  $(3m)^{th}$ ,  $l_{\min}$  is updated so that  $\sum_{j=1}^{l_{\min}} p_j \leq 3d_1 < \sum_{j=1}^{l_{\min}+1} p_j$ . And the number of jobs that have already been transported is  $\min(l_{\min}, 2K)$ . Therefore, on  $(2m+1)^{th}$  trip, at most  $\min(l_{2m+1} - \min(l_{\min}, 2K), K)$  jobs can be transported. This updating mechanism is repeated on the first trip of each round.

We can summarize the notations and calculations used above as follows. Suppose on the  $k^{th}$  trip, the truck arrives at the plant it visits at time  $t$ . Denote  $l_k$  to be the number of jobs that can be produced on that plant until time  $t$ . Assume that the truck's previous visit to that plant was on time  $t_{\min}$ . Denote  $l_{\min}$  to be the number of jobs already produced on that plant, i.e. the number of jobs produced until time  $t_{\min}$ . Assuming that trip  $k$  is on the  $T^{th}$  round, we can express the number of jobs to be transported on trip  $k$  as  $\min(l_k - \min(l_{\min}, (T-1) \cdot K), K)$ . Note that for the trips in the first round  $l_{\min} = 0$ .

Keeping the calculations shown in Table 4.4 in mind, the algorithm for Lower Bound 5 can be summarized as follows:

Step 0) Index jobs in non-decreasing order of processing times and plants in non-decreasing order of distances to the customer area. Initialize *noJobs* array. Set  $k=1$  and  $numSent = 0$ .

Step 1) Calculate  $t$  and  $t_{\min}$  for trip  $k$  as shown in Table 4.4. Calculate  $l_k$  and  $l_{\min}$  with respect to  $t$  and  $t_{\min}$  values.

Step 2) Set  $noJobs[k] = \min(l_k - \min(l_{\min}, K), K)$ . If  $noJobs[k] \leq n - numSent$ , go to step 3. Otherwise, go to step 4.

Step 3) Increase  $numSent$  by  $noJobs[k]$ . If  $numSent < n$ , increment  $k$  and go to step 1. Otherwise, i.e. if  $numSent = n$ , go to step 5.

Step 4) Set  $noJobs[k] = n - numSent$ . Go to step 5.

Step 5) Set the total completion time to  $\sum_{k'=1}^k [(2k'd)noJobs[k']]$ . Return the total completion time and stop.

**Table 4.4:**  $t$  and  $t_{\min}$  calculation for Lower Bound 5

|                | <b>Trip Number</b> | <b><math>t</math> value</b>                  | <b><math>t_{\min}</math> value</b> |
|----------------|--------------------|--|------------------------------------|
| <b>Round 1</b> | 1                  | $A_1 = d_m$                                  | 0                                  |
|                | 2                  | $A_2 = 2d_m + d_{m-1}$                       | 0                                  |
|                | ....               | ...  | ...                                |
|                | $m$                | $A_m = 2d_m + 2d_{m-1} + \dots + 2d_2 + d_1$ | 0                                  |
| <b>Round 2</b> | $m+1$              | $2(d_m + d_{m-1} + \dots + d_2) + A_1$       | $d_1$                              |
|                | $m+2$              | $2(d_m + d_{m-1} + \dots + d_2) + A_2$       | $d_1$                              |
|                | ...                | ...  | ...                                |
|                | $2m$               | $2(d_m + d_{m-1} + \dots + d_2) + A_m$       | $d_1$                              |
| <b>Round 3</b> | $2m+1$             | $4(d_m + d_{m-1} + \dots + d_2) + A_1$       | $3d_1$                             |
|                | $2m+2$             | $4(d_m + d_{m-1} + \dots + d_2) + A_2$       | $3d_1$                             |
|                | ...                | ...  | ...                                |
|                | $3m$               | $4(d_m + d_{m-1} + \dots + d_2) + A_m$       | $3d_1$                             |

This lower bound generation algorithm runs in  $O(m^2 + n^2)$  time and a pseudocode of it is given in Appendix A.3.

### 4.3.3. Exact Solution Method for the General Problem

Exact solution method for this problem, is very similar to MIP-3. Only two constraints are different. Instead of constraint (9.2) of MIP-3, this method has constraint (9). And instead of (11.2), this method has constraint (11.3) which has the same inequality with constraint (11) but different domain for  $k$ .

Assumptions:

We assume without loss of generality that jobs are indexed in non-decreasing order of their processing times. That is,  $p_1 \leq p_2 \leq \dots \leq p_n$ .

Decision Variables:

$$X_{ij} = \begin{cases} 1, & \text{if job } j \text{ is assigned to plant } i \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n$$

$$Y_{jk} = \begin{cases} 1, & \text{if job } j \text{ is transported on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } j = 1, 2, \dots, n \text{ and } k = 1, 2, \dots, n$$

$$W_{ik} = \begin{cases} 1, & \text{if plant } i \text{ is visited on trip } k \\ 0, & \text{otherwise} \end{cases} \quad \text{for } i = 1, 2, \dots, m \text{ and } k = 1, 2, \dots, n$$

$C_j$  = process completion time of job  $j$  on the plant it is assigned to,  $j = 1, 2, \dots, n$

$T_j$  = time job  $j$  reaches the customer,  $j = 1, 2, \dots, n$

$Q_k$  = time truck reaches the customer at the end of  $k^{\text{th}}$  trip,  $k = 1, 2, \dots, n$

Mixed Integer Programming Model (MIP-4)

$$(17) \quad \text{minimize} \quad \sum_{j=1}^n T_j$$

*subject to*

$$(2), (3), (6.2), (7.2), (8), (9), (10.2), (12), (13.2), (14), (15.2), (16.2), (18.2), (19.2), (22)$$

$$(11.3) \quad (M_1 + d_i) \cdot (2 - X_{ij} - Y_{jk}) + Q_k \geq C_j + d_i, \quad i = 1, \dots, m, \quad j = 1, \dots, n, \\ k = 1, \dots, n$$

In addition to the constraints above, we have the valid inequality given in Section 4.3.2.1.

#### 4.3.4. Heuristic Method for the General Problem

In the previous sections of this chapter, we presented heuristics developed for the special cases of this problem that are observed in common practical applications. All these heuristics can be used to obtain a solution for this main problem. However, we develop one more heuristic method, Heuristic 7, specially designed for this general problem.

In Theorem 1(iv), it is stated that the truck leaves a plant either as soon as it arrives there or waits for the completion of a job. The question here is, if the truck waits at the plant, how much it should wait. In other words, assuming  $A$  jobs have already been produced until the truck arrives at a plant, for how many more job completions should the truck wait. Although we could not prove it analytically, we believe that in most cases whenever the truck arrives at a plant, it follows one of the three following options:

1. Leaves the plant immediately
2. Waits for one more job
3. Waits until the truck is fully loaded

The second option means that truck will wait for the completion of the job that has already started its processing, but not completed, at the time the truck arrives to the plant.

We study the third option in Section 4.2. Although we study the first option in Section 4.3.2, since first and second options are closely related to each other, we develop Heuristic 7 to address these two options.

There are three main concepts used in this method. The first concept is the batch sliding mechanism, explained before. The second concept is the gain-loss justification, introduced in the problem with a no wait constraint. The third concept is named as *ratio-to-wait*. This concept can best be explained on an example. Suppose that the processing of job  $j$  has already started but not completed until the arrival of the truck.. If the percentage of job  $j$ 's completed part is greater than or equal to *ratio-to-wait*, then the truck waits for the completion of job  $j$ , otherwise it leaves the plant immediately. Here, it is obvious that, when *ratio-to-wait* is equal to 1, the truck never waits for a job, i.e. the problem with no wait constraint. Our preliminary tests indicate that there exists no common *ratio-to-wait* value that performs well for all parameter settings. Therefore, in Heuristic 7, we let *ratio-to-wait* be equal to  $r$ , where  $r = 0.1, 0.2, \dots, 1$ , and among these  $r$  values, choose the one yielding the smallest total completion time.

Following the discussions above, Heuristic 7 can be summarized as follows:

Step 0) Index jobs in non-decreasing order of processing times and plants in non-decreasing order of distances to the customer area. Set *totCompTime* to 0, *numSent* = 0. Calculate  $\bar{p}$ . Set *ratio-to-wait* = 0.1. For each plant  $i$ , set *numJobs*[ $i$ ] = 0, *prodNum* = 0. Set *bestCompTime* to a very large value.

Step 1) Set  $i = 1$ . Determine the indexes and calculate the number of jobs that can be completely produced in the available processing time of plant  $i$ . Set *prodNum* to this value. Decrease available processing time by the sum of processing times of these jobs. If within updated available processing time, *ratio-to-wait* of the next job can be completed, increment *prodNum*. If  $prodNum \geq K$ , set *numJobs*[ $i$ ] =  $K$  and go to step 2. Otherwise, go to step 4.

Step 2) Apply *batch sliding* with batch size  $numJobs[i]$ . Assign the resulting batch to plant  $i$ . Increase  $numSent$  by  $numJobs[i]$ . Update  $totCompTime$ . If  $numSent < n$ , go to step 1. Otherwise, update  $totCompTime$ , if necessary update  $bestCompTime$ , and go to step 3.

Step 3) If  $ratio-to-wait < 1$ , reset everything except  $bestCompTime$ , increase  $ratio-to-wait$  by 0.1 and go to step 1. Otherwise, return  $bestCompTime$  and stop.

Step 4) Increment  $i$  and calculate the number of jobs that can be produced in plant  $i$  as explained in step 1. If value found is greater than or equal to  $K$ , set  $numJobs[i] = K$  and go to step 5. Otherwise, go to step 5 without changing the value of  $numJobs[i]$ .

Step 5) If  $numJobs[i]$  satisfies *gain-loss justification* conditions, go to step 2. Otherwise, go to step 6.

Step 6) If  $i < m$ , go to step 4. Otherwise, set  $i = 1$  and go to step 2.

A detailed pseudocode of this algorithm can be found in Appendix B.7. This heuristic runs in  $O(mn^3)$  time.

#### 4.3.5. Lower Bound for the General Problem (Lower Bound 6)

In this problem, we do not have any constraint that can let us obtain a tighter lower bound as in the previous problems. Therefore, for this problem, we calculate the lower bound analytically.

It is supposed that each plant has an equal distance  $d = \min_i d_i$  to the customer. In any of the trips, it is not known whether the truck leaves the plant immediately or waits for the completion of a job. In order to find a valid lower bound, we need to suppose it leaves the

plant immediately. The only exception to this assumption is the first trip. In the first trip, the truck takes at least one job, i.e. the job with the smallest processing time ( $J_1$ ), and leaves the plant either at the process completion time of  $J_1$  or as soon as it arrives at the plant. Since the route of the truck is not known, the number of jobs to be produced until the arrival time of the truck in the following trips is not known. However, to make the lower bound valid, we assume in each trip, the truck finds  $K$  jobs already produced.

Then, with the assumptions above, the total completion time can be expressed with the following formulation:

$$\begin{aligned}
 & K \cdot [A + d] + K \cdot [A + 3d] + \dots + K \cdot [A + (2q - 1)d] + (n - qK) \cdot [A + (2q + 1)d] \\
 = & n \cdot A + (n - qK) \cdot (2q + 1) \cdot d + K \cdot d \cdot q^2 \\
 & \text{where } A = \max \{p_1, d\} \text{ and } q = \left\lfloor \frac{n}{K} \right\rfloor.
 \end{aligned}$$



# Chapter 5

## EXPERIMENTAL DESIGN AND NUMERICAL RESULTS

In this chapter, we perform experimentation and give numerical results for the methods presented in Chapter 4. In Section 5.1, the parameter settings of the test problems are presented. The results obtained by applying our methods on these test problems are given in Section 5.2.

### 5.1. Experimental Design

We consider five parameters and each combination of these parameters defines a different problem. These parameters are: number of plants,  $m$ ; number of jobs,  $n$ ; the capacity of the truck,  $K$ ; processing times of the jobs,  $p_j$ , where  $j=1,2,\dots,n$ ; and the distances of the plants to the customer,  $d_i$ , where  $i=1,2,\dots,m$ . Although our problems are difficult to solve even with two plants, we wanted to observe their performance in under a more general setting. Therefore, the number of plants,  $m$ , is set to 3.

In the choices of parameters  $n$  and  $K$ , two possible cases related to the physical sizes of the products are considered. In the first case, the company may be producing products with large physical volumes like household appliances. In the second case, the company produces products with small physical sizes. In such a case, the products are batched together

in the form of a unitized load, such as a unitized load or a box, before transported. To be able to cover both cases, a job is either a large volume product or a unitized load of small volume products. Following these discussions, the values set for  $n$  and  $K$  are given in Table 5.1. For the soft drink manufacturer mentioned in Chapter 1, 1512 products constitute a palette. In such a case, 55 jobs correspond to 83160 products and this number is usually far more than the customer demands. Hence, having at most 55 jobs is sufficient to cover even the situations with palettes with fewer products.

**Table 5.1:** Parameter settings for number of jobs and truck capacity

| Parameters | Values         |
|------------|----------------|
| $n$        | 10, 25, 40, 55 |
| $K$        | 2, 4, 6, 8     |

It is not reasonable to set the processing times of the jobs and distances of the plants to a single value as done in  $n$  and  $K$ . Instead, ranges for them, i.e.  $[p_{\min}, p_{\max}]$  and  $[d_{\min}, d_{\max}]$ , should be determined. While determining these ranges, it was taken into consideration that a job is either a large volume product or a unitized load.

The range ( $D_{range}$ ) and mean ( $D_{mean}$ ) of plant distances are two main factors that may affect the performance of the proposed methods.  $D_{range}$  is defined as  $(d_{\max} - d_{\min})$  while  $D_{mean}$  is defined as  $(d_{\max} + d_{\min})/2$ . In order to be able to determine the effect of these factors, plant distances used in the test problems are generated from the following three ranges:

- Plant Distance Range 1 :  $D_{range} = 6$  ,  $D_{mean} = 25$
- Plant Distance Range 2 :  $D_{range} = 6$  ,  $D_{mean} = 35$

- Plant Distance Range 3 :  $D_{range} = 26$  ,  $D_{mean} = 35$

To determine the effect of range ( $P_{range}$ ) of processing times on the performance of the proposed methods, processing times are first grouped into two as small and large ranges. For the assessment of the effect of mean ( $P_{mean}$ ), small range group is divided into three subgroups as small, medium and large mean. Processing times used in the test problems are generated from the following four ranges:

- Processing Time Range 1 :  $P_{range} = 10$  ,  $P_{mean} = 6$
- Processing Time Range 2 :  $P_{range} = 10$  ,  $P_{mean} = 10$
- Processing Time Range 3 :  $P_{range} = 10$  ,  $P_{mean} = 30$
- Processing Time Range 4 :  $P_{range} = 34$  ,  $P_{mean} = 18$

Hence, as seen in Table 5.2, there are twelve ( $[p_{min}, p_{max}]$ ,  $[d_{min}, d_{max}]$ ) combinations from which the processing times and plant distances are generated by using a uniform distribution. For each of these 12 combinations, there exist 16 different  $(n, K)$  pairs. Therefore, a total of 192 test problems are created and for each of these problems 5 instances are generated randomly.

All heuristics and lower bound algorithms are coded in C++ and run on a PC with a 1.8 GHz AMD Turion 64 processor and 512 MB memory (recall that these procedures run in polynomial time). The exact methods are solved by calling the MIP solver of GAMS on a computer with 3.73 GHz, 2 Dual-Core Intel Hyperthreading Xeon CPU processor and 24 GB shared memory.

**Table 5.2 :** Parameter settings for processing times and plant distances

|  |                                   |  |                                    |
|--|-----------------------------------|--|------------------------------------|
| <b>Processing</b><br><b>Time Range 1</b> | $p_j \in [1,11], d_i \in [22,28]$ | <b>Processing</b><br><b>Time Range 3</b> | $p_j \in [25,35], d_i \in [22,28]$ |
|  | $p_j \in [1,11], d_i \in [32,38]$ |  | $p_j \in [25,35], d_i \in [32,38]$ |
|  | $p_j \in [1,11], d_i \in [22,48]$ |  | $p_j \in [25,35], d_i \in [22,48]$ |
| <b>Processing</b><br><b>Time Range 2</b> | $p_j \in [5,15], d_i \in [22,28]$ | <b>Processing</b><br><b>Time Range 4</b> | $p_j \in [1,35], d_i \in [22,28]$  |
|  | $p_j \in [5,15], d_i \in [32,38]$ |  | $p_j \in [1,35], d_i \in [32,38]$  |
|  | $p_j \in [5,15], d_i \in [22,48]$ |  | $p_j \in [1,35], d_i \in [22,48]$  |

## 5.2. Numerical Results

In this section, the results of the proposed methods for the problems studied are given in the order they are presented in Chapter 4. For each problem, the results are grouped according to their processing time ranges. The impacts of the number of jobs, truck capacity, and plant distance range will be given under these groups.

To assess the performance of the proposed heuristics, firstly the percentage gaps between the total completion times obtained by the heuristics and the corresponding lower bounds, named as *LB gap*, are calculated by using the following formula:

$$LB\ Gap = \frac{(Heuristic\ Value - Lower\ Bound\ Value)}{Lower\ Bound\ Value} \cdot 100$$

If the calculated gaps are large, optimal solutions are found for instances with small number of jobs. By comparing the heuristic results of these instances with the optimal results, we

attempted to determine the cause of the large heuristic-lower bound gap: poor performance of the heuristic or loose lower bound. The percentage gaps between heuristic results and optimal results, named as *optimality gap*, are calculated by the following formula:

$$\text{Optimality Gap} = \frac{(\text{Heuristic Value} - \text{Optimal Value})}{\text{Optimal Value}} \cdot 100$$

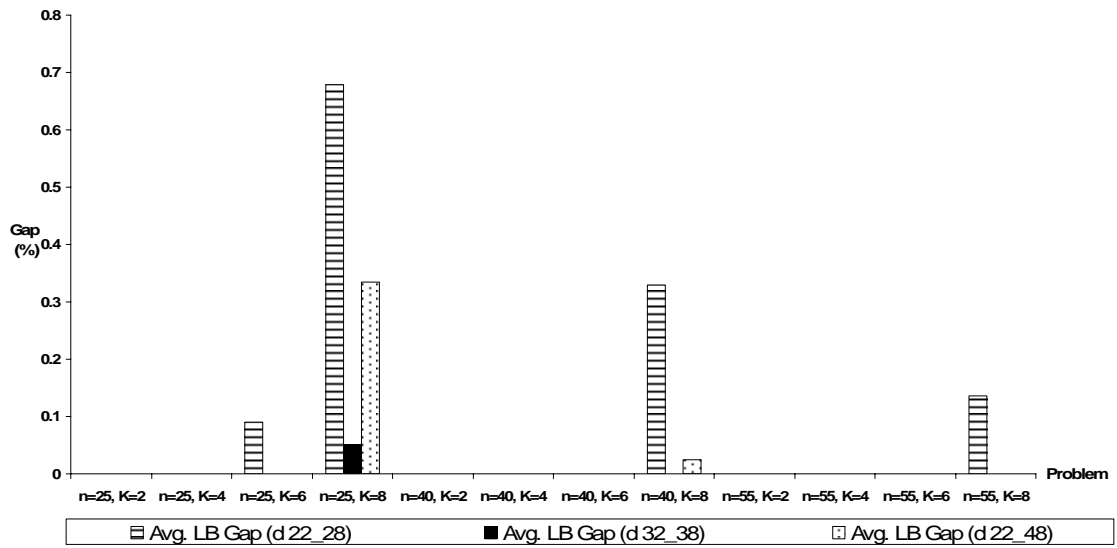
In the tables in Appendix C, D, E and F, average and maximum *LB gap* and *optimality gap* values are also given. These values are calculated by taking the average or maximum of the results of 5 random instances for each problem.

### 5.2.1. Numerical Results and Discussions for Last Trip Partial Problem

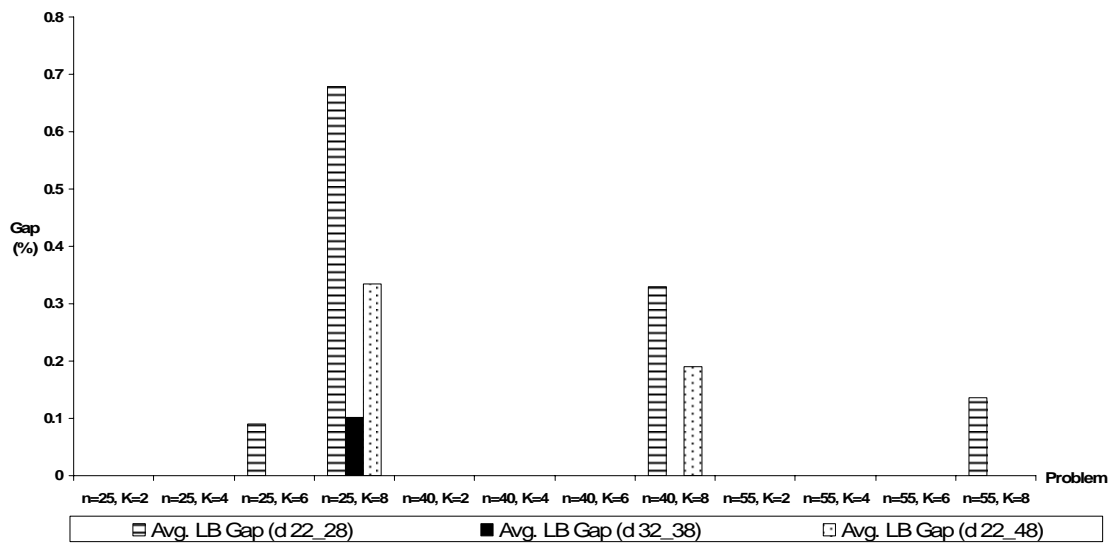
As explained in Chapter 4, one exact algorithm, MIP-1, two heuristic algorithms, Heuristics 1 and 2, and one lower bound generation algorithm are developed for this problem. The results obtained by the proposed methods are given in Appendix C.

#### **Processing Time Range 1:**

In this range, both heuristics yield the same or very close total completion times and these values are optimal at least for 67 of 80 tests. For the rest, the gap between the heuristic results and lower bound is very small (see Tables C.1, C.2 and C.3 in Appendix C for details). For all plant distance ranges in this group, *LB gap* values are 0% when there are 10 jobs to be produced and distributed. For other number of jobs values ( $n = 25, 40, 55$ ), *LB gaps* are shown in Figures 5.1 and 5.2 for Heuristic 1 and Heuristic 2, respectively.



**Figure 5.1:** Numerical results for Heuristic 1 for  $n = 25, 40, 55$  where  $p_j \in [1, 11]$



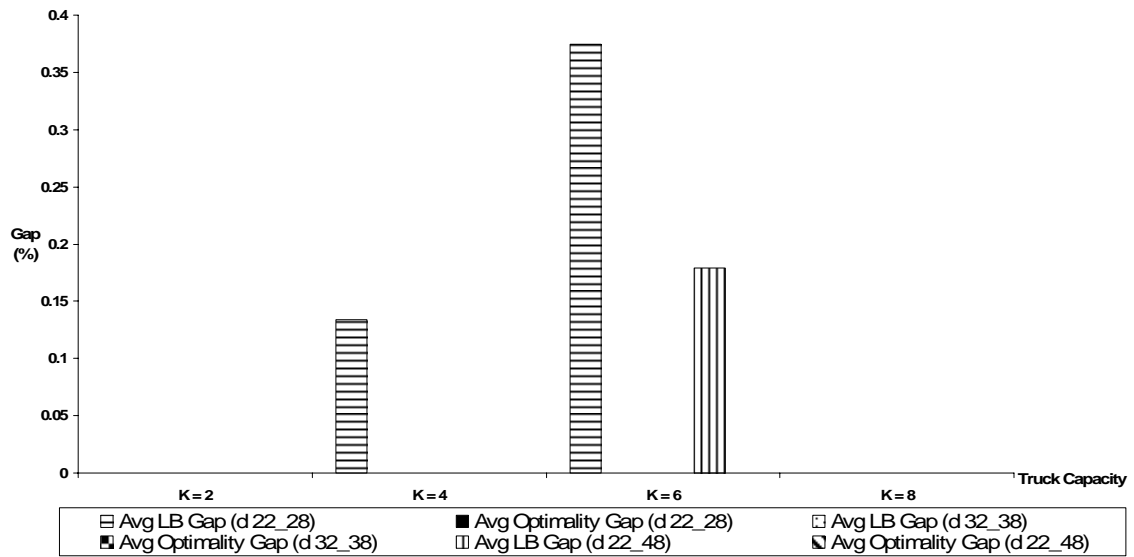
**Figure 5.2:** Numerical results for Heuristic 2 for  $n = 25, 40, 55$  where  $p_j \in [1, 11]$

By comparing Figures 5.1 and 5.2 it can be seen that Heuristic 1 performs better than Heuristic 2 in this processing time range. Although there are six data to be shown in the plots, for some  $(n, K)$  pairs, there are less than six bars. This means that *LB gap* was zero for

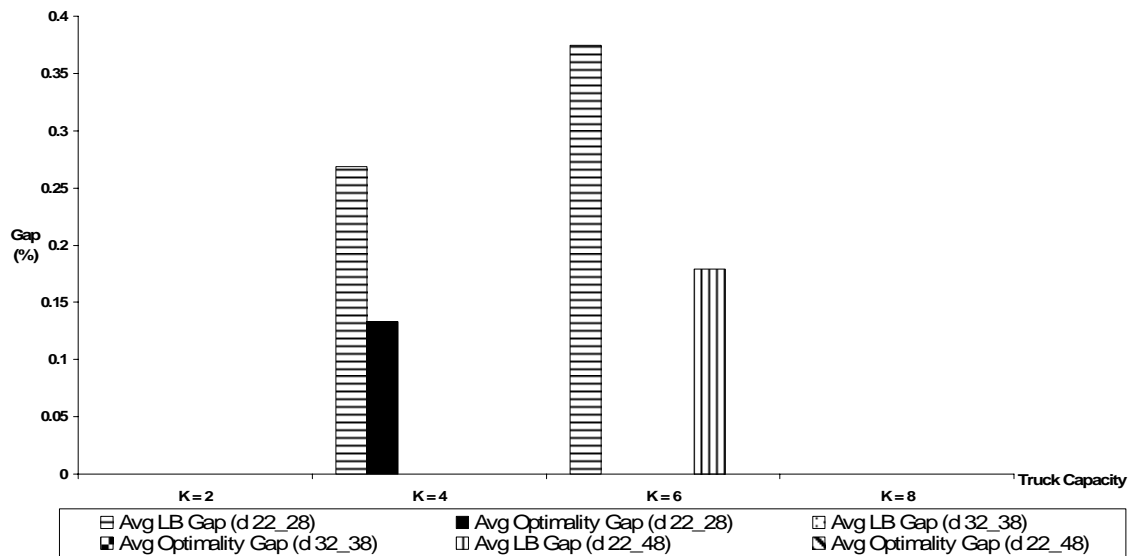
these parameter values. Since the mean of the processing times is small when compared to the mean of plant distances, the truck can make fully loaded trips only by visiting closer plants. As the capacity of the truck increases, the first trip becomes problematic because there may not be  $K$  jobs produced until the truck arrives to the first plant visited. As the mean of the plant distances increases, the probability that  $K$  jobs would be produced until the arrival of the truck to the first visited plant increases. Hence, *LB gap* decreases. This can be observed by comparing the 1<sup>st</sup> and 3<sup>rd</sup> bar columns for each  $(n, K)$  pair, in Figures 5.1 and 5.2. The impact of a change in the range of plant distances can be seen by comparing the 3<sup>rd</sup> and 5<sup>th</sup> bar columns for each  $(n, K)$  pair, in Figures 5.1 and 5.2. As the range increases, although the mean remains the same, the distance of the closest plant to the customer decreases. This decreases the probability of producing  $K$  jobs until the arrival of the truck on the first trip. Hence, *LB gap* increases.

### **Processing Time Range 2:**

This range has larger processing times than the previous one. Because of this increase in processing times, it is not possible to send the truck fully loaded by always visiting the closest plant. Especially, when the truck capacity is large, i.e.  $K = 6$  or  $8$ , in the proposed heuristics the truck may have to visit the second closest plant on the second or a later trip. Since the lower bound is calculated by considering that each plant has the same distance to the customer, i.e. the distance of the closest plant, the usage of a farther plant causes *LB gap* to be greater than zero. For 10 jobs, the *LB* and *optimality gaps* are shown in Figures 5.3 and 5.4 for Heuristic 1 and Heuristic 2, respectively. As can be seen in these figures, Heuristic 1 yields optimal results for this processing time range. For more than 10 jobs, since obtaining the optimal result takes a long time, exact algorithm is used only for the instances with *LB gap* larger than 10%. Maximum *LB gap* is less than 6% and hence only the *LB gaps* are given for problems with more than 10 jobs. Detailed test results for this processing time range can be found in Tables C.4, C.5 and C.6 in Appendix C.



**Figure 5.3:** Numerical results for Heuristic 1 for  $n = 10$  where  $p_j \in [5,15]$

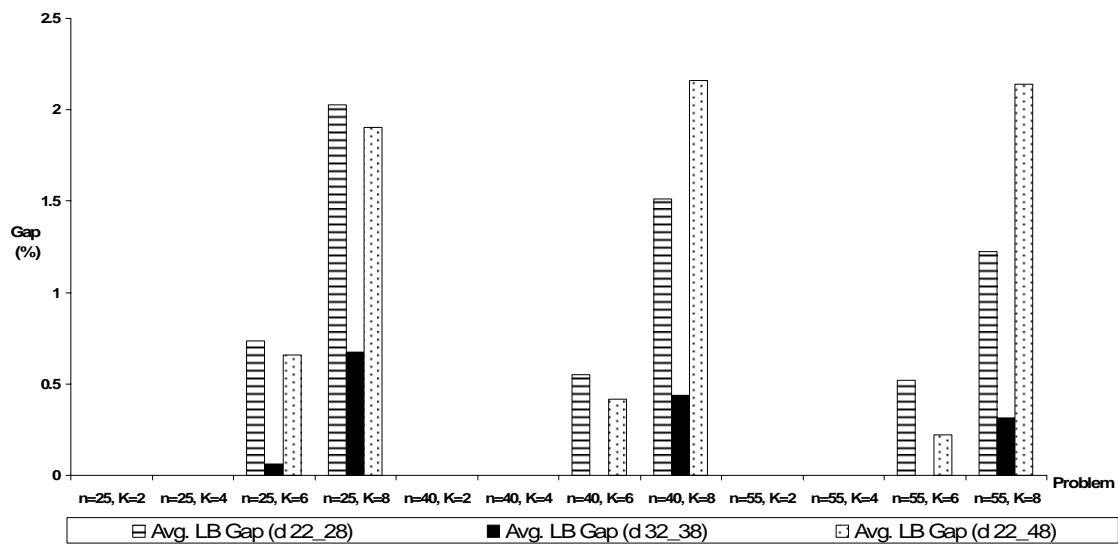


**Figure 5.4:** Numerical results for Heuristic 2 for  $n = 10$  where  $p_j \in [5,15]$

As seen by comparing 1<sup>st</sup> and 3<sup>rd</sup> bar columns for each  $(n, K)$  pair in Figures 5.5 and 5.6, an increase in the mean of the plant distance range decreases *LB gap* because of the

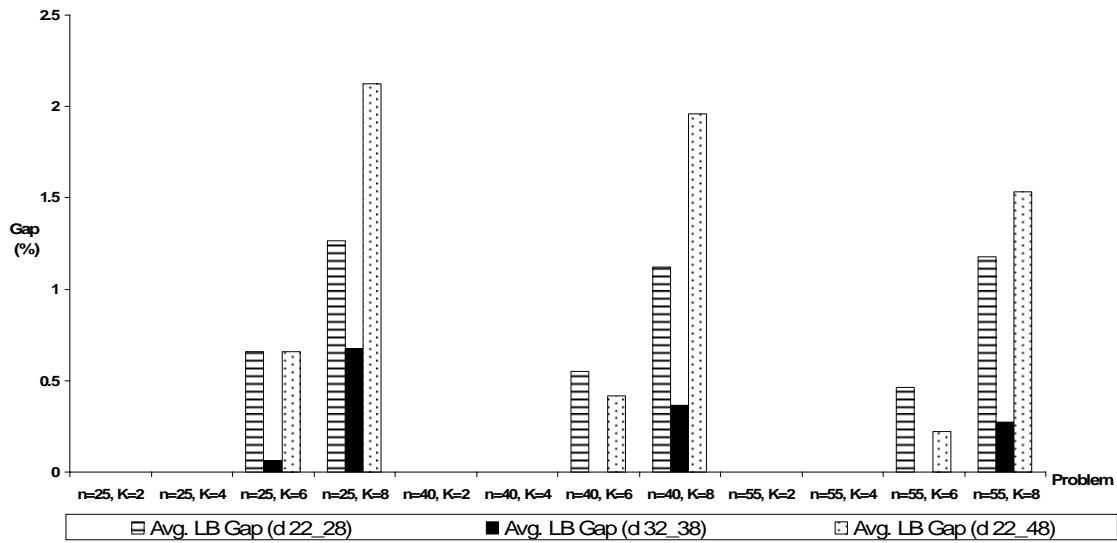


reasons explained in Processing Time Range 1. As the range of the plant distances increases, the distance difference between the closest plant and the second closest plant increases. Hence, when the second closest plant is visited, the deviation from the lower bound will be larger for the instances that have larger difference between the closest and farthest plant, i.e. larger plant distance range.



**Figure 5.5:** Numerical results for Heuristic 1 for  $n = 25, 40, 55$  where  $p_j \in [5, 15]$

It should be noted that, for this processing time range, Heuristic 2 outperforms Heuristic 1 in most of the instances. The reason for this performance difference is inherent in the ways these heuristics make the choices of jobs to assign to a selected plant. When the truck visits the second closest plant, Heuristic 2 assigns the  $K$ -size batch with greatest processing time to this plant, and is left with the jobs having smaller processing times. Hence, the truck would be able to transport  $K$  jobs from the closest plant on its next trip. However, since Heuristic 1 assigns the first unassigned  $K$  jobs to the second closest plant, it is left with jobs having larger processing times. Then the truck cannot transport  $K$  jobs from the closest plant in its next trip and hence needs to make the trip to a farther plant and this causes a delay in trip completion times.

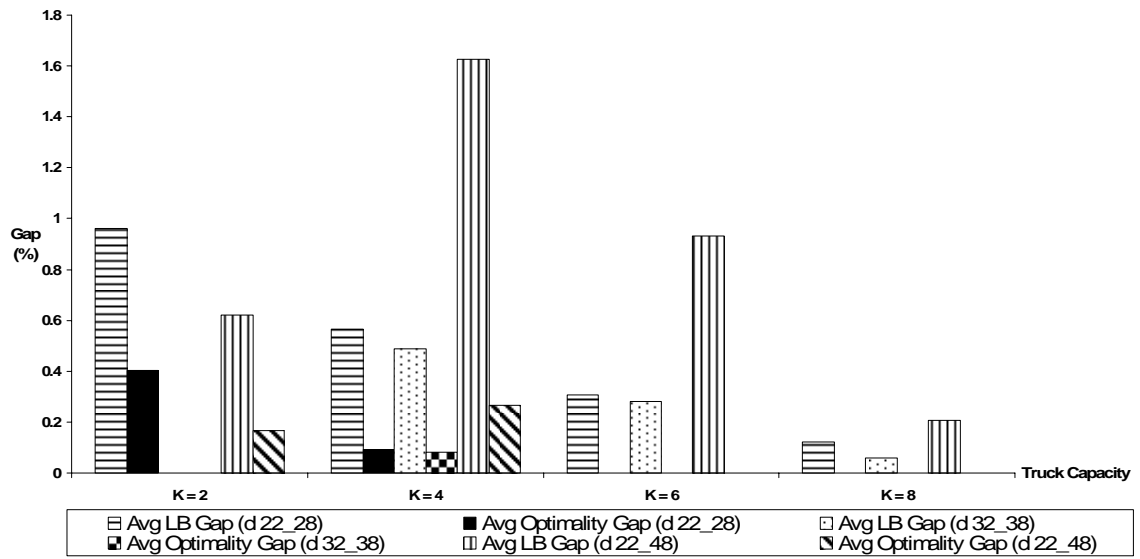


**Figure 5.6:** Numerical results for Heuristic 2 for  $n = 25, 40, 55$  where  $p_j \in [5, 15]$

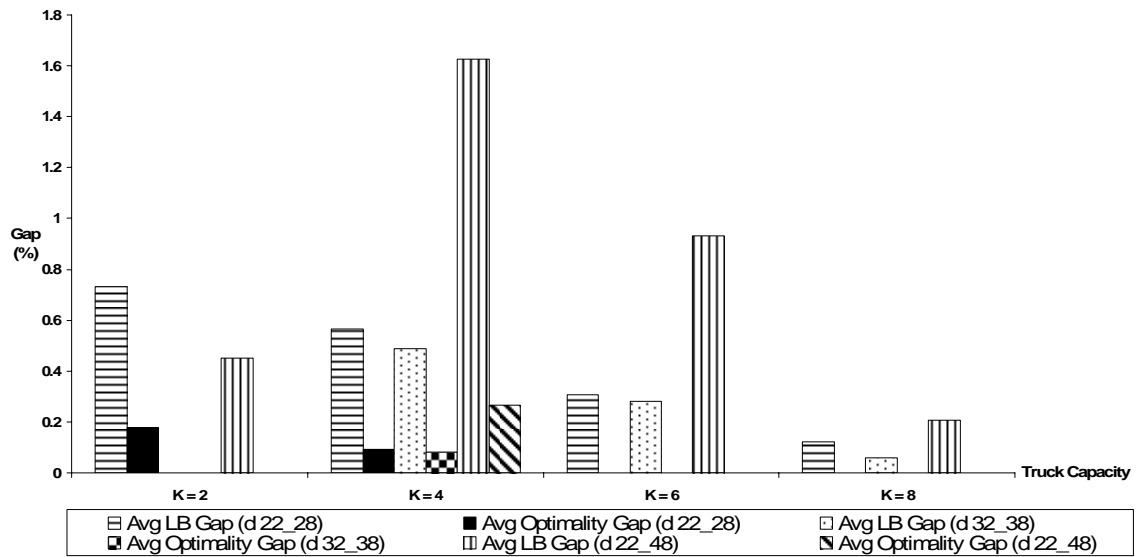
### Processing Time Range 3:

The processing times used in this range are so large that even if the truck capacity is set to the smallest value, i.e.  $K = 2$ , it is not possible to fill the truck by visiting the closest plant in every trip. Therefore, the truck requires visiting farther plants and, as explained above, this causes a deviation from the lower bound yielding *LB gaps* larger than 0. In Figures 5.7 and 5.8, it can be seen that *LB gaps* are very small for 10 jobs. For more than 10 jobs, all average *LB gaps* are smaller than 10% as can be seen in Figures 5.9 and 5.10. The test results for this range are given in Tables C.7, C.8 and C.9 in Appendix C.

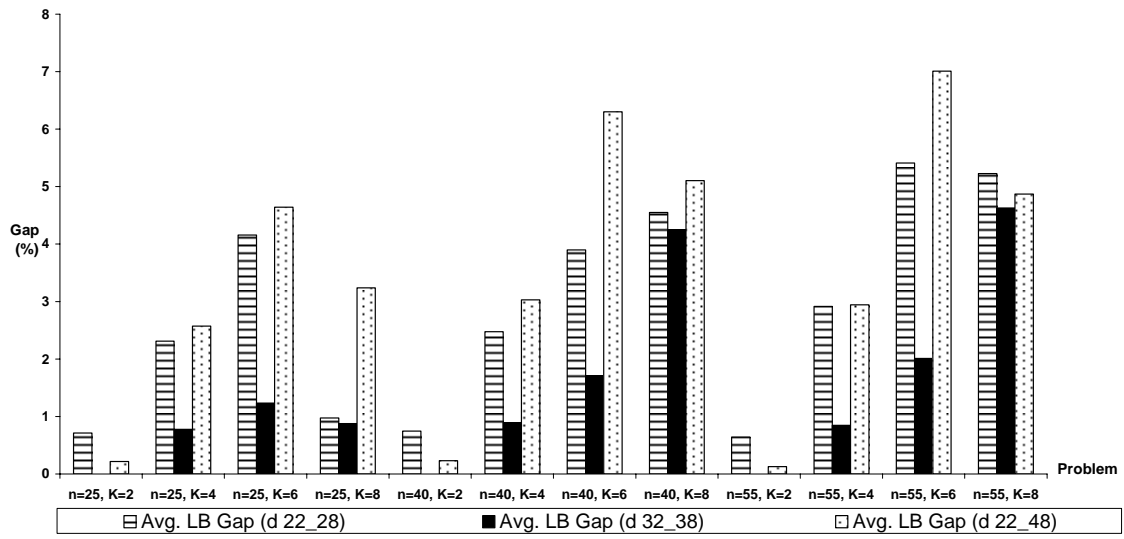
Here, one important point to mention is that the *LB gaps* in this range are higher than the gaps of previous ranges. The reason for this is the increase in the processing times. As processing times increase, the probability that the truck finds  $K$  jobs already produced whenever it arrives to a plant decreases. However, the lower bound is calculated based on the assumption that the truck finds  $K$  jobs. Therefore, lower bound is not tight in this range as it is in the previous ranges.



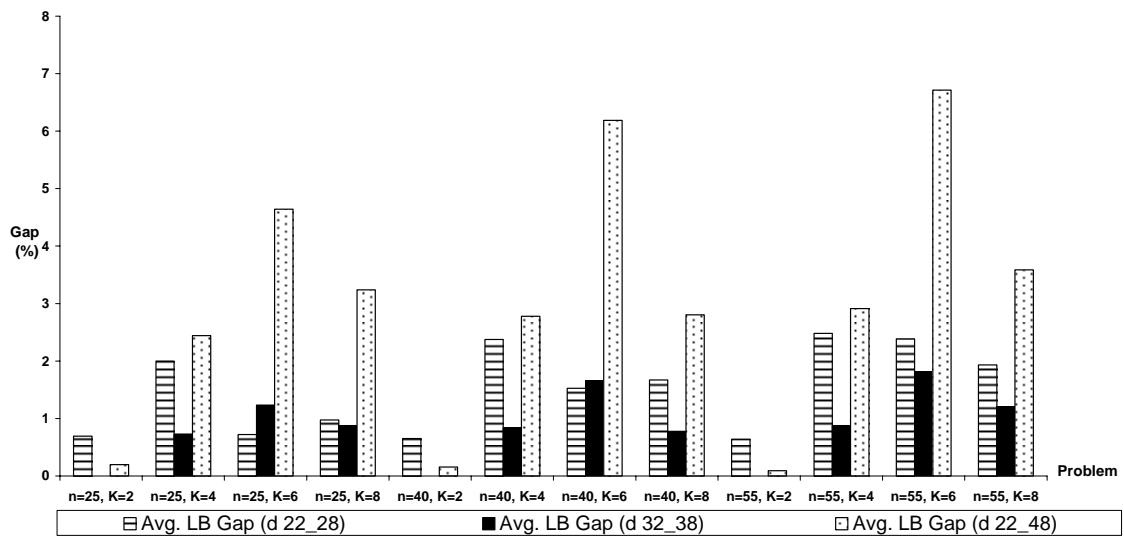
**Figure 5.7:** Numerical results for Heuristic 1 for  $n = 10$  where  $p_j \in [25, 35]$



**Figure 5.8:** Numerical results for Heuristic 2 for  $n = 10$  where  $p_j \in [25, 35]$



**Figure 5.9:** Numerical results for Heuristic 1 for  $n = 25, 40, 55$  where  $p_j \in [25, 35]$



**Figure 5.10:** Numerical results for Heuristic 2 for  $n = 25, 40, 55$  where  $p_j \in [25, 35]$

In general, as explained for the previous ranges, an increase in the mean of the plant distances causes a decrease in average *LB gap*. However, in Figure 5.10 for  $(n = 25, K = 6)$  and  $(n = 40, K = 6)$ , it is observed that an increase in the mean plant distance causes an increase in average *LB gap*. The reason for this unexpected situation can be explained as follows. In these problems, since the processing times are large, farther plants are also visited. When the closest plant is visited after visiting farther plants, for the problems with  $d_i \in [32, 38]$ , the truck finds  $K$  jobs already produced and the updating mechanism in the lower bound generation does not work. However, for the problems with  $d_i \in [22, 28]$ , the truck does not find  $K$  jobs produced as it arrives to the closest plant and the updating mechanism in the lower bound works and hence *LB gap* is smaller.

#### **Processing Time Range 4:**

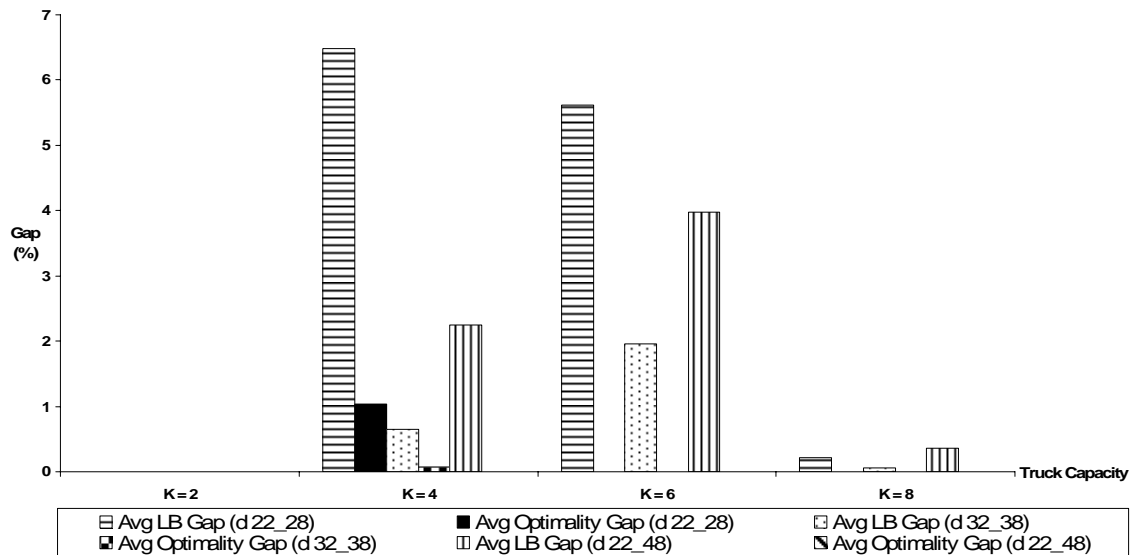
This is the processing time range that has the largest *LB gap* values. Since the range of the processing times is large, updating mechanism in the lower bound generation method may not work and hence obtained lower bounds may be looser than the previous ranges. As can be seen in Figures 5.11 and 5.12, *LB gaps* around 20% exist for 10 jobs. However, the maximum *optimality gap* is smaller than 2.5%. In Figures 5.13 and 5.14, for the problem with  $(n = 25, K = 8)$ , high *LB gap* values are observed. For these instances with *LB gap* value greater than 10%, exact methods could not yield the optimal solution in a short time. By increasing the resource limit to 50000 seconds, we obtained the optimal solution except for 3 of the instances (see Tables C.10, C.11 and C.12 in Appendix C for details). As seen in Tables 5.3 and 5.4, proposed heuristics yield close to optimal results.

**Table 5.3 :** *LB and optimality gaps* for Heuristics 1 and 2 for  $(n = 25, K = 8)$  and  $d_i \in [22, 28]$

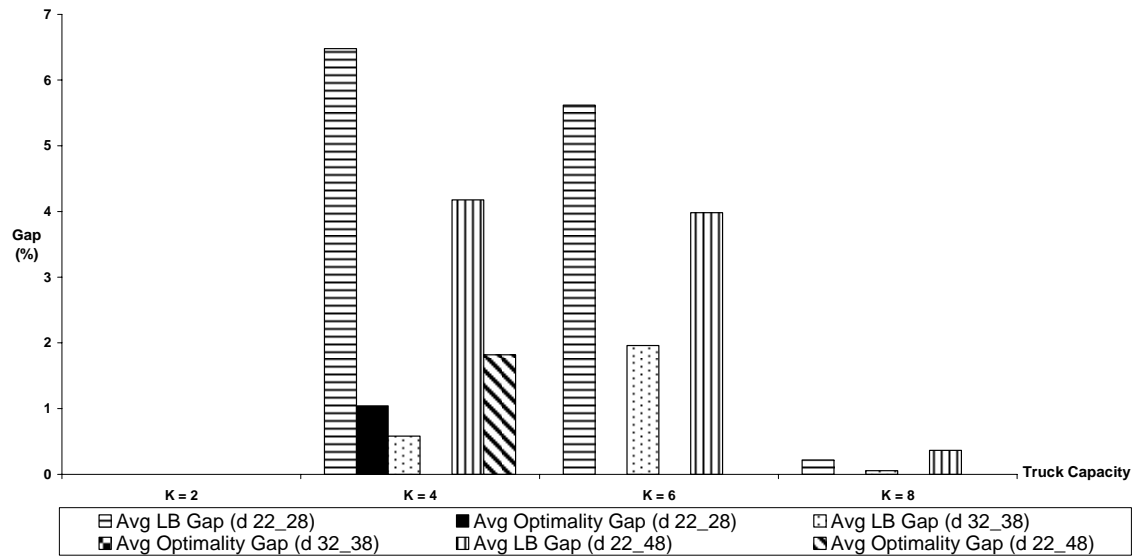
| $n$ | $K$ | LB Gap (%)  |             | Optimality Gap (%) |             |
|-----|-----|-------------|-------------|--------------------|-------------|
|     |     | Heuristic 1 | Heuristic 2 | Heuristic 1        | Heuristic 2 |
| 25  | 8   | 39.98       | 39.98       | 1.10               | 1.10        |
|     |     | 29.67       | 29.67       | 0.76               | 0.76        |
|     |     | 41.89       | 41.89       | 1.58               | 1.58        |
|     |     | 17.94       | 17.94       | 0.77               | 0.77        |
|     |     | 17.72       | 17.72       | 0.35               | 0.35        |

**Table 5.4 :** *LB and optimality gaps* for Heuristics 1 and 2 for  $(n = 25, K = 8)$  and  $d_i \in [22, 48]$

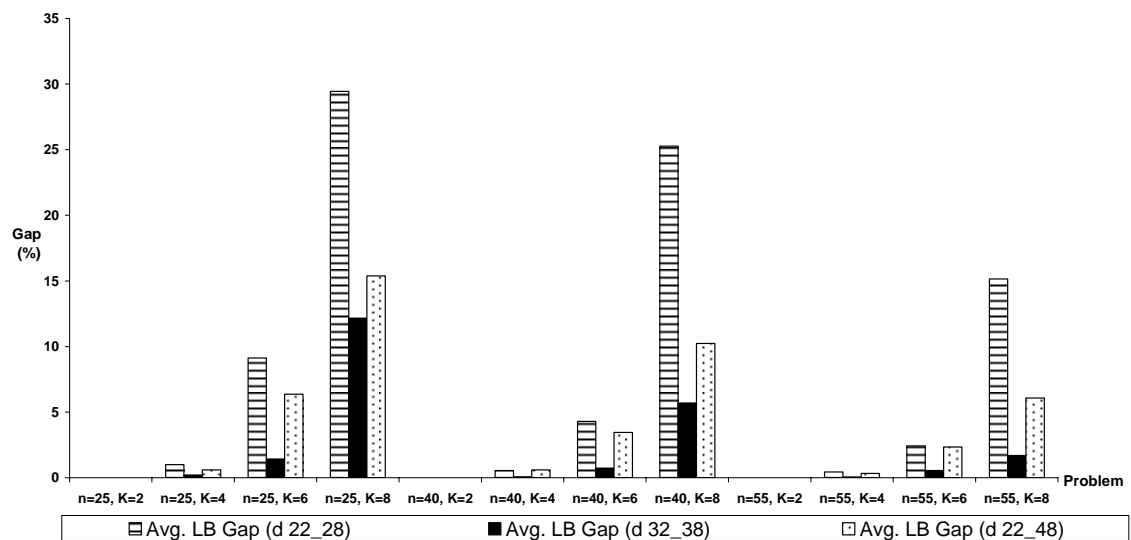
| $n$ | $K$ | LB Gap (%)  |             | Optimality Gap (%) |             |
|-----|-----|-------------|-------------|--------------------|-------------|
|     |     | Heuristic 1 | Heuristic 2 | Heuristic 1        | Heuristic 2 |
| 25  | 8   | 12.64       | 12.64       | 0.40               | 0.40        |
|     |     | 20.59       | 20.59       | 0.73               | 0.73        |
|     |     | 33.31       | 33.84       | 1.40               | 1.80        |



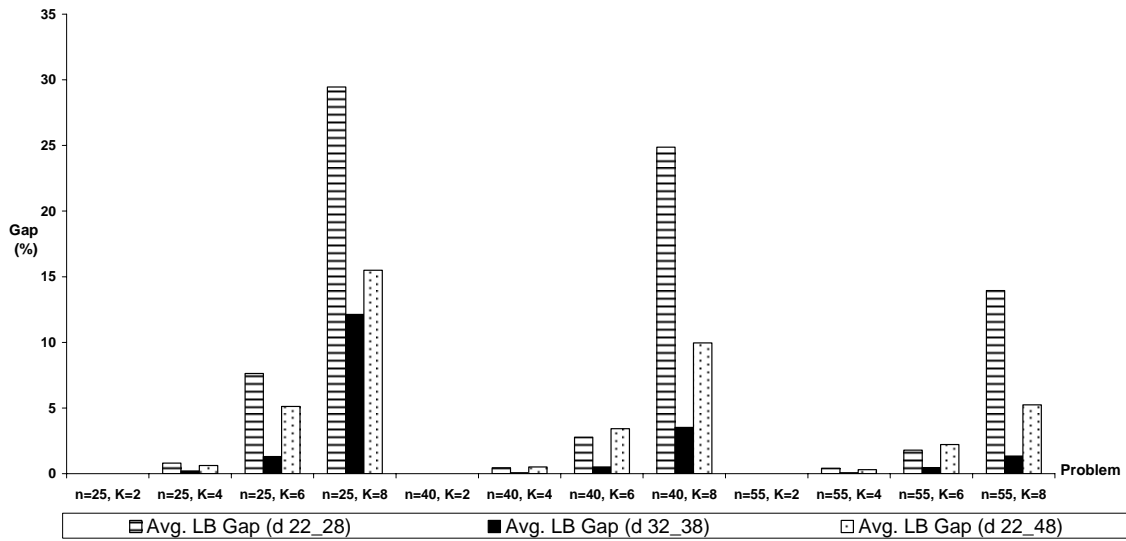
**Figure 5.11:** Numerical results for Heuristic 1 for  $n = 10$  where  $p_j \in [1, 35]$



**Figure 5.12:** Numerical results for Heuristic 2 for  $n = 10$  where  $p_j \in [1, 35]$



**Figure 5.13:** Numerical results for Heuristic 1 for  $n = 25, 40, 55$  where  $p_j \in [1, 35]$



**Figure 5.14:** Numerical results for Heuristic 2 for  $n = 25, 40, 55$  where  $p_j \in [1, 35]$

As in the previous processing time ranges, in this range, average *LB gap* decreases as the mean of the plant distance range increases. An increase in the range, increases average *LB gap*.

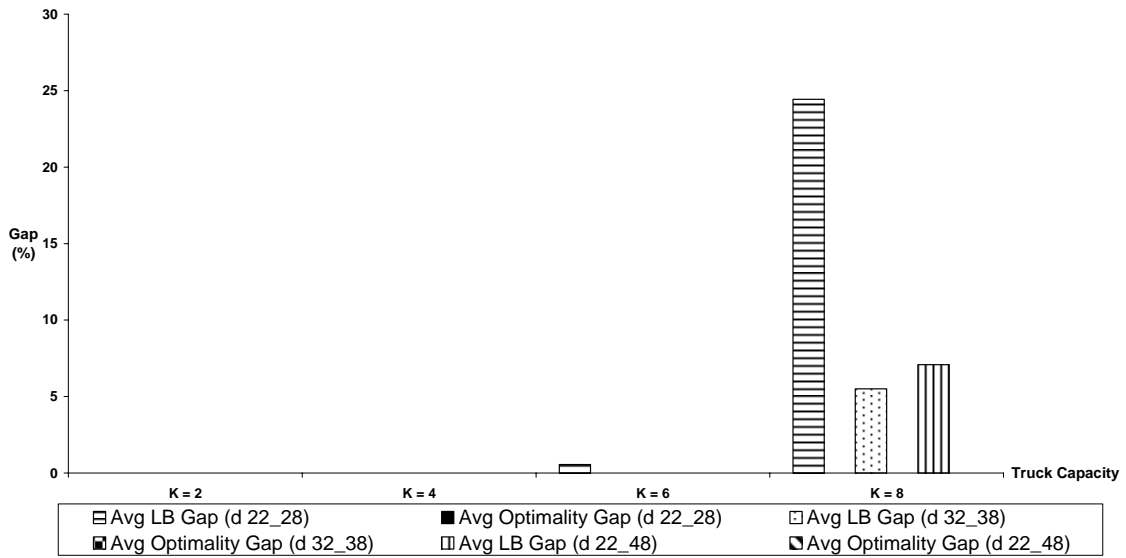
### 5.2.2. Numerical Results and Discussions for Fully Loaded Trips Problem

In this case, although we develop three different lower bound generation methods, in the results we use only two of them since Lower Bound 2 always yields worse results. It is not possible to say that Lower Bound 3 outperforms Lower bound 4 or the opposite. Therefore, for each instance we choose the one yielding larger lower bound value between these two methods. The lower bound values obtained and other test results for this problem is given in Appendix D.



### Processing Time Range 1:

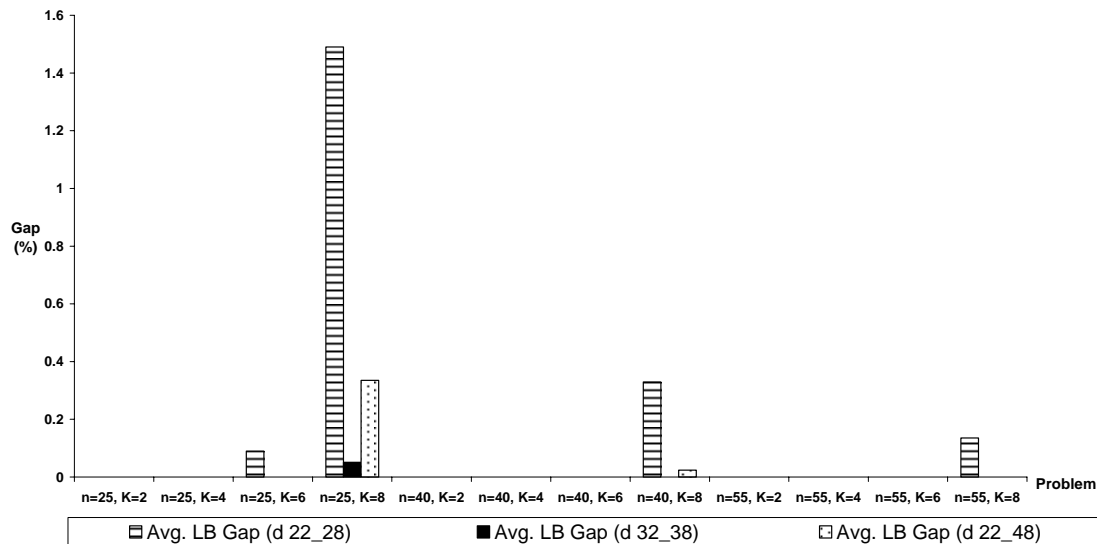
In this range, the gap between the heuristic result and the lower bound is small in general. The only problematic case is the problem with  $n = 10$  and  $K = 8$ . For this problem, for all plant distance ranges, *LB gap* is large, however, as shown in Figure 5.15 for 10 jobs, proposed heuristics generate near optimal solutions. Here, only the figure for Heuristic 3 is given because the results of Heuristics 3 and 4 are the same for 10 jobs.



**Figure 5.15:** Numerical results for Heuristic 3 for  $n = 10$  where  $p_j \in [1, 11]$

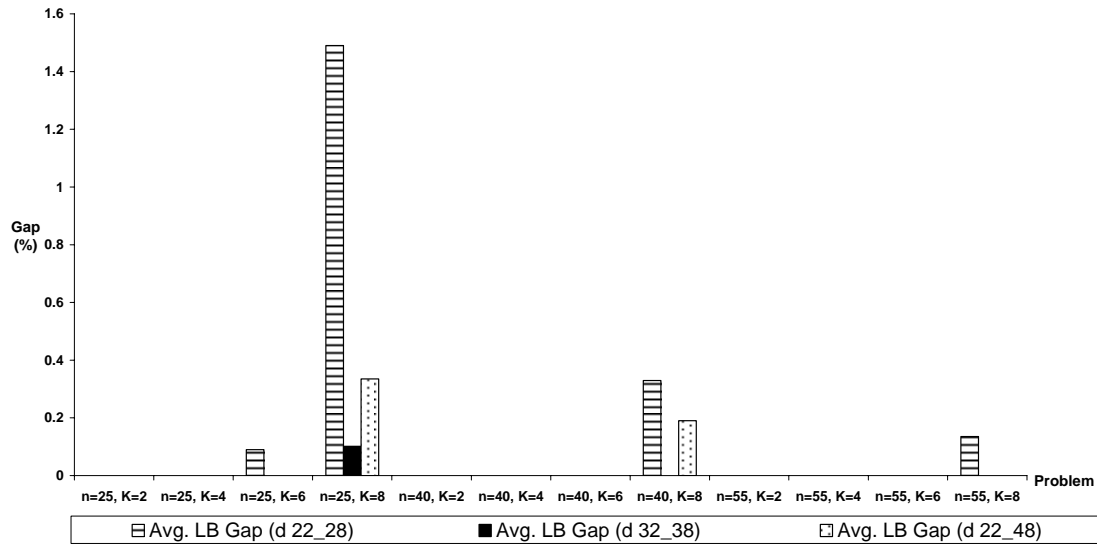
Since the heuristics can provide near optimal solutions, the reason for large *LB gaps* is the poor performance of the lower bound. The reason for this performance is inherent in the calculation of completion time of the first trip. Since it is not known which trip would be partially loaded, we suppose in the lower bound that the first trip is partially loaded and calculate the departure time of the truck from the first visited plant accordingly. However, in order to obtain a valid lower bound, we calculate the lower bound as if the truck transports  $K$  jobs in its first trip with this departure time. When the truck capacity is large, it is not possible to send the first truck fully loaded from the closest plant and this causes the lower bound to be loose. As seen in Figures 5.16 and 5.17, when more than 10 jobs require

transportation, this effect of the first trip vanishes because of the updating mechanism on the first trips of each round. This is the reason for small *LB gaps* with large number of jobs.



**Figure 5.16:** Numerical results for Heuristic 3 for  $n = 25, 40, 55$  where  $p_j \in [1, 11]$

As seen by comparing the 3<sup>rd</sup> and 5<sup>th</sup> column bars for each  $(n, K)$  pair in Figures 5.16 and 5.19, *LB gap* decreases as mean of the plant distance range increases. As plant distances increases, the probability that the truck leaves a plant immediately and fully loaded increases. Since this is what we suppose in the calculations of the lower bound, the decrease in the *LB gap* with the increase in distance range is in compliance with our expectations. In fact, this situation holds not only for this range but for all processing time ranges. Therefore, we can conclude that for the full truck case, as the mean of the plant distance range increases, *LB gap* decreases.



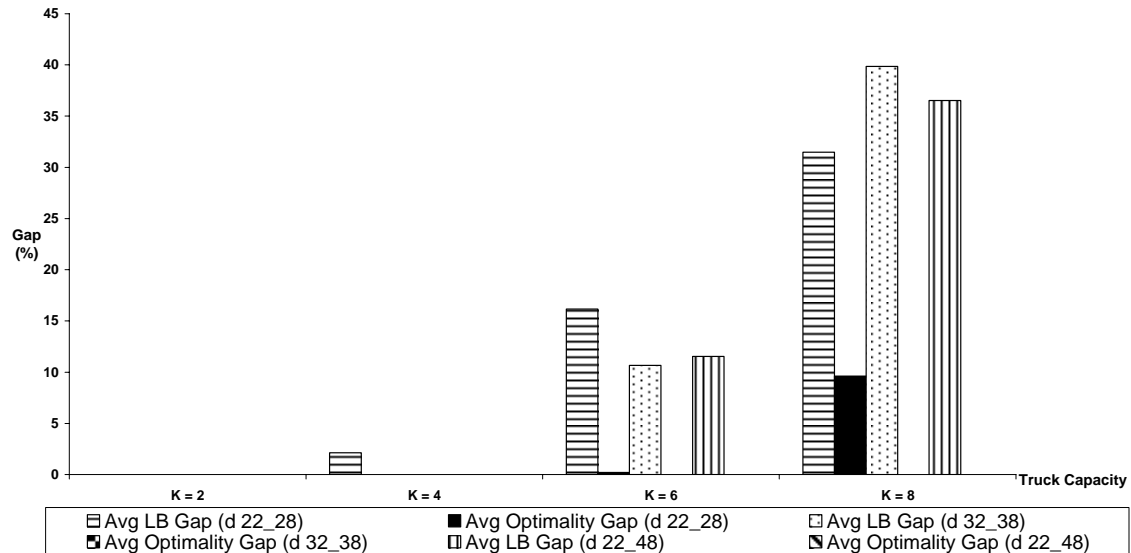
**Figure 5.17:** Numerical results for Heuristic 4 for  $n = 25, 40, 55$  where  $p_j \in [1, 11]$

Since the processing times are small and it is possible to send the truck fully loaded without causing it to wait at a plant, sending only the last truck partially loaded is better from the perspective of obtaining smaller total completion times. This result can be observed by comparing Table D.1 with C.1; Table D.2 with C.2 and Table D.3 with C.3.

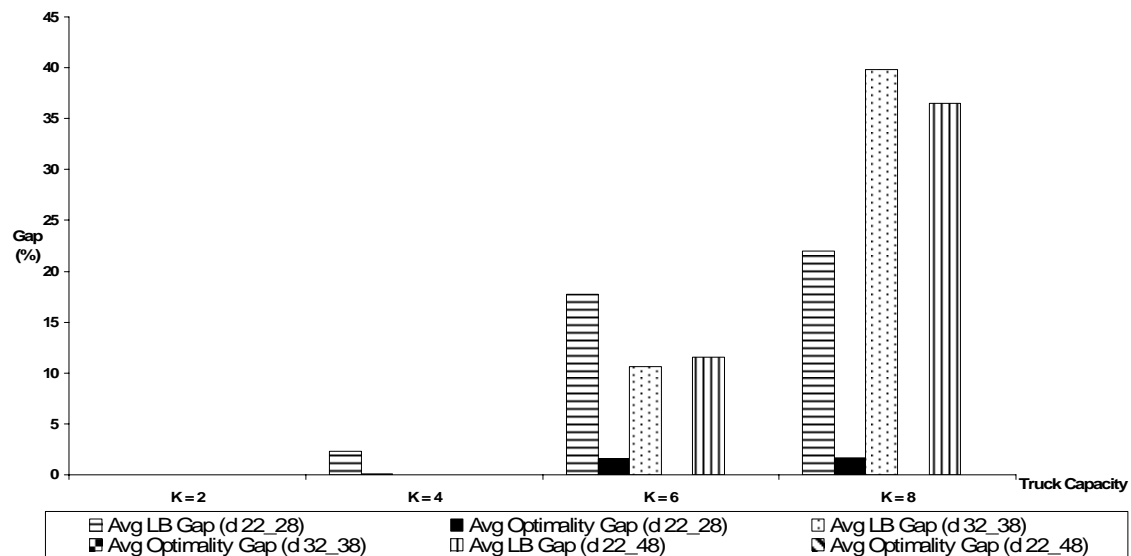
### Processing Time Range 2:

In this range, since the processing times are larger than range 1, sending the last truck partially loaded is better only if the capacity of the truck is small. As truck capacity increases, it gets harder to fill the truck in the first trips and hence waiting at a plant for the truck to be fully loaded in the first trips causes a delay in the trip completion times of the following trips. Also, while generating the lower bound, since it was assumed that the truck can be fully loaded as soon as it arrives to a plant, as the truck capacity increases and the probability of filling the truck in the first trips decreases, *LB gap* increases. In Figures 5.18 and 5.19, for 10 jobs, it is shown that *LB gaps* can be very large due to poor performance of the lower bounds

because of the reason mentioned above. The maximum optimality gap obtained by Heuristic 4 is 5.86%, seen in the distance range [22,28].

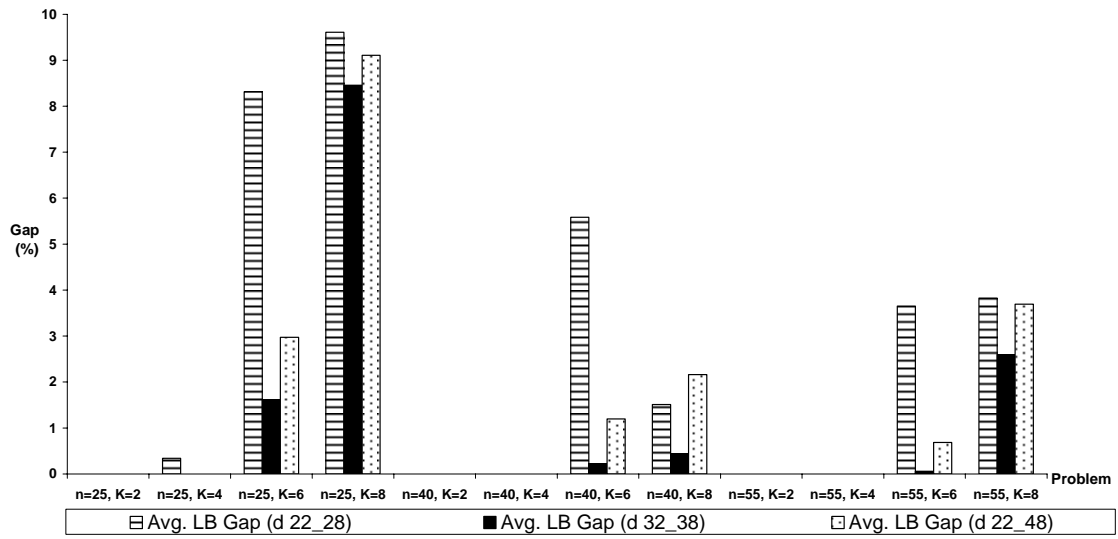


**Figure 5.18:** Numerical results for Heuristic 3 for  $n = 10$  where  $p_j \in [5,15]$

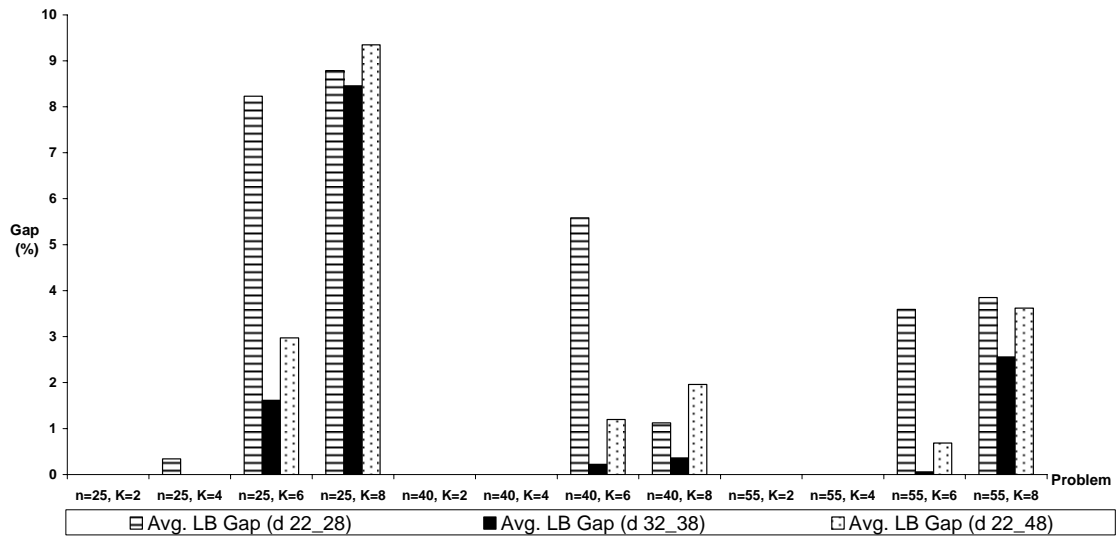


**Figure 5.19:** Numerical results for Heuristic 4 for  $n = 10$  where  $p_j \in [5,15]$

As can be seen both from Figures 5.18 and 5.19, and from Figures 5.20 and 5.21, increasing the mean of the plant distance range decreases *LB gaps*. The reason for this result was explained in Processing Time Range 1.



**Figure 5.20:** Numerical results for Heuristic 3 for  $n = 25, 40, 55$  where  $p_j \in [5, 15]$



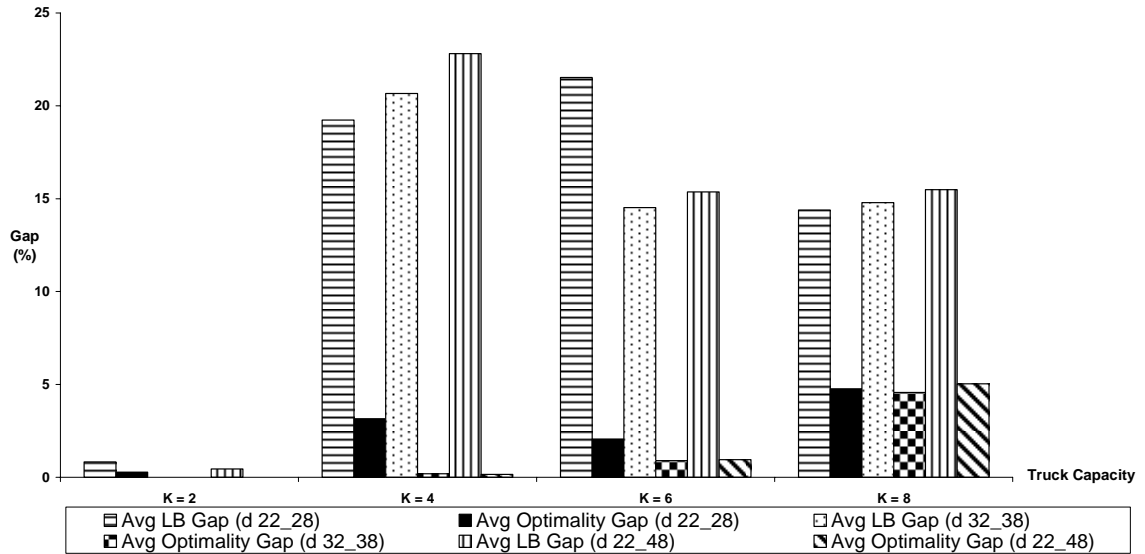
**Figure 5.21:** Numerical results for Heuristic 4 for  $n = 25, 40, 55$  where  $p_j \in [5, 15]$

For 25 jobs, we solved MIP-2 for the instances that have *LB gaps* either larger or close to 10%. However, even in 50000 seconds we could not obtain the optimal solution for those problems. In Tables D.4 and D.5 in Appendix D, the best integer values found at the end of 50000 seconds are given in the optimal results column with a (\*) mark.

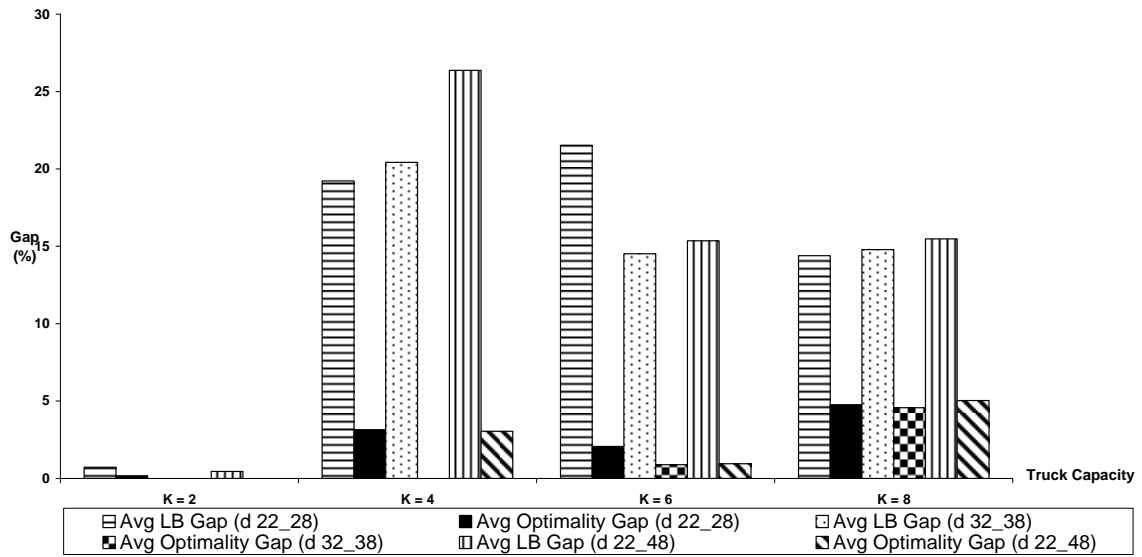
### Processing Time Range 3:

The increase in processing times in this range causes an increase in *LB gap* values. As explained in the results for the problem with only last trip partially loaded, in this processing time range, it is not possible to fill the truck in each trip as is supposed in the lower bound generation. Hence, lower bound values are much smaller when compared to the optimal results. Therefore, large *LB gaps* will be observed as seen in Figures 5.22, 5.23, 5.24 and 5.25. The results for this range are given in Tables D.4, D.5 and D.6 in Appendix D.

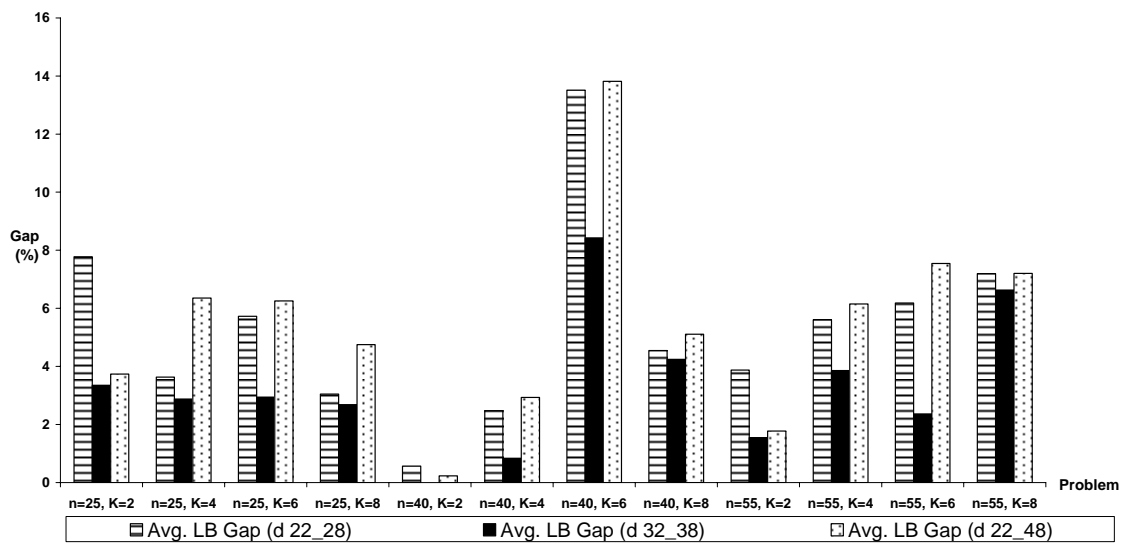
In Figures 5.22 and 5.23, it is shown for 10 jobs that proposed heuristics yield optimal or near-optimal results. For 25 jobs, we tried obtaining the optimal results for the instances with *LB gap* values larger than 10% but could not get the results even in 13.89 hours (50000 seconds).



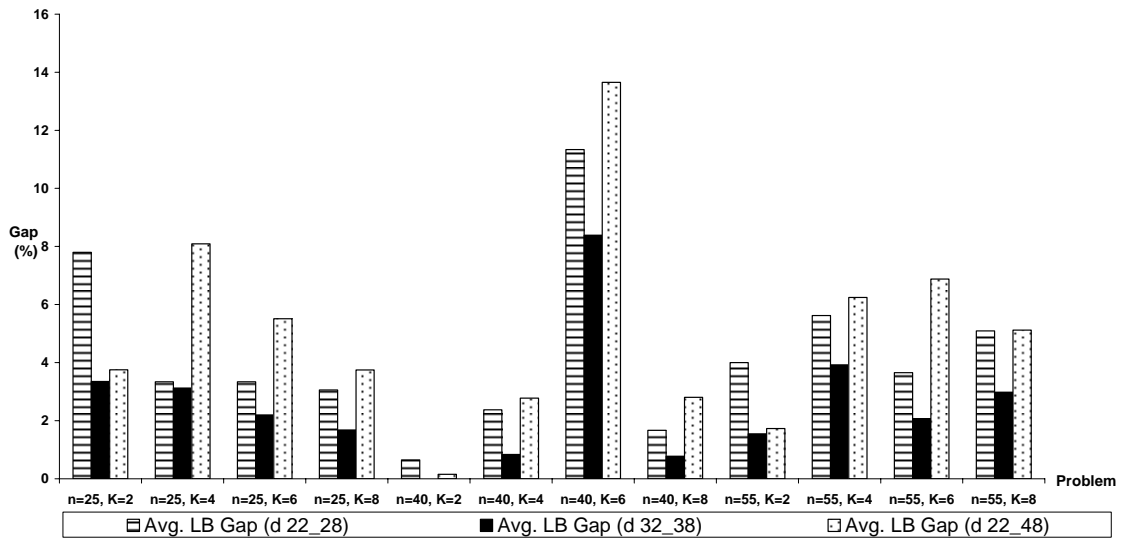
**Figure 5.22:** Numerical results for Heuristic 3 for  $n = 10$  where  $p_j \in [25, 35]$



**Figure 5.23:** Numerical results for Heuristic 4 for  $n = 10$  where  $p_j \in [25, 35]$



**Figure 5.24:** Numerical results for Heuristic 3 for  $n = 25, 40, 55$  where  $p_j \in [25, 35]$



**Figure 5.25:** Numerical results for Heuristic 4 for  $n = 25, 40, 55$  where  $p_j \in [25, 35]$

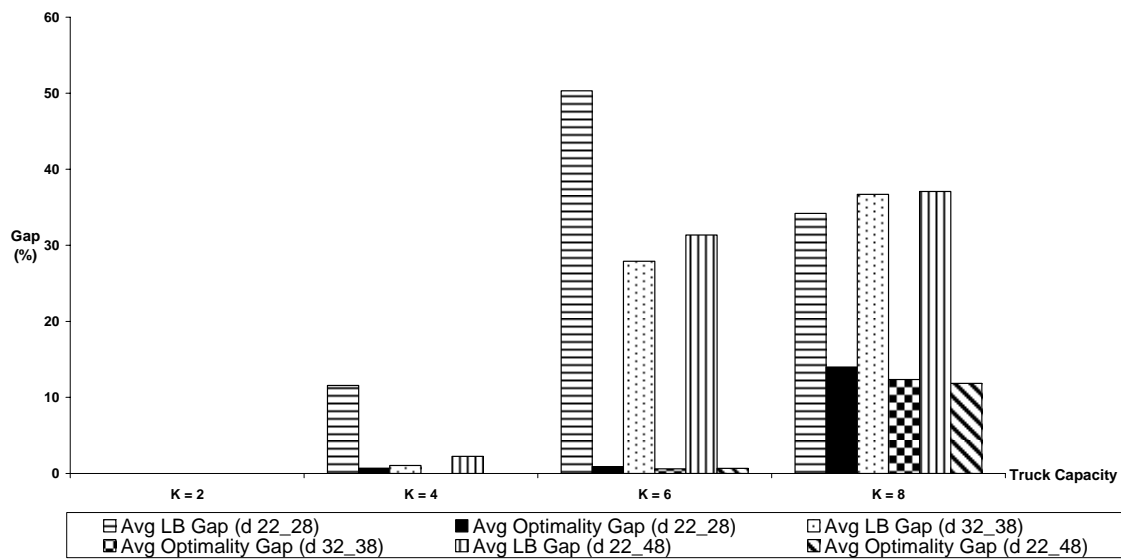
Although can be observed by comparing Table D.5 with A.5; Table D.6 with C.6 and Table D.7 with C.7, it is possible to say intuitively that, sending the first trips fully loaded and the last trip partially loaded would not yield good results in terms of smaller total completion times. Since the processing times are large, for the trips in the beginning of the schedule, the truck will need to wait for the completion of a job at a plant in order to become fully loaded. And this will delay the following trips most of the time unnecessarily.

#### Processing Time Range 4:

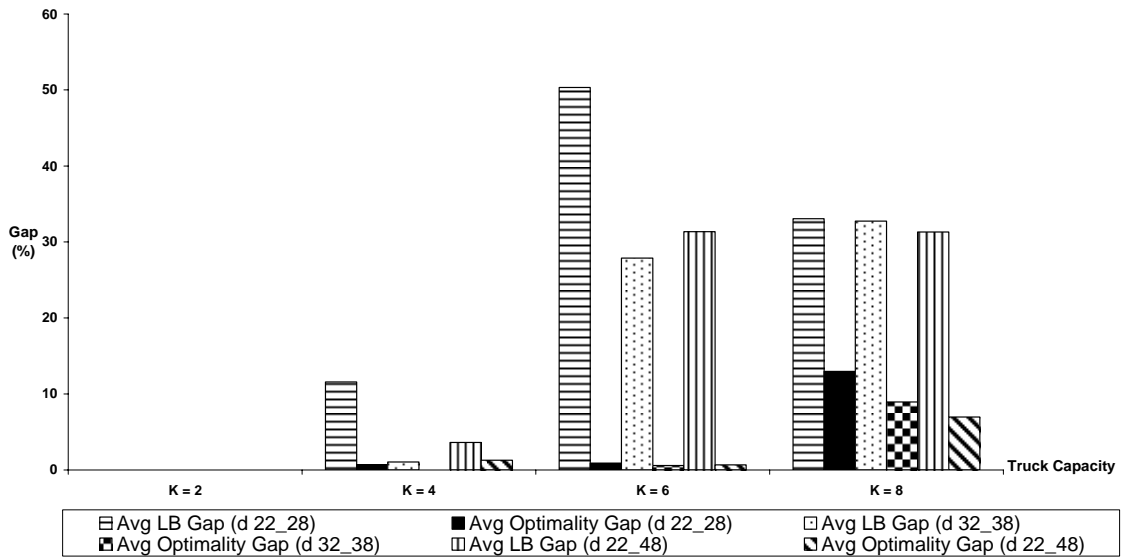
In this range for 10 jobs *optimality gap* can be as high as 15.71% as seen in Figures 5.26 and 5.27. The reason for this is that in our heuristics, if the truck requires taking  $l$  jobs from a plant and it can find that amount of jobs already produced as it arrives to that plant, it leaves that plant immediately. However, with this processing time range, in the optimal solution, even if the truck finds  $l$  jobs already produced as it arrives to a plant; it waits for the completion time of  $l$  largest jobs. Hence, in the following trip, the truck can be fully loaded by either immediately leaving the plant or after waiting a small amount of time. For



example, in the second instance of the problem with  $n=10$  and  $K=8$ , we have  $p = \{3, 5, 10, 11, 19, 21, 31, 31, 34, 34\}$  and  $d = \{24, 25, 28\}$ . Both of our heuristic methods choose sending the last trip partial and transports jobs with processing times  $\{3, 5, 10, 11, 19, 21, 31, 31\}$  from the closest plant on the first trip and the rest from the second plant on the second trip. However, in the optimal solution, jobs with processing times  $\{34, 34\}$  are assigned to the second plant but they are transported on the first trip. After transporting these jobs, the truck goes to the closest plant and waits for the completion time of the remaining eight jobs and transports them. Hence, both in our methods and in the optimal solution, the completion time of the first eight jobs are the same. But the completion time of the last two jobs in the optimal solution is much smaller than the completion time found by our proposed heuristics.

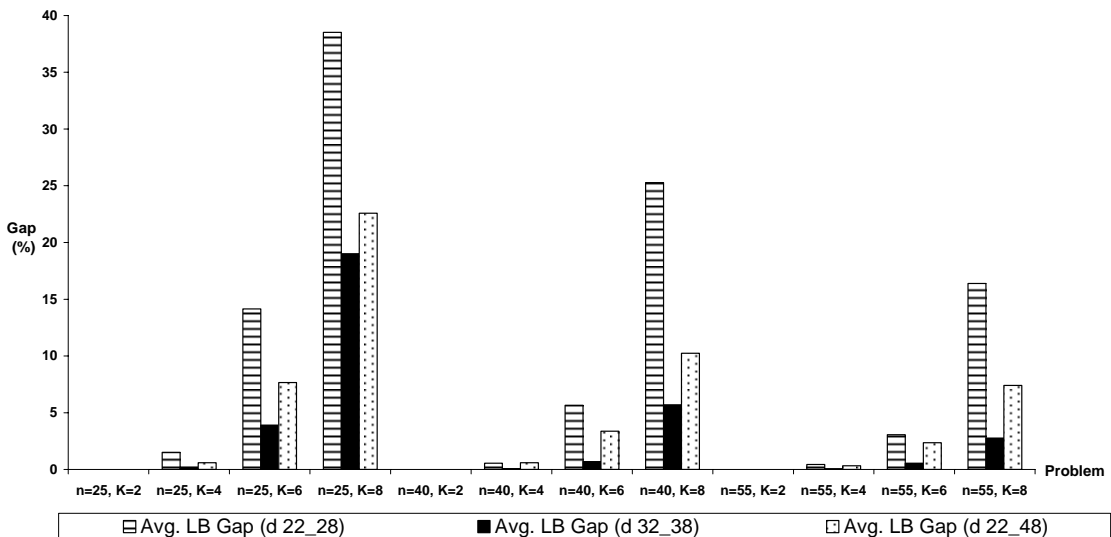


**Figure 5.26:** Numerical results for Heuristic 3 for  $n = 10$  where  $p_j \in [1, 35]$

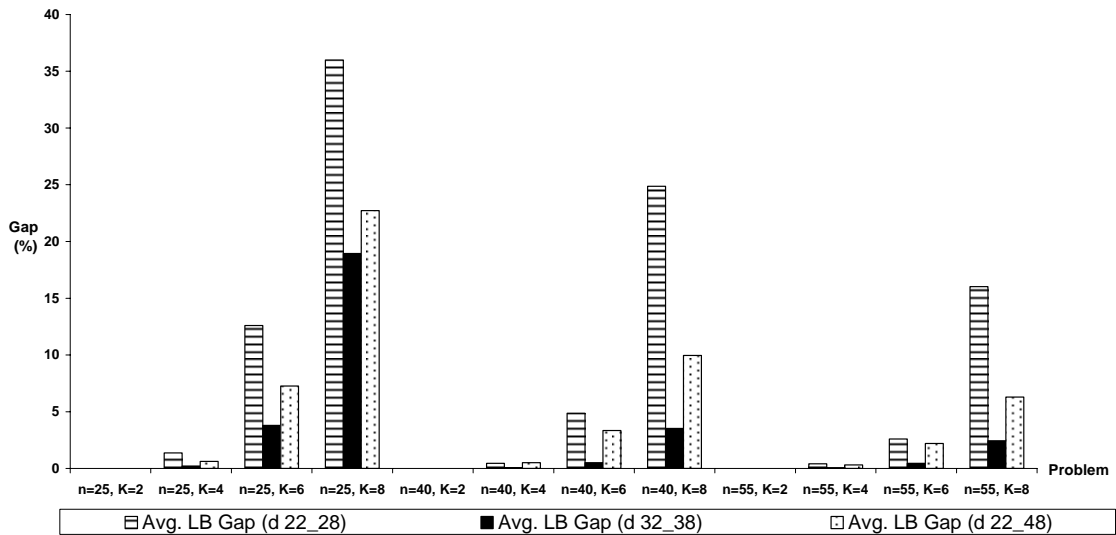


**Figure 5.27:** Numerical results for Heuristic 4 for  $n = 10$  where  $p_j \in [1, 35]$

As observed in Figures 5.28 and 5.29, an increase in the number of jobs causes a decrease in *LB gaps* because the effect of the first trip decreases.



**Figure 5.28:** Numerical results for Heuristic 3 for  $n = 25, 40, 55$  where  $p_j \in [1, 35]$



**Figure 5.29:** Numerical results for Heuristic 4 for  $n = 25, 40, 55$  where  $p_j \in [1, 35]$

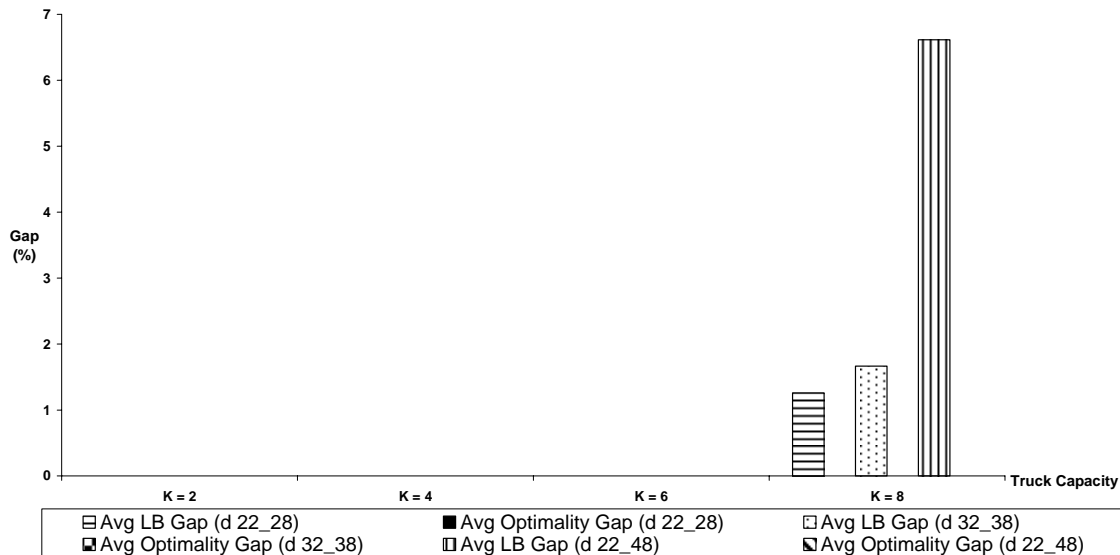
### 5.2.3. Numerical Results and Discussions for the Problem with No Wait Constraint

As explained in detail in Chapter 4, in this problem, the truck does not wait for the completion time of a job at a plant. It leaves the plants it visits on any trip as soon as it arrives there. One important point to mention for this problem is that for all processing time ranges *LB gap* increases or remains the same as the capacity of the truck increases (this pattern can be seen in the result tables in Appendix E). This result follows from the fact that lower bound decreases with increasing capacity. As the capacity increases, the maximum number of jobs that can be transported on each trip increases and hence the number of jobs that can be transported in the trips more to the beginning of the schedule increases. This may cause a decrease in the number of required trips. Therefore, the value of the lower bound decreases.

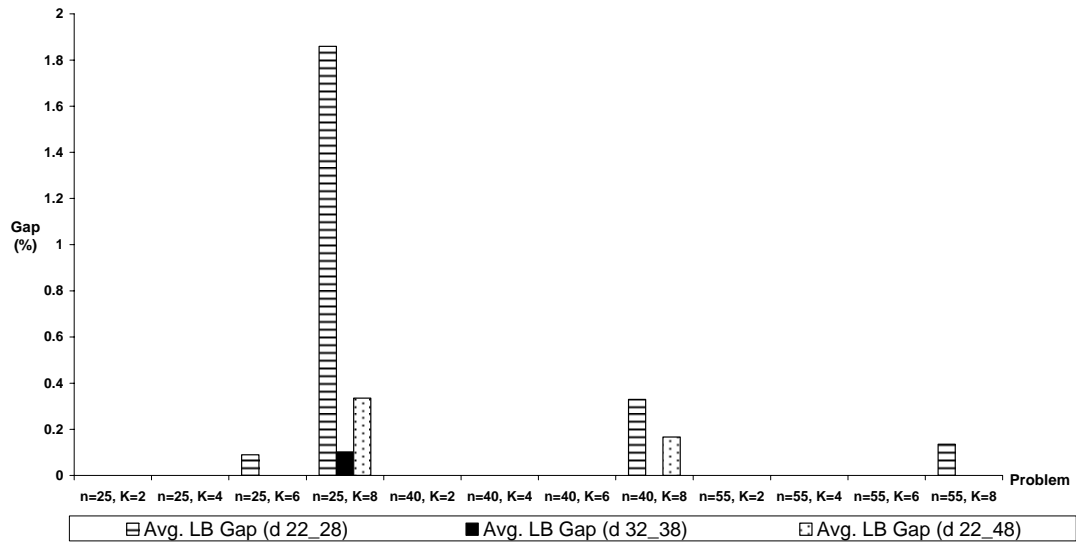
**Processing Time Range 1:**

In this range, Heuristics 5 and 6 yield the same total completion times. For all plant distance ranges and  $(n, K)$  pairs *LB gap* values are very close to 0. The only exception is observed for distance range [22,48] and  $(n = 10, K = 8)$ . But as seen in Figure 5.30, proposed heuristics yield the optimal results even for this exception.

In Figure 5.31, it can be observed that average *LB gaps* are very small. In addition to that, an increase in the mean of the plant distance range causes a decrease in average *LB gaps*. Actually, in this problem for all processing time ranges, an increase in the mean of the distance range causes a decrease in the average *LB gap*. This result has two possible reasons. The first reason is that when the mean plant distance is large, for processing time ranges with small means, jobs are produced only by using the closer plants and the truck usually makes fully loaded trips in compliance with the schedule in the lower bound. The second reason is that for processing times with large means, since the heuristic method may require the usage of farther plants even for the first trip, the schedule generated by the heuristic and the lower bound will be similar and hence *LB gap* will decrease.



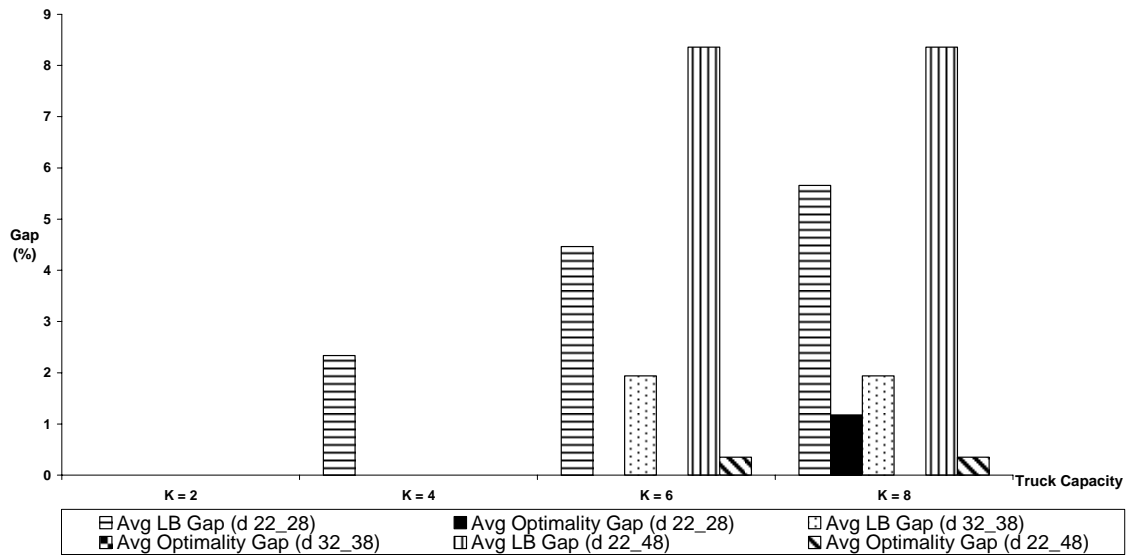
**Figure 5.30:** Numerical results for Heuristic 5 for  $n = 10$  where  $p_j \in [1, 11]$



**Figure 5.31:** Numerical results for Heuristic 5 for  $n = 25, 40, 55$  where  $p_j \in [1, 11]$

### Processing Time Range 2:

In this processing time range, for 10 jobs, it is seen in Figure 5.32 that there exists some instances with *LB gap* values larger than 10%. The results obtained by solving MIP-3 show that proposed heuristics generate optimal or near-optimal solutions for this problem. This implies the poor performance of Lower Bound 5. One possible reason for this performance of the lower bound is that trip completion times are calculated as if each trip is made to the closest plant. Despite this assumption, to be able to obtain a valid lower bound, the number of jobs on the first trip is calculated as if the first trip is made to the farthestmost plant. In our heuristic methods, in the first trip, truck may choose to visit the farthestmost plant and hence the number of jobs transported in the first trip would be the same in the heuristic method and the lower bound. However, in the heuristic methods, completion time of the first trip is calculated based on the distance of the farthestmost plant instead of the closest plant. Hence, Lower Bound 5 yields a smaller total completion time than the heuristic methods.

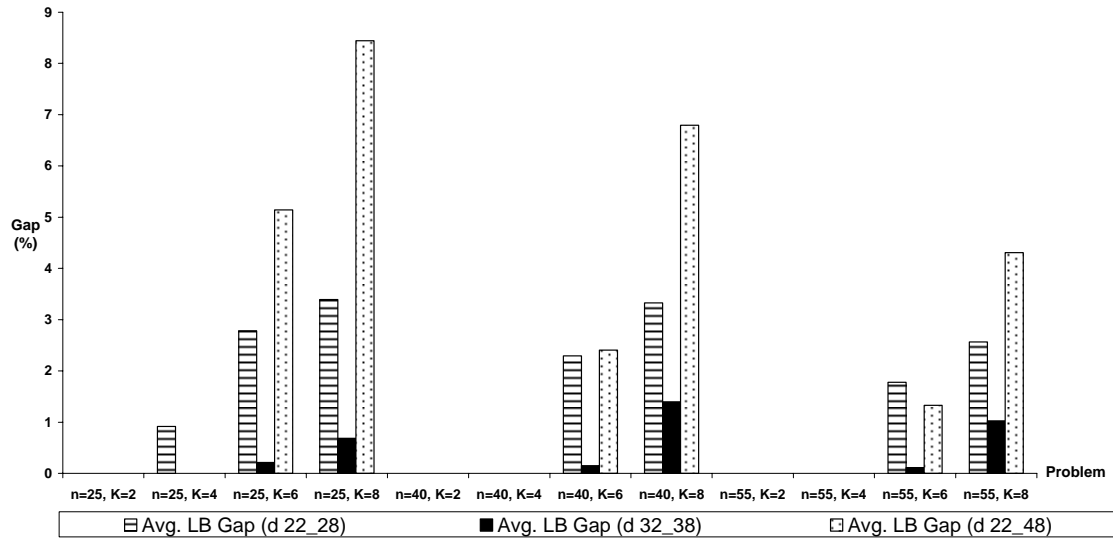


**Figure 5.32:** Numerical results for Heuristic 5 for  $n = 10$  where  $p_j \in [5, 15]$

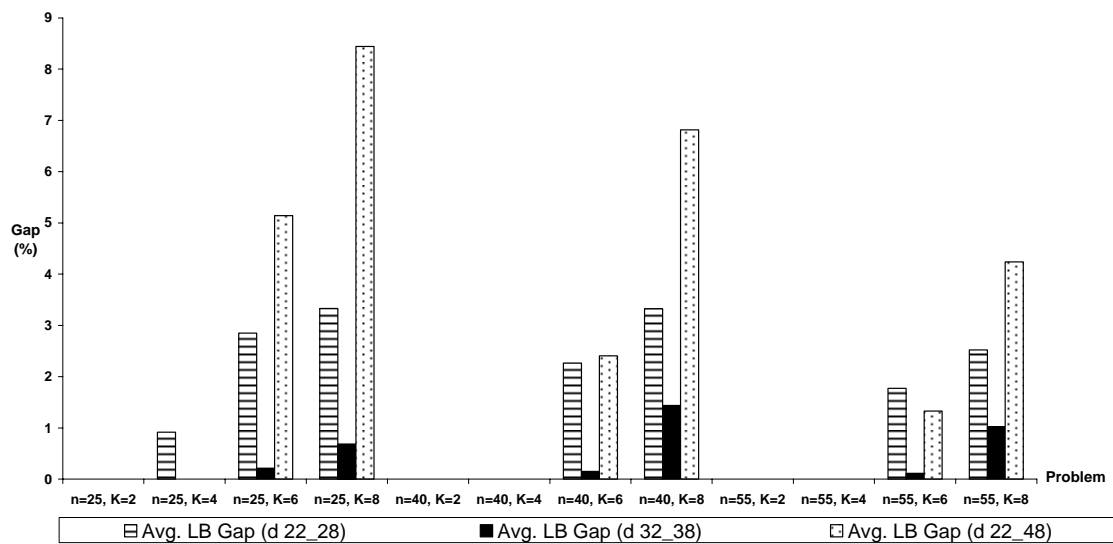
Figures 5.33 and 5.34 show the comparison of the average *LB gaps* for different plant distance ranges. As can be seen in these figures, an increase in the mean of the plant distances causes a decrease in average *LB gaps*. The reasons for this result were explained in Processing Time Range 1.

In the CPU times column of Table E.4 in Appendix E, it is possible to see some recurring values. The reason for this is as follows. The first instance of the problem with  $(n = 10, K = 8)$  is solved optimally. In the optimal solution it was seen that in the first trip 4 jobs and in the second trip 6 jobs were carried. Although the truck capacity is 8, maximum 6 jobs were carried on each trip. Hence, the optimal solution for the first instance of the problem with  $(n = 10, K = 6)$  is the same as the optimal solution of the problem with  $(n = 10, K = 8)$  since all the parameters except the truck capacity are the same. Therefore, the CPU time obtained in solving the first instance of the problem with  $(n = 10, K = 8)$  is applied

to the first instance of the problem with  $(n=10, K=6)$ . This procedure is used for all applicable instances in the problem with no wait constraint and in the general problem.



**Figure 5.33:** Numerical results for Heuristic 5 for  $n = 25, 40, 55$  where  $p_j \in [5, 15]$



**Figure 5.34:** Numerical results for Heuristic 6 for  $n = 25, 40, 55$  where  $p_j \in [5, 15]$

As seen in Figures 5.33 and 5.34, an increase in the range of plant distances causes an increase in average *LB gaps*. This result is in compliance with our expectations because in Lower Bound 5, the number of jobs transported in each trip is calculated as if the truck is visiting farther plants but the completion times of the trips are calculated as if the truck is visiting the closest plant. As the difference between the closest and farthestmost plant increases, lower bound becomes loose and hence *LB gap* increases. This result holds for each processing time range.

### **Processing Time Range 3:**

In this range, we observe *LB gap* values larger than 10%. In order to determine the cause of these large gaps, we tried to obtain the optimal solution for the problems with  $n = 10$ . However, in 5 hours, we could not get the optimal results. Therefore, in order to be able to prove the performance of the proposed heuristic methods, we increased the resource limit to 41.67 hours (i.e. 150000 seconds). Even with this resource limit, we could not obtain the optimal solution for some instances. Therefore, instead of giving a bar chart showing the average gaps, we give the *LB* and *optimality gaps* for the instances for which the optimal solutions could be obtained in Tables 5.5, 5.6 and 5.7. In Tables E.7, E.8 and E.9 in Appendix E, the best integer solutions obtained in 150000 seconds are given with a (\*) mark.

In Figures 5.35 and 5.36, comparisons of the *LB gaps* for different distance ranges are given for Heuristic 5 and Heuristic 6, respectively.



**Table 5.5:** *LB* and *optimality gaps* for Heuristic 5 and Heuristic 6 for  $n=10$  and  $d_i \in [22,28]$

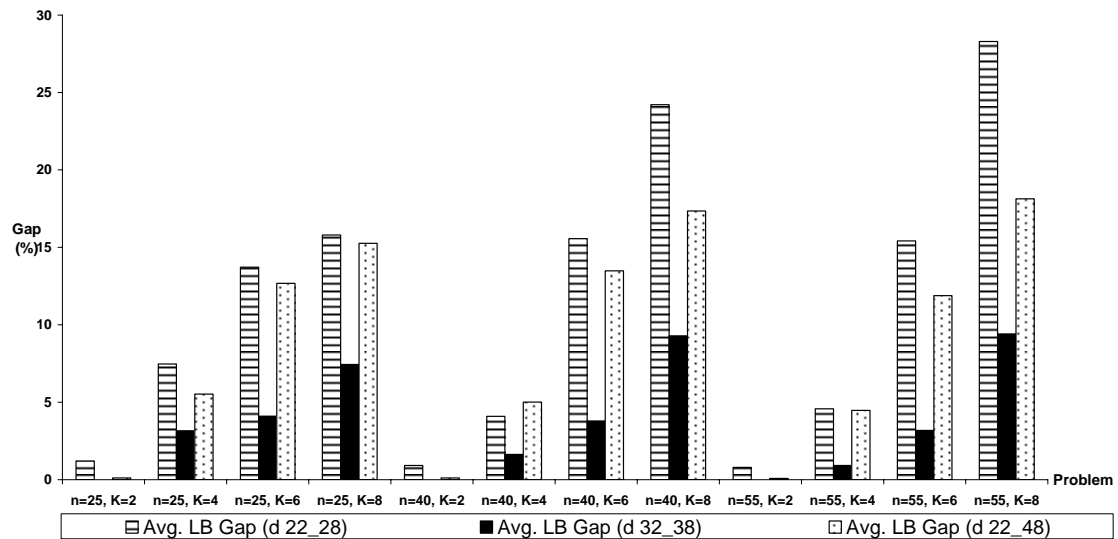
| $n$       | $K$      | LB Gap (%)  |             | Optimality Gap (%) |             |
|-----------|----------|-------------|-------------|--------------------|-------------|
|           |          | Heuristic 5 | Heuristic 6 | Heuristic 5        | Heuristic 6 |
| <b>10</b> | <b>4</b> | 8.40        | 2.14        | 6.14               | 0.00        |
|           |          | 16.20       | 16.20       | 8.50               | 8.50        |
|           |          | 9.02        | 9.02        | 0.00               | 0.00        |
|           |          | 9.69        | 9.69        | 6.50               | 6.50        |
|           |          | 8.40        | 8.40        | ---                | ---         |
| <b>10</b> | <b>6</b> | 12.57       | 6.07        | 6.14               | 0.00        |
|           |          | 16.20       | 16.20       | 8.50               | 8.50        |
|           |          | 9.02        | 9.02        | 0.00               | 0.00        |
|           |          | 9.69        | 9.69        | 6.50               | 6.50        |
|           |          | 8.40        | 8.40        | ---                | ---         |
| <b>10</b> | <b>8</b> | 12.57       | 6.07        | 6.14               | 0.00        |
|           |          | 16.20       | 16.20       | 8.50               | 8.50        |
|           |          | 9.02        | 9.02        | 0.00               | 0.00        |
|           |          | 9.69        | 9.69        | 6.50               | 6.50        |
|           |          | 8.40        | 8.40        | ---                | ---         |

**Table 5.6:** *LB* and *optimality gaps* for Heuristic 5 and Heuristic 6 for  $n=10$  and  $d_i \in [32,38]$

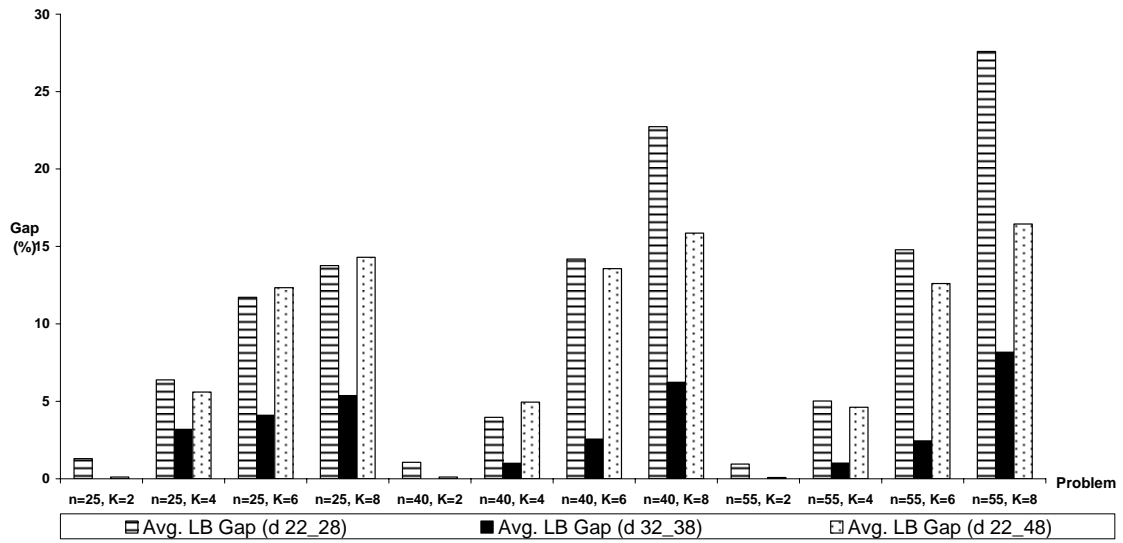
| $n$       | $K$      | LB Gap (%)  |             | Optimality Gap (%) |             |
|-----------|----------|-------------|-------------|--------------------|-------------|
|           |          | Heuristic 5 | Heuristic 6 | Heuristic 5        | Heuristic 6 |
| <b>10</b> | <b>6</b> | 1.62        | 1.62        | 0.00               | 0.00        |
|           |          | 12.38       | 8.21        | 6.50               | 2.56        |
|           |          | 13.26       | 9.09        | 6.53               | 2.61        |
|           |          | 9.03        | 1.62        | 7.29               | 0.00        |
|           |          | 9.03        | 4.86        | 7.90               | 3.78        |
| <b>10</b> | <b>8</b> | 1.62        | 1.62        | 0.00               | 0.00        |
|           |          | 12.38       | 8.21        | 6.50               | 2.56        |
|           |          | 13.26       | 9.09        | 6.53               | 2.61        |
|           |          | 9.03        | 1.62        | 7.29               | 0.00        |
|           |          | 9.03        | 4.86        | 7.90               | 3.78        |

**Table 5.7:** *LB* and *optimality gaps* for Heuristic 5 and Heuristic 6 for  $n=10$  and  $d_i \in [22, 48]$

| $n$ | $K$ | LB Gap (%)  |             | Optimality Gap (%) |             |
|-----|-----|-------------|-------------|--------------------|-------------|
|     |     | Heuristic 5 | Heuristic 6 | Heuristic 5        | Heuristic 6 |
| 10  | 4   | 1.80        | 1.80        | ---                | ---         |
|     |     | 12.26       | 11.48       | 0.69               | 0.00        |
|     |     | 14.29       | 14.29       | 0.00               | 0.00        |
|     |     | 3.89        | 3.89        | ---                | ---         |
|     |     | 0.00        | 0.00        | 0.00               | 0.00        |
| 10  | 6   | 1.88        | 1.88        | 0.00               | 0.00        |
|     |     | 24.06       | 24.06       | ---                | ---         |
|     |     | 19.05       | 19.05       | 0.00               | 0.00        |
|     |     | 4.05        | 4.05        | 0.00               | 0.00        |
|     |     | 0.00        | 0.00        | 0.00               | 0.00        |
| 10  | 8   | 1.88        | 1.88        | 0.00               | 0.00        |
|     |     | 24.06       | 24.06       | ---                | ---         |
|     |     | 19.05       | 19.05       | 0.00               | 0.00        |
|     |     | 4.05        | 4.05        | 0.00               | 0.00        |
|     |     | 0.00        | 0.00        | 0.00               | 0.00        |



**Figure 5.35:** Numerical results for Heuristic 5 for  $n = 25, 40, 55$  where  $p_j \in [25, 35]$



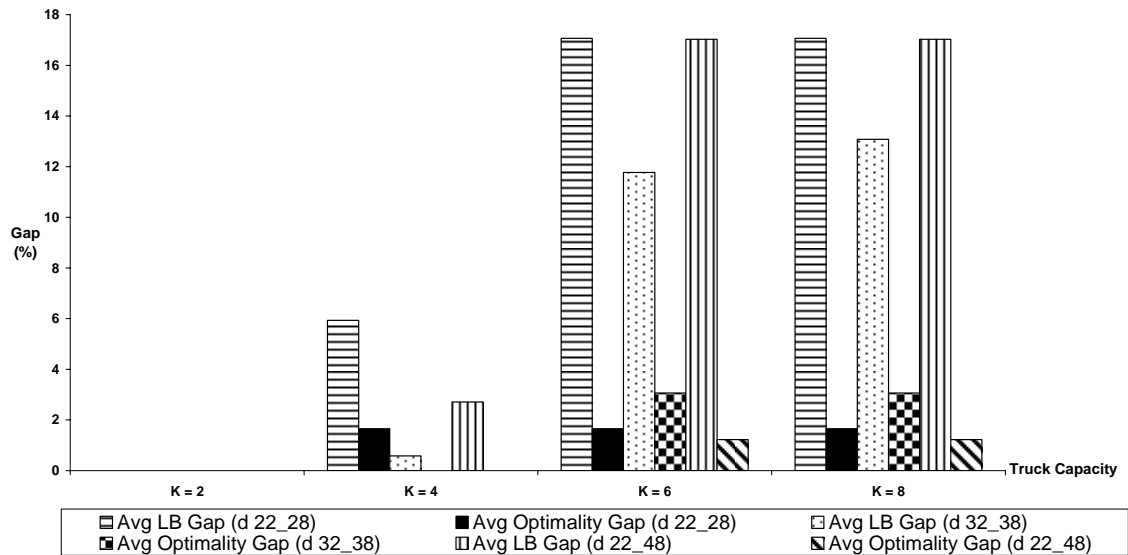
**Figure 5.36:** Numerical results for Heuristic 6 for  $n = 25, 40, 55$  where  $p_j \in [25, 35]$

#### Processing Time Range 4:

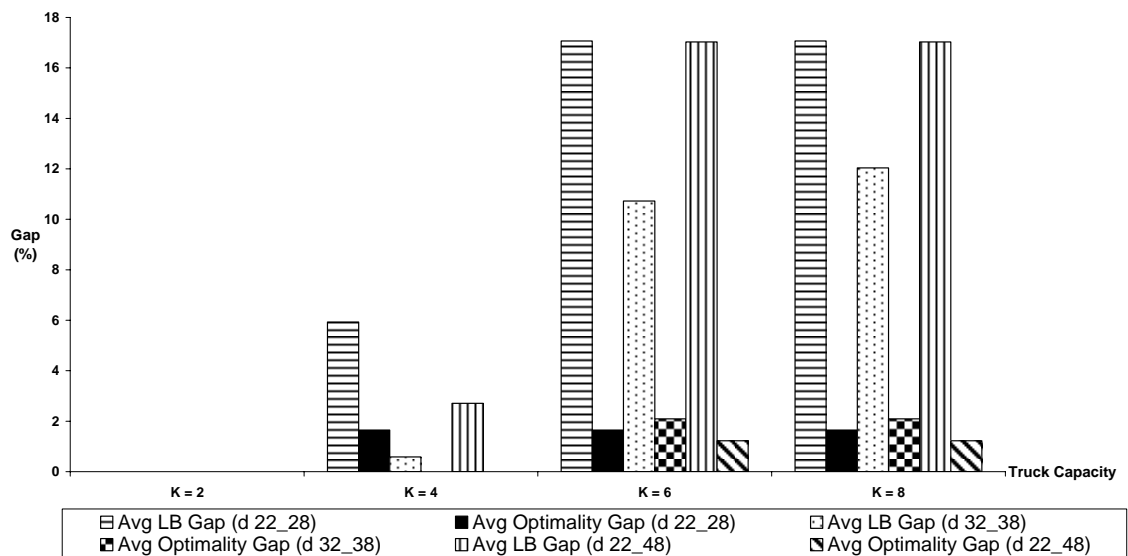
Since the range of the processing times is large, Lower Bound 5 may not yield tight lower bounds. That is because in the lower bound, while calculating the number of jobs to be carried on each trip, the processing times of the smallest jobs are used. However, in the proposed heuristics, as the jobs with smaller processing times are assigned to some plant, the jobs having larger processing times are left and hence the number of jobs to be transported on each trip decreases. This deviation from the lower bound causes *LB gaps* to be large. In Figures 5.37 and 5.38, it can be seen for 10 jobs that proposed heuristics yield either optimal or near-optimal results.

In Figures 5.39 and 5.40, it is observed that as the number of jobs to be transported increases, average *LB gap* decreases. This is related to the large range of processing times. As the number of jobs increases, the number of jobs with smaller processing times also increases. When there are more jobs with smaller processing times, more jobs complete

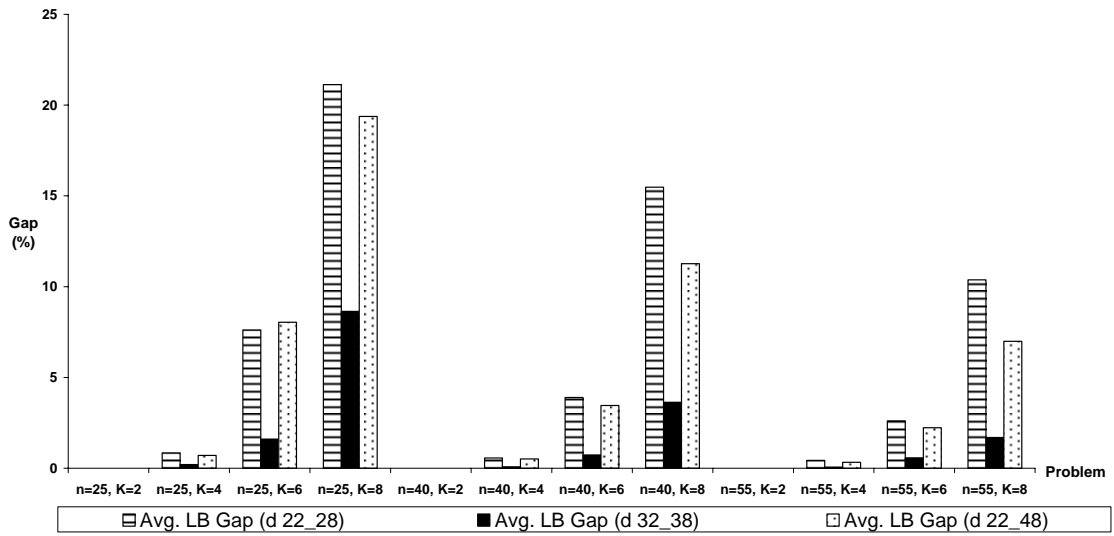
processing earlier and are transported in the beginning of the schedule. Therefore, the number of jobs transported in the first trips increases, decreasing the *LB gap*.



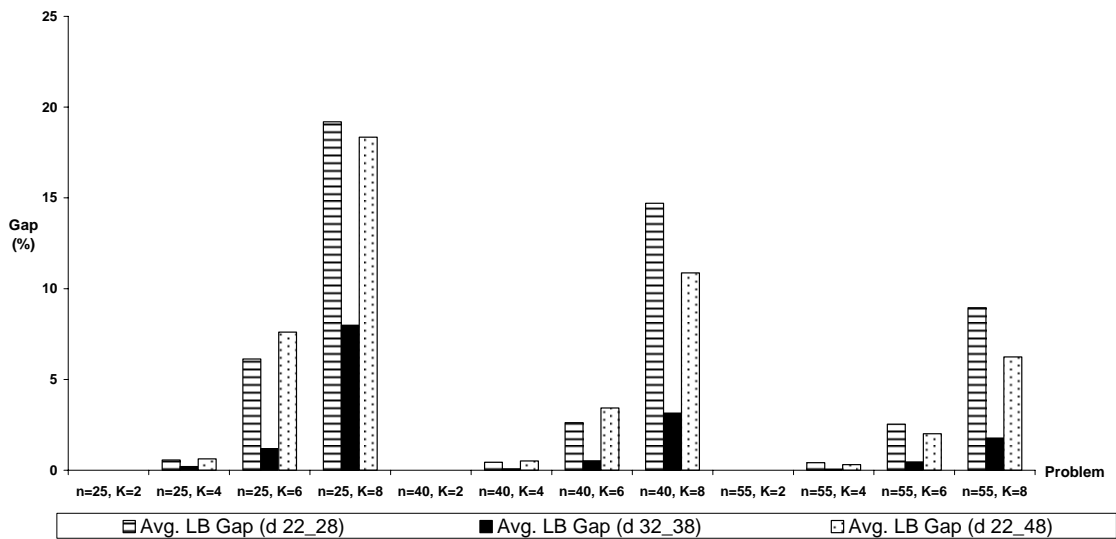
**Figure 5.37:** Numerical results for Heuristic 5 for  $n = 10$  where  $p_j \in [1, 35]$



**Figure 5.38:** Numerical results for Heuristic 6 for  $n = 10$  where  $p_j \in [1, 35]$



**Figure 5.39:** Numerical results for Heuristic 5 for  $n = 25, 40, 55$  where  $p_j \in [1, 35]$



**Figure 5.40:** Numerical results for Heuristic 6 for  $n = 25, 40, 55$  where  $p_j \in [1, 35]$

#### 5.2.4. Numerical Results and Discussions for the General Problem

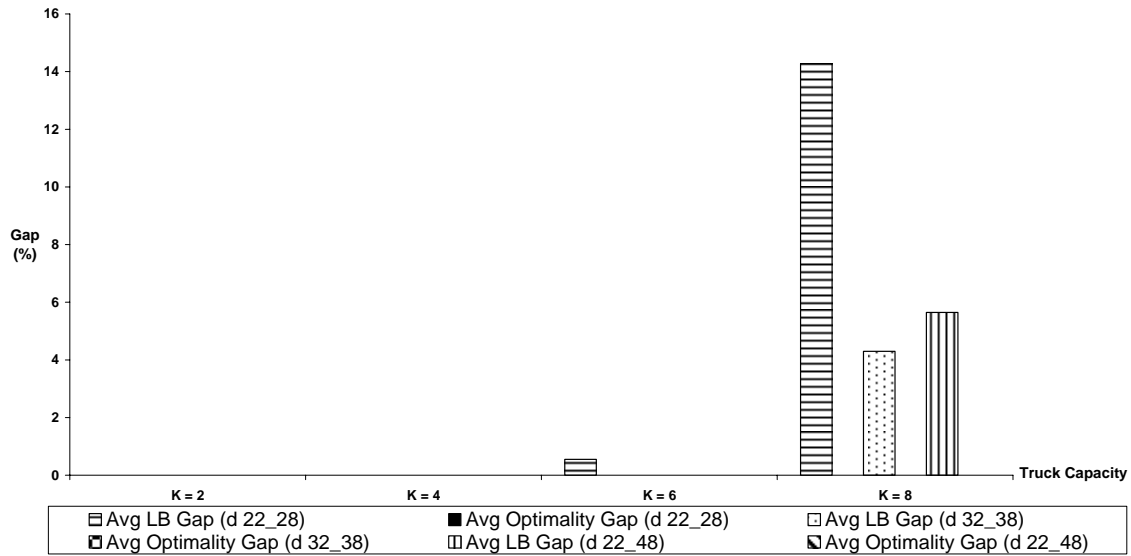
As mentioned in Chapter 4, while generating the lower bound for this problem, it was supposed that the truck leaves the first visited plant either as soon as it arrives there or at the process completion time of the first job. For the rest of the trips, completion times were calculated as if the truck always visits the closest plant and leaves it immediately and fully loaded. As truck capacity increases, the number of jobs transported in each trip increases and hence more jobs complete their transportation in earlier trips. Also, the number of trips required to transport all jobs, i.e.  $\left\lceil \frac{n}{K} \right\rceil$  may decrease. Therefore, as truck capacity increases, the lower bound for the total completion time decreases. This drawback of Lower Bound 6 causes the *LB gap* to increase as the capacity of the truck increases. Also, as the mean of the processing times increases, the possibility of producing  $K$  jobs until the arrival of the truck decreases. Hence, *LB gap* increases.

In this problem, as the mean of the plant distance range increases, *LB gap* decreases. As explained in Sections 5.2.1 and 5.2.2, as the mean distance increases, it becomes more probable that the truck leaves the plant either immediately or after waiting a small amount of time and fully loaded. Since this is the condition Lower Bound 6 is based on, *LB gap* becomes smaller. The effect of an increase in the range of plant distances is not as obvious as the effect of an increase in the mean. If the distance of the closest plant in range [22,48] is smaller than the one in range [32,38], obtained *LB gap* is larger. Conversely, if larger, obtained *LB gap* is smaller.

As mentioned in Chapter 4, since all the problems in the previous sections are special cases of this problem, all methods developed for them can be used to obtain a solution for the main problem. However, in this section, we only investigate the performance of Heuristic 7. The test results with Heuristic 7 can be seen in Appendix F.

### Processing Time Range 1:

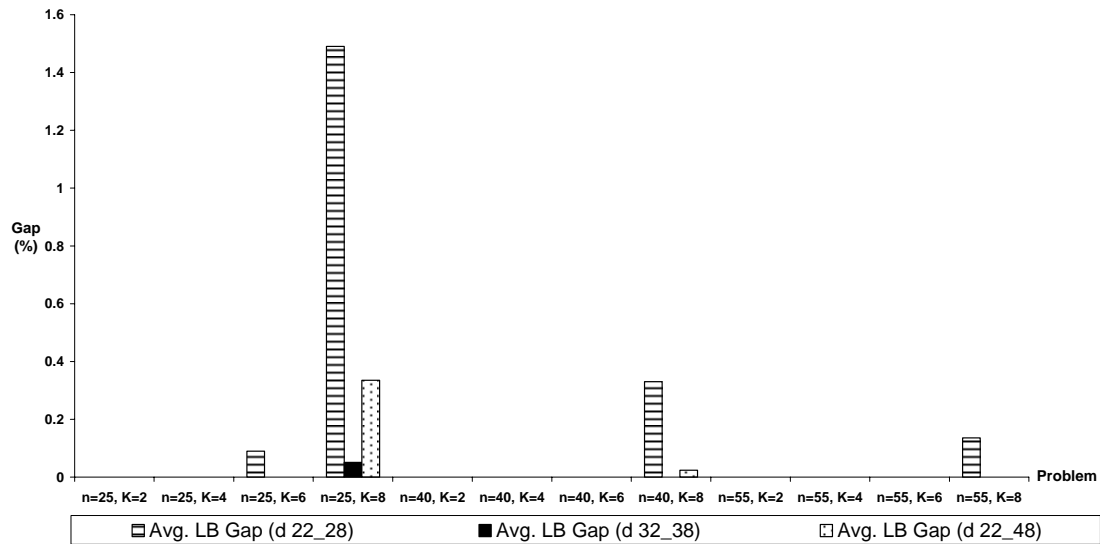
Since the processing times of the jobs are small when compared to the plant distances, in general, all jobs are produced in the closest plant and the truck finds  $K$  jobs already produced when it arrives at the plant. However, when the capacity of the truck increases, it may not be able to transport  $K$  jobs on the first trip by leaving the plant immediately. If the truck waits at the plant for the completion of a job in order to transport more jobs, the completion times of subsequent trips may be delayed. If it leaves the plant immediately by transporting fewer jobs, the number of jobs transported on the later trips increases. Any of these cases will result in *LB gaps* greater than 0. In Figure 5.41, average *LB gap* larger than 10% is observed for  $n = 10$  and  $K = 8$ . As seen in this figure, Heuristic 7 generates the optimal solution.



**Figure 5.41:** Numerical results for Heuristic 7 for  $n = 10$  where  $p_j \in [1, 11]$

As explained in the previous paragraph, the main reason for large *LB gaps* is not being able to transport  $K$  jobs on the first trip from the closest plant. However, as  $n$  increases, the number of trips required to transport all jobs increases and hence the effect of

the first trip decreases. Therefore, for the same  $K$  value, as  $n$  increases,  $LB$  gap decreases. This effect of the increase in the number of jobs can be observed in Figure 5.42.



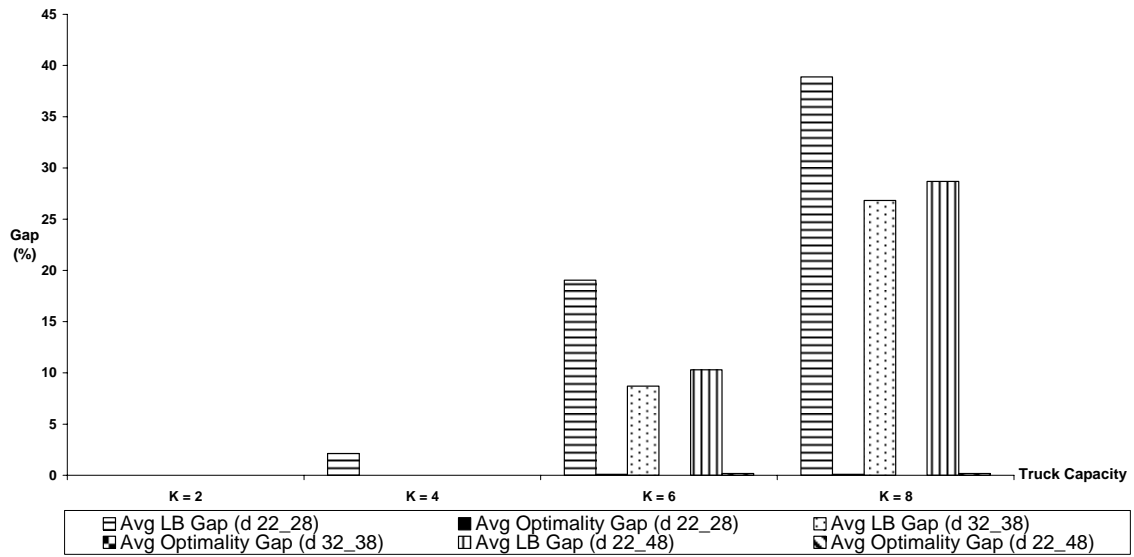
**Figure 5.42:** Numerical results for Heuristic 7 for  $n = 25, 40, 55$  where  $p_j \in [1, 11]$

Also, it should be noted that for this processing time range, Heuristic 7 performs better than the heuristics proposed for the previous problems.

### Processing Time Range 2:

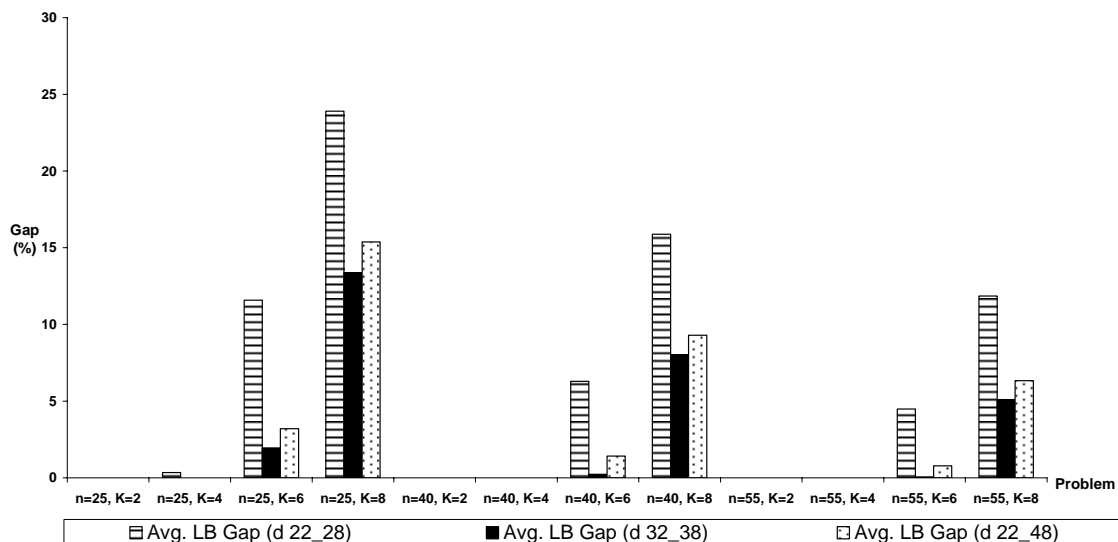
In this range, since  $p_{\max} < d_{\min}$ , in the calculation of the lower bound, the truck is supposed to leave the first plant as soon as it arrives there. Hence, the lower bound values found for this range are the same with the ones found for processing time range 1. However, since the processing times for range 2 are larger, the probability of transporting  $K$  jobs on the first trip is smaller. Therefore, observed  $LB$  gaps are larger when compared to the previous range (at most 43.40%). In Figure 5.43, it is shown for 10 jobs that Heuristic 7 generates optimal or near optimal results with at most 0.89% optimality gap.





**Figure 5.43:** Numerical results for Heuristic 7 for  $n = 10$  where  $p_j \in [5, 15]$

Not being able to transport  $K$  jobs on the first trip without waiting for the completion of a job at the plant is the cause for the deviation from the lower bound. Hence, as  $n$  increases, for the following trips, truck may be able to transport  $K$  jobs without waiting at the plant and deviation from the lower bound will decrease. This can be observed in Figure 5.44.



**Figure 5.44:** Numerical results for Heuristic 7 for  $n = 25, 40, 55$  where  $p_j \in [5, 15]$

### Processing Time Range 3:

The largest processing time values are observed in this range and hence, the probability of sending the truck fully loaded without waiting at a plant is smallest. Therefore, *LB gaps* observed in this range are largest (as high as 146.42%). As explained for the previous ranges, an increase in  $n$  decreases *LB gap* and hence largest gaps occur for 10 jobs. To show that our heuristic methods yield optimal or near optimal solutions for these largest gap instances, we solve MIP-4 to obtain optimal solutions. However, even in 55.55 hours (200000 sec), we could not obtain the optimal solution for some instances (the best integer values obtained in 200000 seconds are given with a (\*) mark in Table F.7). Hence, instead of bar charts showing average *LB* and *optimality gaps*, the percentage gaps are given in Tables 5.8, 5.9 and 5.10 for 10 jobs. In these tables, it can be seen that proposed heuristic yields optimal or near-optimal results.

**Table 5.8:** *LB* and *optimality gaps* for Heuristic 7 for  $n = 10$  and  $d_i \in [22, 28]$

| $n$ | $K$ | LB Gap (%)  | Optimality Gap |
|-----|-----|-------------|----------------|
|     |     | Heuristic 7 | Heuristic 7    |
| 10  | 2   | 17.56       | 0.77           |
|     |     | 17.79       | ---            |
|     |     | 17.71       | ---            |
|     |     | 17.82       | 0.00           |
|     |     | 16.67       | ---            |
| 10  | 4   | 53.21       | 0.00           |
|     |     | 65.22       | 4.03           |
|     |     | 59.67       | 0.00           |
|     |     | 56.09       | 1.11           |
|     |     | 56.09       | 1.18           |
| 10  | 6   | 96.98       | 0.00           |
|     |     | 111.73      | 4.03           |
|     |     | 103.92      | 0.00           |
|     |     | 100.69      | 1.11           |
|     |     | 100.69      | 1.18           |
| 10  | 8   | 129.81      | 0.00           |
|     |     | 146.42      | 4.03           |
|     |     | 136.71      | 0.00           |
|     |     | 134.13      | 1.11           |
|     |     | 134.13      | 1.18           |

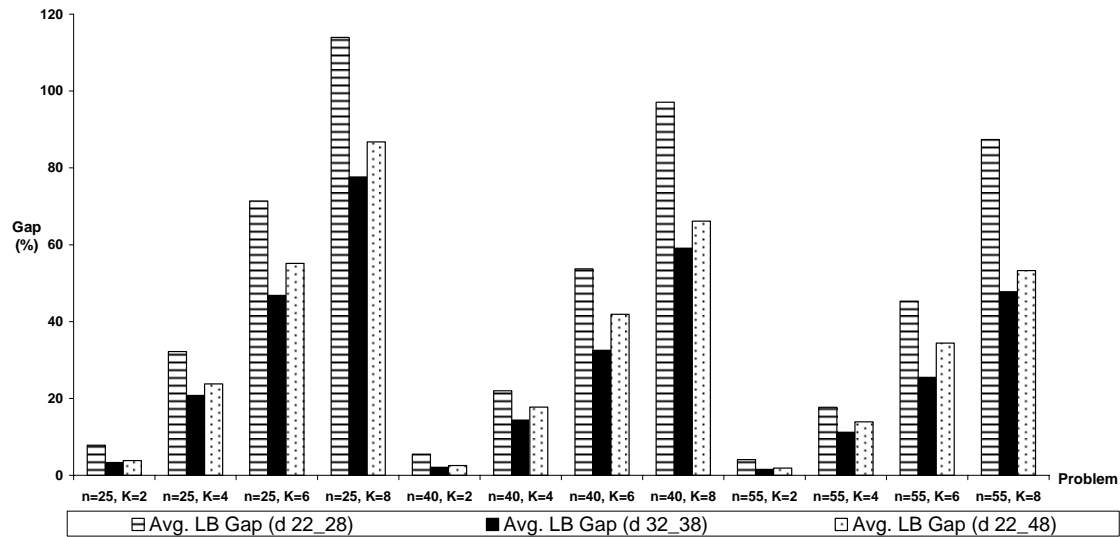
**Table 5.9:** *LB and optimality gaps* for Heuristic 7 for  $n = 10$  and  $d_i \in [32, 38]$

| $n$       | $K$      | LB Gap (%)  | Optimality Gap (%) |
|-----------|----------|-------------|--------------------|
|           |          | Heuristic 7 | Heuristic 7        |
| <b>10</b> | <b>2</b> | 6.94        | 0.00               |
|           |          | 8.33        | 0.00               |
|           |          | 9.09        | 0.00               |
|           |          | 7.87        | 0.00               |
|           |          | 6.94        | 0.00               |
| <b>10</b> | <b>4</b> | 35.03       | 0.00               |
|           |          | 37.42       | 0.00               |
|           |          | 38.72       | 0.00               |
|           |          | 36.57       | 0.00               |
|           |          | 33.80       | 0.00               |
| <b>10</b> | <b>6</b> | 73.61       | 0.00               |
|           |          | 76.68       | 0.00               |
|           |          | 82.68       | 2.43               |
|           |          | 74.21       | 0.00               |
|           |          | 72.02       | 0.00               |
| <b>10</b> | <b>8</b> | 102.55      | 0.00               |
|           |          | 106.13      | 0.00               |
|           |          | 113.13      | 2.43               |
|           |          | 103.24      | 0.00               |
|           |          | 100.69      | 0.00               |

**Table 5.10:** *LB and optimality gaps* for Heuristic 7 for  $n = 10$  and  $d_i \in [22, 48]$

| $n$       | $K$      | LB Gap (%)  | Optimality Gap |
|-----------|----------|-------------|----------------|
|           |          | Heuristic 7 | Heuristic 7    |
| <b>10</b> | <b>2</b> | 4.58        | 0.00           |
|           |          | 11.51       | 0.00           |
|           |          | 16.07       | 0.00           |
|           |          | 7.21        | 0.00           |
|           |          | 5.13        | 0.00           |
| <b>10</b> | <b>4</b> | 32.08       | 0.00           |
|           |          | 47.67       | 0.00           |
|           |          | 58.33       | 0.88           |
|           |          | 39.04       | 0.00           |
|           |          | 30.77       | 0.00           |
| <b>10</b> | <b>6</b> | 70.54       | 1.49           |
|           |          | 89.86       | 0.00           |
|           |          | 103.57      | 0.88           |
|           |          | 78.38       | 0.00           |
|           |          | 68.13       | 0.00           |
| <b>10</b> | <b>8</b> | 98.96       | 1.49           |
|           |          | 121.51      | 0.00           |
|           |          | 137.50      | 0.88           |
|           |          | 108.11      | 0.00           |
|           |          | 96.15       | 0.00           |

In Figure 5.45, the *LB gaps* for different plant distance ranges are given. Since the processing times are large, lower bound is very loose as it supposes the truck makes all trips to the closest plant and leaves the plant fully loaded.

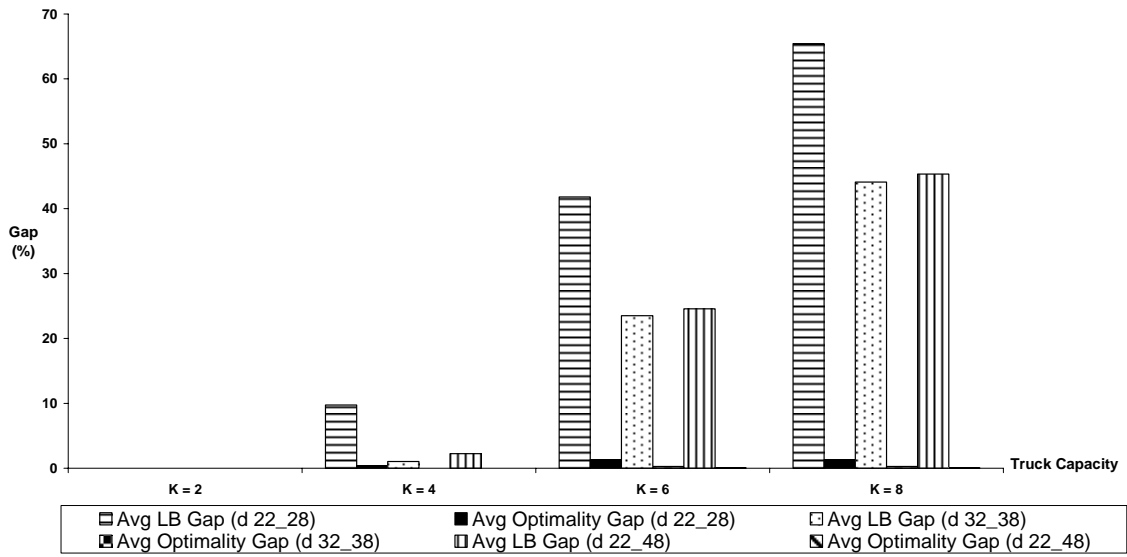


**Figure 5.45:** Numerical results for Heuristic 7 for  $n = 25, 40, 55$  where  $p_j \in [25, 35]$

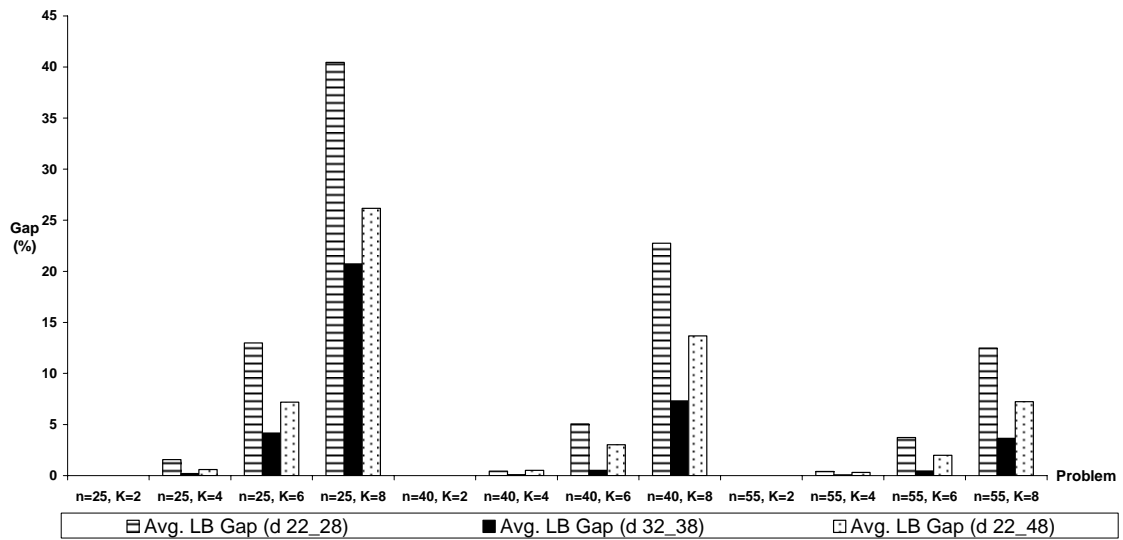
#### Processing Time Range 4:

Since the jobs in the beginning of the job sequence have small processing times, the number of jobs transported on the first trips is greater and hence *LB gaps* are smaller when compared to processing time range 3. Also, since the jobs at the end of the job sequence have larger processing times, the truck may have to visit a farther plant and hence *LB gaps* are larger when compared to the first two ranges.

As the number of jobs increases, *LB gap* decreases. Hence, the largest gaps are observed for 10 jobs. The maximum *LB gap* obtained is 74.52 % and the maximum *optimality gap* obtained is 2.53%. The percentage gaps for 10 jobs are shown in Figure 5.46 for different plant distance ranges.



**Figure 5.46:** Numerical results for Heuristic 7 for  $n = 10$  where  $p_j \in [1, 35]$



**Figure 5.47:** Numerical results for Heuristic 7 for  $n = 25, 40, 55$  where  $p_j \in [1, 35]$

In Figure 5.47, average *LB gaps* of different plant distance ranges are given. The effects of increases in the mean and range of plant distances are explained in the beginning of this section.

### **5.2.5. Comparison of Proposed Methods**

The special cases of the general problem are selected from common practical applications. There are two main strategies used in these applications:

1. Send the trucks fully loaded (one partial trip may occur as explained before)
2. The truck leaves the plant as soon as it arrives there

The first strategy includes Last Trip Partial Problem and Fully Loaded Trips Problem. The second strategy is addressed by No Wait Problem. Especially in the example of the leading soft drink manufacturer these two strategies have been applied for a long time. Any change in these strategies may complicate the operations and also requires education of the personnel. Hence, most of the companies do not want to replace these existing strategies with new ones. Therefore, in order to be able to suggest one of these simple strategies for the general problem, we assess the performance of the proposed heuristics on the general problem.

To determine the quality of proposed methods on the general problem, we compare the results of the proposed methods for special cases and the results for the general problem with respect to two aspects:

1. The optimal results
2. The heuristic results

Comparisons of the optimal results are done only for 10 jobs since it was not possible to obtain optimal solutions for larger problems even in 50000 seconds. The percentage gap between the optimal result of the special case and optimal result of the general problem is calculated as follows:

$$Opt\ Gap = \frac{Optimal\ Solution\ of\ Special\ Case - Optimal\ Solution\ of\ General\ Problem}{Optimal\ Solution\ of\ General\ Problem} \cdot 100$$

For each special case, the average *opt gaps* are calculated and the one yielding the smallest average is chosen.

To compare the heuristic results, for each special case, the best (i.e. the smallest) heuristic value is chosen. These chosen values are then compared to the heuristic results obtained by Heuristic 7. The percentage gap is calculated as follows:

$$HR\ Gap = \frac{Best\ Heuristic\ Value\ of\ Special\ Case - Heuristic\ Value\ of\ General\ Problem}{Heuristic\ Value\ of\ General\ Problem} \cdot 100$$

*HR gaps* are determined for  $n=10,25,40,55$  and average *HR gap* is calculated for each special case. The problem yielding the smallest *HR gap* is chosen. In compliance with our expectations, the problem chosen as a result of optimal solution comparison is the same as the problem chosen as a result of heuristic solution comparison. The problems yielding the best average gaps are listed in Table 5.11 for each processing time and plant distance range.

It is obvious that the total completion times obtained by the heuristics proposed for fully loaded trips problem will always be better than or the same as the ones obtained by the heuristics for last trip partial problem. However, since the policy of sending the last trip partial is easier, we choose that policy when its results are the same with fully loaded trips problem.

For processing time range  $[25,35]$ , as explained in Section 5.2.3 and 5.2.4, we could not obtain the optimal results for some of the instances even with 10 jobs. Hence an average *opt gap* is not given for this problem.

**Table 5.11:** Performance assessment of the methods of special cases for the general problem

|                                    | <b>Chosen Problem</b> | <b>Avg. Opt. Gap (%)</b> | <b>Avg. HR Gap (%)</b> |
|------------------------------------|-----------------------|--------------------------|------------------------|
| $p_j \in [1,11], d_i \in [22,28]$  | No Wait               | 0.67                     | 0.19                   |
| $p_j \in [1,11], d_i \in [32,38]$  | Last Trip Partial     | 0.28                     | 0.07                   |
| $p_j \in [1,11], d_i \in [22,48]$  | Last Trip Partial     | 0.32                     | 0.08                   |
| $p_j \in [5,15], d_i \in [22,28]$  | Full Loaded Trips     | 2.86                     | 1.13                   |
| $p_j \in [5,15], d_i \in [32,38]$  | No Wait               | 0.88                     | 0.71                   |
| $p_j \in [5,15], d_i \in [22,48]$  | No Wait               | 1.12                     | 0.75                   |
| $p_j \in [25,35], d_i \in [22,28]$ | No Wait               | ---                      | 1.17                   |
| $p_j \in [25,35], d_i \in [32,38]$ | No Wait               | ---                      | 2.21                   |
| $p_j \in [25,35], d_i \in [22,48]$ | No Wait               | ---                      | 2.55                   |
| $p_j \in [1,35], d_i \in [22,28]$  | No Wait               | 1.15                     | 0.96                   |
| $p_j \in [1,35], d_i \in [32,38]$  | No Wait               | 1.79                     | 0.89                   |
| $p_j \in [1,35], d_i \in [22,48]$  | No Wait               | 1.20                     | 0.70                   |

In Table 5.11 it can be seen that when the processing times are small compared to the plant distances, sending the truck fully loaded yields smallest gaps. However, as the processing times increase, waiting for the truck to be fully loaded becomes disadvantageous. Hence, leaving the plant immediately yields smallest gaps.



# Chapter 6

## CONCLUSION

In this thesis, we studied the problem of integrated scheduling of production and distribution operations of a manufacturer serving a single customer area from multiple identical production plants at different geographical points. The products are transported from the plants to the customer area by a single capacitated truck. The objective is to minimize the total completion time of the jobs. The completion time of a job is defined as the time it reaches at the customer area.

We considered both this general problem and four special cases motivated by common practical applications. The first special case considers a setting where the assignment of the jobs to the plants is given. A pseudo-polynomial dynamic programming is proposed for that problem.

The soft drink manufacturer that motivates our problem and many other companies tend to be under the impression that they utilize truck capacity better when they send the trucks fully loaded. In addition to that, fully loaded trucks are preferred in some applications to prevent the damage to the products that may be caused when they are shaken or scattered around in the truck. To address this preference, the second special case considers the problem where the truck is fully loaded in each trip except the last one. The last trip may be partially loaded if the number of jobs demanded by the customer is not divisible by the truck capacity. The third special case again has the constraint of trips' being fully loaded; however, it is not

known in this problem which trip would be partially loaded. In the fourth special case, we suppose that the truck does not wait at the plant for the completion of a job. Instead, it takes the jobs that are already produced and leaves the plant immediately.

We proved that both the main problem and the last three special cases are NP-hard at least in the ordinary sense. We developed mixed integer programming (MIP) models for all these problems. Since the MIP models are able to provide optimal solutions only for small instances in a reasonable amount of time, we propose constructive heuristics to solve larger instances. For small instances, the optimal solutions obtained by these MIP models can be used to measure the quality of the proposed heuristics. However, since it is not possible to get optimal solutions for medium and large instances in reasonable CPU times, fast lower bounds are developed to facilitate the performance assessment of the heuristics. Based on extensive computational experimentation with the test problems generated, we observed that proposed heuristics provide optimal or near-optimal results in less than a second.

As mentioned before, three of the special cases consider two different strategies: sending full trucks and not waiting at the plant. Although these strategies are commonly applied, they may not yield the best results in terms of reduced total completion times. However, as observed in the soft drink company, companies are not willing to change these existing strategies. Thus, for different problems we determined which strategy would yield a smaller total completions time. It is shown that when the processing times of the jobs are small with respect to the plant distances, sending the last trip partial and the rest of the trips fully loaded yields the best results on the average. As the ratio of the mean of processing times to the mean of plant distances increases, waiting at the plant for the truck to be fully loaded becomes disadvantageous. Hence, for large processing times, it is a better strategy if the truck leaves the plant as soon as it arrives at there.

Finding stronger lower bounds for the problems studied in this thesis deserves attention as an item for future research. Another item relates to the shipment strategy. In light of the motivating practical application, we considered only direct shipments between the

plants and the customer area. As future research it would be interesting to consider milkruns among the plants. Also the problem of a multi-plant manufacturer serving multiple customer areas would be interesting to study. The problem with multiple capacitated trucks may also be studied.

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# Appendix A

## Pseudocodes of the Lower Bound Generation

### Methods

#### A.1 Lower Bound 1

##### *Algorithm of Lower Bound 1*

Sort plants in nondecreasing distances and reindex  
Sort jobs in nondecreasing processing times and reindex  
Initialize *travelTime* and *arriveTime* arrays  
Set  $LB := 0, jobSent := 0$   
Set  $d$  to closest plant distance  
Set  $partial := n - qK$   
Set  $reqTrip := \left\lceil \frac{n}{K} \right\rceil$   
Set  $minTrip := \left\lfloor \frac{n}{K} \right\rfloor$   
Set  $sumProc$  to sum of processing times for the first  $K$  jobs  
//Calculate *travelTime* for each trip  
**for** each plant  $p_i$   
    **for**  $j$  from 0 to  $(reqTrip - i)$  (increase by  $m$ )  
        Set  $travelTime[i + j] := (2i - 1) d$   
    **end for**  
**end for**  
Set  $leaveTime := \max(sumProc, d)$   
**for** each trip  $t_k$   
    **if**  $(k - 1)$  is divisible by  $m$  **and**  $((k - 1) / m) > 0$  // if trip is the first trip of a round  
        Increase  $jobSent$  by  $m \cdot K$   
        Set  $numJobs := (k / m) \cdot K + \min(K, n - jobSent)$   
        Set  $sumProc1$  to sum of processing times for the first  $numJobs$  jobs



```

        Set leaveTime := max(leaveTime + 2md , sumProc1)
    end if
    Set arriveTime[k] := leaveTime + travelTime[k]
end for
for each trip  $t_k$  such that  $k \neq reqTrip$ 
    Increase LB by ( $K \cdot arriveTime[k]$ )
end for
if n is divisible by K
    Increase LB by ( $K \cdot arriveTime[reqTrip]$ )
end if
Increase LB by (partial · arriveTime[reqTrip])
Return LB

```

## A.2 Lower Bound 3

### *Algorithm of Lower Bound 3*

```

Sort jobs and plants and reindex
Initialize travelTime and arriveTime arrays
Set LB := 0, jobSent := 0
Set d to closest plant distance
Set partial :=  $n - qK$ 
Set  $reqTrip := \left\lceil \frac{n}{K} \right\rceil$ 
Set  $minTrip := \left\lfloor \frac{n}{K} \right\rfloor$ 
//calculate travelTime for each trip
for each plant  $Pl_i$ 
    for j from 0 to ( $reqTrip - 1$ ) (increase by m)
        Set  $travelTime[i + j] := (2i - 1) d$ 
    end for
end for
if partial > 0
    Set sumProc to sum of processing times for the first partial jobs
    Set leaveTime := max (sumProc, d)

```

```

Set  $minTrip1 := \min(2m, reqTrip)$ 
for each trip  $t_k$  such that  $k \leq minTrip1$ 
    if  $(k-1)$  is divisible by  $m$  and  $((k-1)/m) > 0$ 
        Increase  $jobSent$  by  $((m-1) \cdot K + partial)$ 
        Set  $numJobs := partial + \min(K, n - jobSent)$ 
        Set  $sumProc1$  to sum of processing times for the first  $numJobs$  jobs
        Set  $leaveTime := \max(leaveTime + 2md, sumProc1)$ 
    end if
    Set  $arriveTime[k] := leaveTime + travelTime[k]$ 
end for
if  $reqTrip > 2m$ 
    for each trip  $t_k$  such that  $2m+1 \leq k \leq reqTrip$ 
        Calculate  $arriveTime[k]$  by Algorithm Arrival Time Calculation
    end for
end if
else
    Set  $sumProc$  to sum of processing times for the first  $K$  jobs
    Set  $leaveTime := \max(sumProc, d)$ 
    for each trip  $t_k$ 
        Calculate  $arriveTime[k]$  by Algorithm Arrival Time Calculation
    end for
end if
if  $partial > 0$ 
    for each trip  $t_k$  such that  $k \neq reqTrip$ 
        Increase  $LB$  by  $(K \cdot arriveTime[k])$ 
    end for
    Increase  $LB$  by  $(partial \cdot arriveTime[reqTrip])$ 
else
    for each trip  $t_k$ 
        Increase  $LB$  by  $(K \cdot arriveTime[k])$ 
    end for
end if

```

### ***Algorithm Arrival Time Calculation***

```

Given  $partial, k, leaveTime$  and  $jobSent$ 
if  $(k-1)$  is divisible by  $m$  and  $((k-1)/m) > 0$ 
    Increase  $jobSent$  by  $m \cdot K$ 
    Set  $numJobs := (\text{floor}(k/m)) \cdot K + \min(K, n - jobSent)$ 
    Set  $sumProc1$  to sum of processing times for the first  $numJobs$  jobs

```

```

    Set  $leaveTime := \max(leaveTime + 2md, sumProc1)$ 
end if
Set  $arriveTime[k] := leaveTime + travelTime[k]$ 
Return  $arriveTime[k]$ 

```

### A.3 Lower Bound 5

#### *Algorithm of Lower Bound 5*

```

Sort jobs and plants and reindex //  $d_i$  is the distance of plant with index  $i$ 
Initialize array  $A$  //this array holds the values named as  $A_i$  in Table 4.4
Initialize array  $noJobs$  //this array holds the number of jobs on each trip
Set  $LB := 0, jobSent := 0, trip := 0$ 
Set  $d$  to closest plant distance
Set  $sumDist$  to the sum of all plant distances
for each plant  $Pl_i$ 
    Set  $A[i] := 0$ 
end for
Set  $A[1] := d$ 
//calculate the  $A_i$  values given in Table 4.4
for each plant  $Pl_i$  except the first plant
    for  $j$  from  $m$  to  $(m+2-i)$  (decrement by 1)
        Increase  $A[i]$  by  $2d_j$ 
    end for
    Increase  $A[i]$  by  $d_{m-i+1}$ 
end for
while  $jobSent < n$ 
    Increment  $trip$ 
    if  $trip \leq m$ 
        Set  $Sum := 0$ 
        Set  $l_k := 0$  // This was called as  $l_k$  in Table 4.4
        //calculate  $l_k$  value
        for each job  $j$ 
            if  $Sum + p_j \leq A[trip]$ 

```

```

        Increase Sum by  $p_j$  and increment  $l_k$ 
    else break
    end if
end for
Set  $noJobs[trip] := \min(n - jobSent, \min(K, l_k))$ 
Increase jobSent by  $noJobs[trip]$ 
else
    Set  $Sum := 0$ 
    Set  $l_k := 0$ 

    // Determine which trip is the current trip of a round (i.e. 1st, 2nd, 3rd, ...,  $m^{th}$ ) and set
    factor to this value
    Set  $factor := trip - \left\lfloor \frac{trip-1}{m} \right\rfloor \cdot m$ 

    Set  $round := \left\lfloor \frac{trip-1}{m} \right\rfloor$  //Here if truck is on its second round, round will be 1
    for each job j
        if  $Sum + p_j \leq 2 \cdot tour \cdot sumDist + A[factor]$ 
            Increase Sum by  $p_j$  and increment  $l_k$ 
        else break
        end if
    end for
    Set  $Sum2 := 0$ 
    Set  $l_{min} := 0$ 
    for each job j
        if  $Sum2 + p_j \leq (2 \cdot tour - 1) \cdot d$  and  $l_{min} < tour \cdot K$ 
            Increase  $Sum2$  by  $p_j$  and increment  $l_{min}$ 
        else break
        end if
    end for
    Set  $noJobs[trip] := \min(n - jobSent, \min(l_k - l_{min}, K))$ 
    Increase jobSent by  $noJobs[trip]$ 
end if
end while
for each trip  $t_k$  // the number of trips is equal to the value of trip, hence  $k \leq trip$ 
    Increase LB by  $2 \cdot k \cdot d \cdot noJobs[trip]$ 
end for
Return LB

```

# Appendix B

## Pseudocodes of the Proposed Heuristics

### B.1 Heuristic 1 (LPH1)

#### *Algorithm Heuristic 1 (LPH1)*

Sort plants in nondecreasing distances and reindex

Sort jobs in nondecreasing processing times and reindex

Set  $TCT := 0$  //  $TCT$  means total completion time

Set  $minTrip := \left\lceil \frac{n}{K} \right\rceil$  // the number of trips that will be fully loaded

Set  $partial := n - qK$  // the number of jobs in the partially loaded trip

Set  $trip := 0$  // Denotes which trip is the current one, can be at most  $\left\lceil \frac{n}{K} \right\rceil$

Initialize arrays  $AT$  and  $LT$  and set each element of these arrays to 0 //  $AT$  stores the time each plant becomes available for processing while  $LT$  stores the time truck leaves each plant

Initialize array  $NP$  and set each element to 0 // holds the number of jobs sent from each plant

Set  $lastP := 0$  // Denotes the index of the plant visited on the previous trip

**for** the first  $minTrip$  number of trips

    Set  $Sum := 0$

**for** each job  $J_l$  such that  $trip \cdot K + 1 \leq l \leq (trip + 1) \cdot K$

        Increase  $Sum$  by  $p_l$  //  $p_l$  is the processing time of job  $J_l$

**end for**

**if** the number of previously assigned jobs of each plant is the same

        Increase  $AT[1]$  by  $Sum$

        Set  $LT[1] := \max(AT[1], LT[lastP] + d_{lastP} + d_1)$

        Set  $lastP := 1$

        Increment  $trip$

```

    Increase  $NP$  [1] by  $K$ 
    Increase  $TCT$  by  $K \cdot (LT[lastP] + d_{lastP})$ 
else // potential plant selection will be applied
    Set  $selP := 0$ 
    Determine potential plants
    Set  $selP$  to the plant with smallest contribution
    Increase  $AT$  [ $selP$ ] by  $Sum$ 
    Set  $LT$  [ $selP$ ] :=  $\max(AT[selP], LT[lastP] + d_{lastP} + d_{selP})$ 
    Set  $lastP := selP$ 
    Increment  $trip$ 
    Increase  $NP$  [ $lastP$ ] by  $K$ 
    Increase  $TCT$  by  $K \cdot (LT[lastP] + d_{lastP})$ 
end if
end for
if  $partial > 0$ 
    Set  $Sum := 0$ 
    for each job  $J_l$  such that  $minTrip \cdot K + 1 \leq l \leq n$ 
        Increase  $Sum$  by  $p_l$  //  $p_l$  is the processing time of job  $J_l$ 
    end for
    if the number of previously assigned jobs of each plant is the same
        Increase  $AT$  [1] by  $Sum$ 
        Set  $LT$  [1] :=  $\max(AT[1], LT[lastP] + d_{lastP} + d_1)$ 
        Set  $lastP := 1$ 
        Increment  $trip$ 
        Increase  $NP$  [1] by  $partial$ 
        Increase  $TCT$  by  $partial \cdot (LT[lastP] + d_{lastP})$ 
    else // potential plant selection will be applied
        Set  $selP := 0$ 
        Determine potential plants
        Set  $selP$  to the plant with smallest contribution
        Increase  $AT$  [ $selP$ ] by  $Sum$ 
        Set  $LT$  [ $selP$ ] :=  $\max(AT[selP], LT[lastP] + d_{lastP} + d_{selP})$ 
        Set  $lastP := selP$ 
        Increment  $trip$ 
        Increase  $NP$  [ $lastP$ ] by  $partial$ 
        Increase  $TCT$  by  $partial \cdot (LT[lastP] + d_{lastP})$ 
    end if
end if
Return  $TCT$ 

```

### **Algorithm Potential Plant Determination**

Set  $selP := 0$  // Denotes the plant selected among potential plants  
Set  $ratio := NP[1] \div K$  // Since plant 1 will always be the plant with more number of jobs  
Set  $count := 0$   
**for**  $r$  from 0 to  $ratio$   
    Set  $count2 := 0$  // with this counter we ensure that among the plants having the same number of previously assigned jobs, only the closest one is chosen  
  
    **for** each plant  $P_i$  //  $P_i$  denotes Plant  $i$   
        **if**  $NP[i] = r \cdot K$  **and**  $count2 < 1$   
            Determine  $P_i$  as a potential plant  
            Increment  $count$  and  $count2$   
        **end if**  
    **end for**  
**end for**  
**for** each plant  $P_i$   
    **if**  $P_i$  is among the potential plants  
        Set contribution of  $P_i$  to  $\max(LT[lastP] + d_{lastP} + d_i, AT[i] + Sum) + d_i$   
    **end if**  
**end for**  
Sort the potential plants in non-decreasing order of contributions

## **B.2 Heuristic 2 (LPH2)**

### **Algorithm Heuristic 2 (LPH2)**

Sort plants in non-decreasing distances and re-index  
Sort jobs in non-decreasing processing times and re-index  
Set  $TCT := 0$  //  $TCT$  means total completion time  
Set  $minTrip := \left\lfloor \frac{n}{K} \right\rfloor$  // the number of trips that will be fully loaded  
Set  $partial := n - qK$  // the number of jobs in the partially loaded trip  
Set  $trip := 0$  // Denotes which trip is the current one, can be at most  $\left\lceil \frac{n}{K} \right\rceil$

Initialize arrays  $AT$  and  $LT$  and set each element of these arrays to 0 //  $AT$  stores the time each plant becomes available for processing while  $LT$  stores the time truck leaves each plant

Set  $lastP := 0$  // Denotes the index of the plant visited on the previous trip

Set  $initSum := 0$

**for** each job  $J_l$  such that  $1 \leq l \leq K$

Increase  $initSum$  by  $p_l$  //  $p_l$  is the processing time of job  $J_l$

**end for**

**if**  $initSum > d_1$

Increase  $AT[1]$  by  $initSum$

Set  $LT[1] := initSum$

Mark the first  $K$  jobs as assigned and sent

Increase  $TCT$  by  $K \cdot (LT[1] + d_1)$

Increment  $trip$

Set  $lastP := 1$

**else**

Set  $i := 1$

Determine the  $batch$  to assign by  $batch\ sliding$

Set  $sumK := 0$

**for** each  $ij$  such that  $1 \leq ij \leq K$

Increase  $sumK$  by  $p_{batch[ij]}$

Mark job  $J_{ij}$  as assigned and sent

**end for**

Increase  $AT[1]$  by  $sumK$

Set  $LT[1] := d_1$

Increase  $TCT$  by  $2 \cdot K \cdot d_1$

Increment  $trip$

Set  $lastP := 1$

**end if**

**while**  $trip < minTrip$

Set  $batchEmpty := true$

**for** each plant  $P_i$  **and**  $batchEmpty = true$

Set  $assignP := i$

Determine the  $batch$  by  $batch\ sliding$

**end for**

**if**  $batchEmpty = false$

Set  $sumK := 0$

**for** each  $ij$  such that  $1 \leq ij \leq K$

Increase  $sumK$  by  $p_{batch[ij]}$

Mark job  $J_{ij}$  as assigned and sent



**end for**  
 Increase  $AT[assignP]$  by  $sumK$   
 Set  $LT[assignP] := LT[lastP] + d_{lastP} + d_{assignP}$   
 Increase  $TCT$  by  $K \cdot (LT[assignP] + d_{assignP})$   
 Increment  $trip$   
 Set  $lastP := assignP$

**else**  
 Set  $Sum$  to the sum of processing times of the first  $K$  unassigned jobs  
 Set  $cont$  to a very large value  
**for** each plant  $P_i$   
     Set contribution of  $P_i$  to  $(AT[i] + Sum + d_i)$   
     **if** contribution of  $P_i \leq cont$   
         Set  $selP := i$   
     **end if**  
**end for**  
 Increase  $AT[selP]$  by  $Sum$   
 Set  $LT[selP] := AT[selP]$   
 Mark the first  $K$  jobs as assigned and sent  
 Increase  $TCT$  by  $K \cdot (LT[selP] + d_{selP})$   
 Increment  $trip$   
 Set  $lastP := selP$

**end if**  
**end while**  
**if**  $partial > 0$   
 Set  $Sum$  to the sum of processing times of all unassigned jobs  
 Set  $cont$  to a very large value  
**for** each plant  $P_i$   
     Set contribution of  $P_i$  to  $\max(LT[lastP] + d_{lastP} + d_i, AT[i] + Sum) + d_i$   
     **if** contribution of  $P_i \leq cont$   
         Set  $selP := i$   
     **end if**  
**end for**  
 Increase  $AT[selP]$  by  $Sum$   
 Set  $LT[selP] := \max(LT[lastP] + d_{lastP} + d_{selP}, AT[selP])$   
 Mark all unassigned jobs as assigned and sent  
 Increase  $TCT$  by  $K \cdot (LT[selP] + d_{selP})$   
 Increment  $trip$   
 Set  $lastP := selP$

**end if**  
 Return  $TCT$

### **Algorithm Batch Sliding**

```
for each job  $J_i$  such that  $1 \leq l \leq n - K + 1$ 
    Set  $sum$  to the sum of processing times of the first  $K$  unassigned jobs starting with  $l^{th}$  job
    if  $sum \leq LT[lastP] + d_{lastP} + d_i - AT[i]$ 
        Set  $batchEmpty := false$ 
        for  $l'$  from 1 to  $K$ 
            Set  $batch[l']$  to the  $(l')^{th}$  unassigned job starting with  $l^{th}$  job
        end for
    else break
    end if
end for
Return  $batch$ 
```

## **B.3 Heuristic 3 (FTH1)**

### **Algorithm Heuristic 3 (FTH1)**

```
Sort plants in nondecreasing distances and reindex
Sort jobs in nondecreasing processing times and reindex
Set  $TCT := 0$  //  $TCT$  means total completion time
Set  $bestCT$  to a very large value // holds the best total completion time
Set  $minTrip := \left\lfloor \frac{n}{K} \right\rfloor$  // the number of trips that will be fully loaded
Set  $partial := n - qK$  // the number of jobs in the partially loaded trip

if  $partial = 0$ 
    Apply Heuristic 1
    Set  $bestCT$  to the total completion time found in Heuristic 1
else //if a partial batch occurs
    for  $p$  from 0 to  $minTrip$  //  $p$  denotes which trip is partial, if the first trip is partial  $p$  will
    be 0
        Set  $TCT := 0$ 
```

Set  $trip := 0$  // Denotes which trip is the current one, can be at most  $\left\lceil \frac{n}{K} \right\rceil$

Initialize arrays  $AT$  and  $LT$  and set each element of these arrays to 0 //  $AT$  stores the time each plant becomes available for processing while  $LT$  stores the time truck leaves each plant

Initialize array  $NP$  and set each element to 0 // holds the number of jobs sent from each plant

Set  $lastP := 0$  // Denotes the index of the plant visited on the previous trip

**if**  $p = 0$  // if the first trip is partial

Set  $Sum$  to the total processing time of the first *partial* jobs

Increase  $AT[1]$  by  $Sum$

Set  $LT[1] := \max(AT[1], LT[lastP] + d_{lastP} + d_1)$

Set  $lastP := 1$

Increment  $trip$

Increase  $NP[1]$  by *partial*

Increase  $TCT$  by  $partial \cdot (LT[lastP] + d_{lastP})$

**for** the last *minTrip* number of trips

Set  $Sum := 0$

**for** each job  $J_l$  such that  $partial + 1 + (trip - 1)K \leq l \leq partial + trip \cdot K$

Increase  $Sum$  by  $p_l$  //  $p_l$  is the processing time of job  $J_l$

**end for**

**if** the number of previously assigned jobs of each plant is the same

Increase  $AT[1]$  by  $Sum$

Set  $LT[1] := \max(AT[1], LT[lastP] + d_{lastP} + d_1)$

Set  $lastP := 1$

Increment  $trip$

Increase  $NP[1]$  by  $K$

Increase  $TCT$  by  $K \cdot (LT[lastP] + d_{lastP})$

**else** // potential plant selection will be applied

Set  $selP := 0$

Determine *potential plants*

Set  $selP$  to the plant with smallest contribution

Increase  $AT[selP]$  by  $Sum$

Set  $LT[selP] := \max(AT[selP], LT[lastP] + d_{lastP} + d_{selP})$

Set  $lastP := selP$

Increment  $trip$

Increase  $NP[lastP]$  by  $K$

Increase  $TCT$  by  $K \cdot (LT[lastP] + d_{lastP})$

**end if**

**end for**

```

if  $TCT \leq bestCT$ 
    Set  $bestCT := TCT$ 
end if
else // a trip other than the first one is partial
    for each  $trip$ 
        Set  $Sum := 0$ 
        if  $trip < p$ 
            for each job  $J_l$  such that  $trip \cdot K + 1 \leq l \leq (trip + 1)K$ 
                Increase  $Sum$  by  $p_l$  //  $p_l$  is the processing time of job  $J_l$ 
            end for
        else if  $trip = p$ 
            for each job  $J_l$  such that  $p \cdot K + 1 \leq l \leq p \cdot K + partial$ 
                Increase  $Sum$  by  $p_l$  //  $p_l$  is the processing time of job  $J_l$ 
            end for
        else
            for each job  $J_l$  such that  $(trip - 1) \cdot K + partial + 1 \leq l \leq trip \cdot K + partial$ 
                Increase  $Sum$  by  $p_l$  //  $p_l$  is the processing time of job  $J_l$ 
            end for
        end if
        if the number of previously assigned jobs of each plant is the same
            Increase  $AT[1]$  by  $Sum$ 
            Set  $LT[1] := \max(AT[1], LT[lastP] + d_{lastP} + d_1)$ 
            Set  $lastP := 1$ 
            Increment  $trip$ 
            if  $trip - 1 \neq p$ 
                Increase  $NP[1]$  by  $K$ 
                Increase  $TCT$  by  $K \cdot (LT[lastP] + d_{lastP})$ 
            else
                Increase  $NP[1]$  by  $partial$ 
                Increase  $TCT$  by  $partial \cdot (LT[lastP] + d_{lastP})$ 
            end if
        else
            Set  $selP := 0$ 
            Determine potential plants
            Set  $selP$  to the plant with smallest contribution
            Increase  $AT[selP]$  by  $Sum$ 
            Set  $LT[selP] := \max(AT[selP], LT[lastP] + d_{lastP} + d_{selP})$ 
            Set  $lastP := selP$ 
            Increment  $trip$ 
            if  $trip - 1 \neq p$ 

```

```

        Increase  $NP [lastP]$  by  $K$ 
        Increase  $TCT$  by  $K \cdot (LT [lastP] + d_{lastP})$ 
    else
        Increase  $NP [lastP]$  by  $partial$ 
        Increase  $TCT$  by  $partial \cdot (LT [lastP] + d_{lastP})$ 
    end if
end if
end if
end for
if  $TCT \leq bestCT$ 
    Set  $bestCT := TCT$ 
end if
end if
end for
end if
Return  $bestCT$ 

```

### **Algorithm Potential Plant Determination 2**

```

Set  $selP := 0$  // Denotes the plant selected among potential plants
Set  $maxSent := 0$  // Since plant 1 will always be the plant with more number of jobs
for each plant  $P_i$ 
    if  $NP[i] \geq maxSent$ 
        Set  $maxSent := NP[i]$ 
    end if
end for

Set  $count := 0$ 
for  $r$  from 0 to  $maxSent$ 
    Set  $count2 := 0$  // with this counter we ensure that among the plants having the same
    number of previously assigned jobs, only the closest one is chosen
    for each plant  $P_i$  //  $P_i$  denotes Plant  $i$ 
        if  $NP [i] = r$  and  $count2 < 1$ 
            Determine  $P_i$  as a potential plant
            Increment  $count$  and  $count2$ 
        end if
    end for
end for
for each plant  $P_i$ 
    if  $P_i$  is among the potential plants
        Set contribution of  $P_i$  to  $\max (LT [lastP] + d_{lastP} + d_i, AT [i] + Sum) + d_i$ 
    end if
end for

```

**end if**  
**end for**  
Sort the potential plants in non-decreasing order of contributions

## B.4 Heuristic 4 (FTH2)

### Algorithm Heuristic 4 (FTH2)

Sort plants in non-decreasing distances and re-index  
Sort jobs in non-decreasing processing times and re-index  
Set  $TCT := 0$  //  $TCT$  means total completion time  
Set  $bestCT$  to a very large value // holds the best total completion time  
Set  $minTrip := \left\lfloor \frac{n}{K} \right\rfloor$  // the number of trips that will be fully loaded  
Set  $partial := n - qK$  // the number of jobs in the partially loaded trip  
Set  $trip := 0$  // Denotes which trip is the current one, can be at most  $\left\lceil \frac{n}{K} \right\rceil$   
**if**  $partial = 0$   
    Apply Heuristic 2  
    Set  $bestCT$  to the total completion time found in Heuristic 2  
**else**  
    **for**  $p$  from 1 to  $minTrip + 1$  //  $p$  denotes which trip is partial  
        Set  $TCT := 0$   
        Set  $trip := 0$  // Denotes which trip is the current one, can be at most  $\left\lceil \frac{n}{K} \right\rceil$   
        Initialize arrays  $AT$  and  $LT$  and set each element of these arrays to 0 //  $AT$  stores the time each plant becomes available for processing while  $LT$  stores the time truck leaves each plant  
        Initialize array  $NP$  and set each element to 0 // holds the number of jobs sent from each plant  
        Set  $lastP := 0$  // Denotes the index of the plant visited on the previous trip  
        Set  $batchEmpty := true$   
        **if**  $p = 1$  // if the first trip is partial  
            Set  $initSum$  to the total processing time of the first  $partial$  jobs  
            **if**  $initSum > d_1$

Increase  $AT [1]$  by  $initSum$   
 Set  $LT [1] := initSum$   
 Mark the first *partial* jobs as assigned and sent  
 Increase  $TCT$  by  $partial \cdot (LT [1] + d_1)$   
 Increment  $trip$   
 Set  $lastP := 1$   
**else**  
 Set  $i := 1$   
 Determine the *batch* to assign by *batch sliding*  
 Set  $sumK := 0$   
**for** each  $ij$  such that  $1 \leq ij \leq partial$   
     Increase  $sumK$  by  $p_{batch[ij]}$   
     Mark job  $J_{ij}$  as assigned and sent  
**end for**  
 Increase  $AT [1]$  by  $sumK$   
 Set  $LT [1] := d_1$   
 Increase  $TCT$  by  $2 \cdot partial \cdot d_1$   
 Increment  $trip$   
 Set  $lastP := 1$   
**end if**  
**while**  $trip < minTrip + 1$   
     Set  $batchEmpty := true$   
     **for** each plant  $P_i$  **and**  $batchEmpty = true$   
         Set  $assignP := i$   
         Determine the *batch* by *batch sliding*  
     **end for**  
     **if**  $batchEmpty = false$   
         Set  $sumK := 0$   
         **for** each  $ij$  such that  $1 \leq ij \leq K$   
             Increase  $sumK$  by  $p_{batch[ij]}$   
             Mark job  $J_{ij}$  as assigned and sent  
         **end for**  
         Increase  $AT [assignP]$  by  $sumK$   
         Set  $LT [assignP] := LT [lastP] + d_{lastP} + d_{assignP}$   
         Increase  $TCT$  by  $K \cdot (LT [assignP] + d_{assignP})$   
         Increment  $trip$   
         Set  $lastP := assignP$   
     **else**  
         Set  $Sum$  to the sum of processing times of the first  $K$  unassigned jobs  
         Set  $cont$  to a very large value

```

for each plant  $P_i$ 
    Set contribution of  $P_i$  to  $(AT[i] + Sum + d_i)$ 
    if contribution of  $P_i \leq cont$ 
        Set  $selP := i$ 
    end if
end for
    Increase  $AT[selP]$  by  $Sum$ 
    Set  $LT[selP] := AT[selP]$ 
    Mark the first  $K$  jobs as assigned and sent
    Increase  $TCT$  by  $K \cdot (LT[selP] + d_{selP})$ 
    Increment  $trip$ 
    Set  $lastP := selP$ 
end if
end while
if  $TCT \leq bestCT$ 
    Set  $bestCT := TCT$ 
end if
else // if a trip other than the first one is partial
    Set  $initSum$  to the total processing time of the first  $K$  jobs
    if  $initSum > d_1$ 
        Increase  $AT[1]$  by  $initSum$ 
        Set  $LT[1] := initSum$ 
        Mark the first partial jobs as assigned and sent
        Increase  $TCT$  by  $K \cdot (LT[1] + d_1)$ 
        Increment  $trip$ 
        Set  $lastP := 1$ 
    else
        Set  $i := 1$ 
        Determine the batch to assign by batch sliding
        Set  $sumK := 0$ 
        for each  $ij$  such that  $1 \leq ij \leq K$ 
            Increase  $sumK$  by  $p_{batch[ij]}$ 
            Mark job  $J_{ij}$  as assigned and sent
        end for
        Increase  $AT[1]$  by  $sumK$ 
        Set  $LT[1] := d_1$ 
        Increase  $TCT$  by  $2 \cdot K \cdot d_1$ 
        Increment  $trip$ 
        Set  $lastP := 1$ 
    end if

```



```

while  $trip + 1 < p$ 
  Set  $batchEmpty := true$ 
  for each plant  $P_i$  and  $batchEmpty = true$ 
    Set  $assignP := i$ 
    Determine the  $batch$  by  $batch\ sliding$ 
  end for
  if  $batchEmpty = false$ 
    Set  $sumK := 0$ 
    for each  $ij$  such that  $1 \leq ij \leq K$ 
      Increase  $sumK$  by  $p_{batch[ij]}$ 
      Mark job  $J_{ij}$  as assigned and sent
    end for
    Increase  $AT[assignP]$  by  $sumK$ 
    Set  $LT[assignP] := LT[lastP] + d_{lastP} + d_{assignP}$ 
    Increase  $TCT$  by  $K \cdot (LT[assignP] + d_{assignP})$ 
    Increment  $trip$ 
    Set  $lastP := assignP$ 
  else
    Set  $Sum$  to the sum of processing times of the first  $K$  unassigned jobs
    Set  $cont$  to a very large value
    for each plant  $P_i$ 
      Set contribution of  $P_i$  to  $(AT[i] + Sum + d_i)$ 
      if contribution of  $P_i \leq cont$ 
        Set  $selP := i$ 
      end if
    end for
    Increase  $AT[selP]$  by  $Sum$ 
    Set  $LT[selP] := AT[selP]$ 
    Mark the first  $K$  jobs as assigned and sent
    Increase  $TCT$  by  $K \cdot (LT[selP] + d_{selP})$ 
    Increment  $trip$ 
    Set  $lastP := selP$ 
  end if
end while
if  $trip + 1 = p$ 
  if  $trip + 1 = minTrip + 1$  //if the last trip is partial
    Set  $Sum$  to the sum of processing times of all unassigned jobs
    Set  $cont$  to a very large value
    for each plant  $P_i$ 
      Set contribution of  $P_i$  to  $\max(LT[lastP] + d_{lastP} + d_i, AT[i] + Sum) + d_i$ 

```

```

    if contribution of  $P_i \leq cont$ 
        Set  $selP := i$ 
    end if
end for
Increase  $AT[selP]$  by  $Sum$ 
Set  $LT[selP] := \max(LT[lastP] + d_{lastP} + d_{selP}, AT[selP])$ 
Mark all unassigned jobs as assigned and sent
Increase  $TCT$  by  $K \cdot (LT[selP] + d_{selP})$ 
Increment  $trip$ 
Set  $lastP := selP$ 
else
Set  $batchEmpty := true$ 
for each plant  $P_i$  and  $batchEmpty = true$ 
    Set  $assignP := i$ 
    Determine the  $batch$  by  $batch\ sliding$ 
end for
if  $batchEmpty = false$ 
    Set  $sumK := 0$ 
    for each  $ij$  such that  $1 \leq ij \leq K$ 
        Increase  $sumK$  by  $p_{batch[ij]}$ 
        Mark job  $J_{ij}$  as assigned and sent
    end for
    Increase  $AT[assignP]$  by  $sumK$ 
    Set  $LT[assignP] := LT[lastP] + d_{lastP} + d_{assignP}$ 
    Increase  $TCT$  by  $K \cdot (LT[assignP] + d_{assignP})$ 
    Increment  $trip$ 
    Set  $lastP := assignP$ 
else
    Set  $Sum$  to the sum of processing times of the first  $K$  unassigned jobs
    Set  $cont$  to a very large value
    for each plant  $P_i$ 
        Set contribution of  $P_i$  to  $(AT[i] + Sum + d_i)$ 
        if contribution of  $P_i \leq cont$ 
            Set  $selP := i$ 
        end if
    end for
    Increase  $AT[selP]$  by  $Sum$ 
    Set  $LT[selP] := AT[selP]$ 
    Mark the first  $K$  jobs as assigned and sent

```

```

        Increase  $TCT$  by  $K \cdot (LT[selP] + d_{selP})$ 
        Increment  $trip$ 
        Set  $lastP := selP$ 
    end if
end if
end if
if  $p \neq minTrip + 1$ 
    while  $trip < minTrip + 1$ 
        Set  $batchEmpty := true$ 
        for each plant  $P_i$  and  $batchEmpty = true$ 
            Set  $assignP := i$ 
            Determine the  $batch$  by  $batch\ sliding$ 
        end for
        if  $batchEmpty = false$ 
            Set  $sumK := 0$ 
            for each  $ij$  such that  $1 \leq ij \leq K$ 
                Increase  $sumK$  by  $p_{batch[ij]}$ 
                Mark job  $J_{ij}$  as assigned and sent
            end for
            Increase  $AT[assignP]$  by  $sumK$ 
            Set  $LT[assignP] := LT[lastP] + d_{lastP} + d_{assignP}$ 
            Increase  $TCT$  by  $K \cdot (LT[assignP] + d_{assignP})$ 
            Increment  $trip$ 
            Set  $lastP := assignP$ 
        else
            Set  $Sum$  to the sum of processing times of the first  $K$  unassigned jobs
            Set  $cont$  to a very large value
            for each plant  $P_i$ 
                Set contribution of  $P_i$  to  $(AT[i] + Sum + d_i)$ 
                if contribution of  $P_i \leq cont$ 
                    Set  $selP := i$ 
                end if
            end for
            Increase  $AT[selP]$  by  $Sum$ 
            Set  $LT[selP] := AT[selP]$ 
            Mark the first  $K$  jobs as assigned and sent
            Increase  $TCT$  by  $K \cdot (LT[selP] + d_{selP})$ 
            Increment  $trip$ 
            Set  $lastP := selP$ 
        end if
    end while
end if
end if

```

```

        end if
      end while
    end if
    if  $TCT \leq bestCT$ 
      Set  $bestCT := TCT$ 
    end if
  end if
end for
end if
Return  $bestCT$ 

```

## B.5 Heuristic 5 (NWH1)

### *Algorithm Heuristic 5 (NWH1)*

```

Sort plants in nondecreasing distances and reindex
Sort jobs in nondecreasing processing times and reindex
Set  $TCT := 0$  //  $TCT$  means total completion time
Set  $numSent := 0, lastP := 0$ 
Initialize arrays  $AT$  and  $LT$  and set each element of these arrays to 0 //  $AT$  stores the time
each plant becomes available for processing while  $LT$  stores the time truck leaves each plant

Initialize array  $NP$  and set each element to 0 // holds the number of jobs sent from each
plant
Set  $ptotal$  to the sum of processing times of all jobs
Set  $pbar := ptotal \div n$ 
while  $numSent < n$ 
  for each plant  $P_i$ 
    Set  $NP[i] := 0$ 
  end for
  Set  $sum := 0$ 
  for each job  $J_l$  such that  $numSent + 1 \leq l \leq n$ 
    if  $AT[1] + sum + p_l \leq LT[lastP] + d_{lastP} + d_1$  and  $NP[1] < K$ 
      Increase  $sum$  by  $p_l$ 
      Increment  $NP[1]$ 
    else break
  end if

```

```

end for
if  $NP[1] = K$ 
    Increase  $numSent$  by  $NP[1]$ 
    Increase  $AT[1]$  by  $sum$ 
    Set  $LT[1] := LT[lastP] + d_{lastP} + d_1$ 
    Set  $lastP := 1$ 
    Increase  $TCT$  by  $K \cdot (LT[1] + d_1)$ 
else
    Set  $justified := false$ 
    for each plant  $P_i$  except the first plant
        Set  $NP[i] := 0$ 
        Set  $sum := 0$ 
        for each job  $J_l$  such that  $numSent + 1 \leq l \leq n$ 
            if  $AT[i] + sum + p_l \leq LT[lastP] + d_{lastP} + d_i$  and  $NP[i] < K$ 
                Increase  $sum$  by  $p_l$ 
                Increment  $NP[i]$ 
            else break
            end if
        end for
        if  $2 \cdot (d_i - d_1) / pbar < (NP[i] - NP[1])$  and  $(NP[i] - NP[1]) \geq 1$ 
            Increase  $numSent$  by  $NP[i]$ 
            Increase  $AT[i]$  by  $sum$ 
            Set  $LT[i] := LT[lastP] + d_{lastP} + d_i$ 
            Set  $lastP := i$ 
            Increase  $TCT$  by  $NP[i] \cdot (LT[i] + d_i)$ 
            Set  $justified = true$ 
            break
        end if
    end for
    if  $justified = false$ 
        Increase  $numSent$  by  $NP[1]$ 
        Increase  $AT[1]$  by  $sum$ 
        Set  $LT[1] := LT[lastP] + d_{lastP} + d_1$ 
        Set  $lastP := 1$ 
        Increase  $TCT$  by  $NP[1] \cdot (LT[1] + d_1)$ 
    end if
end if
end while
Return  $TCT$ 

```

## B.6 Heuristic 6 (NWH2)

### Algorithm Heuristic 6 (NWH2)

Sort plants in nondecreasing distances and reindex  
Sort jobs in nondecreasing processing times and reindex  
Set  $TCT := 0$  //  $TCT$  means total completion time  
Set  $numSent := 0, lastP := 0$   
Initialize arrays  $AT$  and  $LT$  and set each element of these arrays to 0 //  $AT$  stores the time each plant becomes available for processing while  $LT$  stores the time truck leaves each plant

Initialize array  $NP$  and set each element to 0 // holds the number of jobs sent from each plant

Set  $ptotal$  to the sum of processing times of all jobs  
Set  $pbar := ptotal \div n$

**while**  $numSent < n$   
  **for** each plant  $P_i$   
    Set  $NP[i] := 0$   
  **end for**  
  Set  $sum := 0$   
  **for** each job  $J_l$  such that  $numSent + 1 \leq l \leq n$   
    **if**  $AT[1] + sum + p_l \leq LT[lastP] + d_{lastP} + d_1$  **and**  $NP[1] < K$   
      Increase  $sum$  by  $p_l$   
      Increment  $NP[1]$   
    **else break**  
    **end if**  
  **end for**  
  **if**  $NP[1] = K$   
    Set  $sum2 := 0$   
    Apply *batch sliding*  
    **for** each  $ij$  such that  $1 \leq ij \leq NP[1]$   
      Increase  $sum2$  by  $p_{batch[ij]}$   
      Mark job  $J_{ij}$  as assigned and sent  
    **end for**  
    Increase  $numSent$  by  $NP[1]$   
    Increase  $AT[1]$  by  $sum2$   
    Set  $LT[1] := LT[lastP] + d_{lastP} + d_1$   
    Set  $lastP := 1$

Increase  $TCT$  by  $K \cdot (LT[1] + d_1)$

**else**

Set  $justified := false$

**for** each plant  $P_i$  except the first plant

Set  $NP[i] := 0$

Set  $sum := 0$

**for** each job  $J_l$  such that  $numSent + 1 \leq l \leq n$

**if**  $AT[i] + sum + p_l \leq LT[lastP] + d_{lastP} + d_i$  **and**  $NP[i] < K$

Increase  $sum$  by  $p_l$

Increment  $NP[i]$

**else break**

**end if**

**end for**

**if**  $2 \cdot (d_i - d_1) / pbar < (NP[i] - NP[1])$  **and**  $(NP[i] - NP[1]) \geq 1$

Set  $sum2 := 0$

Apply *batch sliding*

**for** each  $ij$  such that  $1 \leq ij \leq NP[i]$

Increase  $sum2$  by  $p_{batch[ij]}$

Mark job  $J_{ij}$  as assigned and sent

**end for**

Increase  $numSent$  by  $NP[i]$

Increase  $AT[i]$  by  $sum2$

Set  $LT[i] := LT[lastP] + d_{lastP} + d_i$

Set  $lastP := i$

Increase  $TCT$  by  $NP[i] \cdot (LT[i] + d_i)$

Set  $justified = true$

**break**

**end if**

**end for**

**if**  $justified = false$

Set  $sum2 := 0$

Apply *batch sliding*

**for** each  $ij$  such that  $1 \leq ij \leq NP[1]$

Increase  $sum2$  by  $p_{batch[ij]}$

Mark job  $J_{ij}$  as assigned and sent

**end for**

Increase  $numSent$  by  $NP[1]$

Increase  $AT[1]$  by  $sum2$

Set  $LT[1] := LT[lastP] + d_{lastP} + d_1$

```

    Set  $lastP := 1$ 
    Increase  $TCT$  by  $NP[1] \cdot (LT[1] + d_1)$ 
  end if
end if
end while
Return  $TCT$ 

```

## B.7 Heuristic 7 (GH)

### Algorithm Heuristic 7 (GH)

```

Sort plants in nondecreasing distances and reindex
Sort jobs in nondecreasing processing times and reindex
Initialize array  $NP$  and set each element to 0 // holds the number of jobs sent from each
plant
Set  $bestCT$  to a very large value // Denotes the best completion time
Set  $ptotal$  to the sum of processing times of all jobs
Set  $pbar := ptotal \div n$ 
for each  $ratio\text{-}to\text{-}wait$  such that  $0.1 \leq ratio\text{-}to\text{-}wait \leq 1$  (Increase by 0.1)
  Initialize arrays  $AT$  and  $LT$  and set each element of these arrays to 0 //  $AT$  stores the
time each plant becomes available for processing while  $LT$  stores the time truck leaves each
plant

  Set  $TCT := 0$  //  $TCT$  means total completion time
  Set  $numSent := 0, lastP := 0$ 
  while  $numSent < n$ 
    Set  $batchEmpty := true$ 
    for each plant  $P_i$ 
      Set  $NP[i] := 0$ 
    end for
    Set  $sum := 0$ 
    for each job  $J_l$  such that  $1 \leq l \leq n$ 
      if  $AT[1] + sum + p_l \leq LT[lastP] + d_{lastP} + d_1$  and  $NP[1] < K$  and  $J_l$  is
unassigned
        Increase  $sum$  by  $p_l$ 
        Increment  $NP[1]$ 
      else

```



```

        if  $AT [1] + sum + (ratio\text{-}to\text{-}wait) \cdot p_l \leq LT [lastP] + d_{lastP} + d_1$  and  $NP [1] < K$ 
and  $J_l$  is unassigned
            Increase  $sum$  by  $p_l$ 
            Increment  $NP [1]$ 
        end if
    end if
end for
if  $NP [1] = K$ 
    Apply batch sliding
    if  $batchEmpty = false$ 
        Set  $sum2 := 0$ 
        for each  $ij$  such that  $1 \leq ij \leq NP [1]$ 
            Increase  $sum2$  by  $p_{batch[ij]}$ 
            Mark job  $J_{ij}$  as assigned and sent
        end for
        Increase  $numSent$  by  $NP [1]$ 
        Increase  $AT [1]$  by  $sum2$ 
        Set  $LT [1] := \max (AT [1], LT [lastP] + d_{lastP} + d_1)$ 
        Set  $lastP := 1$ 
        Increase  $TCT$  by  $K \cdot (LT [1] + d_1)$ 
    else
        Set  $sum2$  to the sum of processing times of the first  $NP [1]$  unassigned jobs
        Mark the first  $NP [1]$  jobs as assigned and sent
        Increase  $AT [1]$  by  $sum2$ 
        Set  $LT [1] := \max (AT [1], LT [lastP] + d_{lastP} + d_1)$ 
        Set  $lastP := 1$ 
        Increase  $TCT$  by  $K \cdot (LT [1] + d_1)$ 
    end if
else
    Set  $justified := false$ 
    for each plant  $P_i$  except the first plant
        Set  $NP [i] := 0$ 
        Set  $sum := 0$ 
        for each job  $J_l$  such that  $numSent + 1 \leq l \leq n$ 
            if  $AT [i] + sum + p_l \leq LT [lastP] + d_{lastP} + d_i$  and  $NP [i] < K$  and  $J_l$  is
unassigned
                Increase  $sum$  by  $p_l$ 
                Increment  $NP [i]$ 
            else

```

```

        if  $AT [i] + sum + (ratio-to-wait) \cdot p_i \leq LT [lastP] + d_{lastP} + d_i$  and  $NP [i]$ 
<  $K$  and  $J_i$  is unassigned
            Increase  $sum$  by  $p_i$ 
            Increment  $NP [i]$ 
        end if
    end if
end for
    if  $2 \cdot (d_i - d_1) / pbar < (NP [i] - NP [1])$  and  $(NP [i] - NP [1]) \geq 1$ 
        Apply batch sliding
        if  $batchEmpty = false$ 
            Set  $sum2 := 0$ 
            for each  $ij$  such that  $1 \leq ij \leq NP [i]$ 
                Increase  $sum2$  by  $p_{batch[ij]}$ 
                Mark job  $J_{ij}$  as assigned and sent
            end for
            Increase  $numSent$  by  $NP [i]$ 
            Increase  $AT [i]$  by  $sum2$ 
            Set  $LT [i] := \max (AT [i], LT [lastP] + d_{lastP} + d_i)$ 
            Set  $lastP := i$ 
            Increase  $TCT$  by  $NP [i] \cdot (LT [i] + d_i)$ 
            Set  $justified = true$ 
            break
        else
            Set  $sum2$  to the sum of processing times of the first  $NP [i]$  unassigned
            jobs
            Mark the first  $NP [i]$  jobs as assigned and sent
            Increase  $AT [i]$  by  $sum2$ 
            Set  $LT [i] := \max (AT [i], LT [lastP] + d_{lastP} + d_i)$ 
            Set  $lastP := i$ 
            Increase  $TCT$  by  $NP [i] \cdot (LT [i] + d_i)$ 
            Set  $justified = true$ 
            break
        end if
    end if
end for
if  $justified = false$ 
    Apply batch sliding
    if  $batchEmpty = false$ 
        Set  $sum2 := 0$ 
        for each  $ij$  such that  $1 \leq ij \leq NP [1]$ 

```

```

        Increase  $sum2$  by  $p_{batch[ij]}$ 
        Mark job  $J_{ij}$  as assigned and sent
    end for
    Increase  $numSent$  by  $NP[1]$ 
    Increase  $AT[1]$  by  $sum2$ 
    Set  $LT[1] := \max(AT[1], LT[lastP] + d_{lastP} + d_1)$ 
    Set  $lastP := 1$ 
    Increase  $TCT$  by  $NP[1] \cdot (LT[1] + d_1)$ 
else
    Set  $sum2$  to the sum of processing times of the first  $NP[1]$  unassigned jobs
    Mark the first  $NP[1]$  jobs as assigned and sent
    Increase  $AT[1]$  by  $sum2$ 
    Set  $LT[1] := \max(AT[1], LT[lastP] + d_{lastP} + d_1)$ 
    Set  $lastP := 1$ 
    Increase  $TCT$  by  $NP[1] \cdot (LT[1] + d_1)$ 
end if
end if
end while
if  $TCT \leq bestCT$ 
    Set  $bestCT := TCT$ 
end if
end for
Return  $bestCT$ 

```

# **Appendix C**

## Numerical Results for Last Trip Partial Problem

|           | $K$      | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----------|----------|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|           |          |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| <b>10</b> | <b>2</b> | 1         | 1560                             | 1560                             | 1560           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 1440                             | 1440                             | 1440           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 1380                             | 1380                             | 1380           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 1560                             | 1560                             | 1560           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 1560                             | 1560                             | 1560           | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>4</b> | 1         | 936                              | 936                              | 936            | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 864                              | 864                              | 864            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 828                              | 828                              | 828            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 936                              | 936                              | 936            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 936                              | 936                              | 936            | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>6</b> | 1         | 728                              | 728                              | 728            | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 672                              | 672                              | 672            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 644                              | 644                              | 644            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 728                              | 728                              | 728            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 748                              | 748                              | 748            | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>8</b> | 1         | 724                              | 724                              | 724            | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 776                              | 776                              | 776            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 672                              | 672                              | 672            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 744                              | 744                              | 744            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 814                              | 814                              | 814            | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.1** : Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 25  | 2   | 1         | 8788                             | 8788                             | 8788           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 8112                             | 8112                             | 8112           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 7774                             | 7774                             | 7774           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 8788                             | 8788                             | 8788           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 8788                             | 8788                             | 8788           | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 4   | 1         | 4732                             | 4732                             | 4732           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 4368                             | 4368                             | 4368           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 4186                             | 4186                             | 4186           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 4732                             | 4732                             | 4732           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 4732                             | 4732                             | 4732           | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 6   | 1         | 3380                             | 3380                             | 3380           | 0.00                   | 0.00  | 0.09                           | 0.09  | 0.45                           | 0.45  |
|     |     | 2         | 3134                             | 3120                             | 3120           | 0.45                   | 0.45  |                                |       |                                |       |
|     |     | 3         | 2990                             | 2990                             | 2990           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 3380                             | 3380                             | 3380           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 3380                             | 3380                             | 3380           | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 8   | 1         | 2722                             | 2704                             | 2704           | 0.67                   | 0.67  | 0.68                           | 0.68  | 1.31                           | 1.31  |
|     |     | 2         | 2630                             | 2596                             | 2596           | 1.31                   | 1.31  |                                |       |                                |       |
|     |     | 3         | 2410                             | 2392                             | 2392           | 0.75                   | 0.75  |                                |       |                                |       |
|     |     | 4         | 2722                             | 2704                             | 2704           | 0.67                   | 0.67  |                                |       |                                |       |
|     |     | 5         | 2704                             | 2704                             | 2704           | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.1 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 40  | 2   | 1         | 21840                            | 21840                            | 21840          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 20160                            | 20160                            | 20160          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 19320                            | 19320                            | 19320          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 21840                            | 21840                            | 21840          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 21840                            | 21840                            | 21840          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 4   | 1         | 11440                            | 11440                            | 11440          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 10560                            | 10560                            | 10560          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 10120                            | 10120                            | 10120          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 11440                            | 11440                            | 11440          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 11440                            | 11440                            | 11440          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 6   | 1         | 8008                             | 8008                             | 8008           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 7392                             | 7392                             | 7392           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 7084                             | 7084                             | 7084           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 8008                             | 8008                             | 8008           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 8008                             | 8008                             | 8008           | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 8   | 1         | 6256                             | 6256                             | 6240           | 0.26                   | 0.26  | 0.33                           | 0.33  | 0.58                           | 0.58  |
|     |     | 2         | 5792                             | 5792                             | 5760           | 0.56                   | 0.56  |                                |       |                                |       |
|     |     | 3         | 5552                             | 5552                             | 5520           | 0.58                   | 0.58  |                                |       |                                |       |
|     |     | 4         | 6256                             | 6256                             | 6240           | 0.26                   | 0.26  |                                |       |                                |       |
|     |     | 5         | 6240                             | 6240                             | 6240           | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.1 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 55  | 2   | 1         | 40768                            | 40768                            | 40768          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 37632                            | 37632                            | 37632          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 36064                            | 36064                            | 36064          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 40768                            | 40768                            | 40768          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 40768                            | 40768                            | 40768          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 4   | 1         | 21112                            | 21112                            | 21112          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 19488                            | 19488                            | 19488          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 18676                            | 18676                            | 18676          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 21112                            | 21112                            | 21112          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 21112                            | 21112                            | 21112          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 6   | 1         | 14560                            | 14560                            | 14560          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 13440                            | 13440                            | 13440          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 12880                            | 12880                            | 12880          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 14560                            | 14560                            | 14560          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 14560                            | 14560                            | 14560          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 8   | 1         | 11298                            | 11298                            | 11284          | 0.12                   | 0.12  | 0.14                           | 0.14  | 0.29                           | 0.29  |
|     |     | 2         | 10446                            | 10446                            | 10416          | 0.29                   | 0.29  |                                |       |                                |       |
|     |     | 3         | 9996                             | 9996                             | 9982           | 0.14                   | 0.14  |                                |       |                                |       |
|     |     | 4         | 11298                            | 11298                            | 11284          | 0.12                   | 0.12  |                                |       |                                |       |
|     |     | 5         | 11284                            | 11284                            | 11284          | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.1 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$



| $n$       | $K$      | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----------|----------|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|           |          |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| <b>10</b> | <b>2</b> | 1         | 2160                             | 2160                             | 2160           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 2040                             | 2040                             | 2040           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 1980                             | 1980                             | 1980           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 2160                             | 2160                             | 2160           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 2160                             | 2160                             | 2160           | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>4</b> | 1         | 1296                             | 1296                             | 1296           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 1224                             | 1224                             | 1224           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 1188                             | 1188                             | 1188           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 1296                             | 1296                             | 1296           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 1296                             | 1296                             | 1296           | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>6</b> | 1         | 1008                             | 1008                             | 1008           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 952                              | 952                              | 952            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 924                              | 924                              | 924            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 1008                             | 1008                             | 1008           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 1008                             | 1008                             | 1008           | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>8</b> | 1         | 864                              | 864                              | 864            | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 916                              | 916                              | 916            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 812                              | 812                              | 812            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 884                              | 884                              | 884            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 954                              | 954                              | 954            | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.2** : Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 25  | 2   | 1         | 12168                            | 12168                            | 12168          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 11492                            | 11492                            | 11492          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 11154                            | 11154                            | 11154          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 12168                            | 12168                            | 12168          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 12168                            | 12168                            | 12168          | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 4   | 1         | 6552                             | 6552                             | 6552           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 6188                             | 6188                             | 6188           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 6006                             | 6006                             | 6006           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 6552                             | 6552                             | 6552           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 6552                             | 6552                             | 6552           | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 6   | 1         | 4680                             | 4680                             | 4680           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 4420                             | 4420                             | 4420           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 4290                             | 4290                             | 4290           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 4680                             | 4680                             | 4680           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 4680                             | 4680                             | 4680           | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 8   | 1         | 3744                             | 3744                             | 3744           | 0.00                   | 0.00  | 0.05                           | 0.10  | 0.25                           | 0.51  |
|     |     | 2         | 3545                             | 3554                             | 3536           | 0.25                   | 0.51  |                                |       |                                |       |
|     |     | 3         | 3432                             | 3432                             | 3432           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 3744                             | 3744                             | 3744           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 3744                             | 3744                             | 3744           | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.2 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 40  | 2   | 1         | 30240                            | 30240                            | 30240          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 28560                            | 28560                            | 28560          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 27720                            | 27720                            | 27720          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 30240                            | 30240                            | 30240          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 30240                            | 30240                            | 30240          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 4   | 1         | 15840                            | 15840                            | 15840          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 14960                            | 14960                            | 14960          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 14520                            | 14520                            | 14520          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 15840                            | 15840                            | 15840          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 15840                            | 15840                            | 15840          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 6   | 1         | 11088                            | 11088                            | 11088          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 10472                            | 10472                            | 10472          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 10164                            | 10164                            | 10164          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 11088                            | 11088                            | 11088          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 11088                            | 11088                            | 11088          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 8   | 1         | 8640                             | 8640                             | 8640           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 8160                             | 8160                             | 8160           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 7920                             | 7920                             | 7920           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 8640                             | 8640                             | 8640           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 8640                             | 8640                             | 8640           | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.2 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 55  | 2   | 1         | 56448                            | 56448                            | 56448          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 53312                            | 53312                            | 53312          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 51744                            | 51744                            | 51744          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 56448                            | 56448                            | 56448          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 56448                            | 56448                            | 56448          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 4   | 1         | 29232                            | 29232                            | 29232          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 27608                            | 27608                            | 27608          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 26796                            | 26796                            | 26796          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 29232                            | 29232                            | 29232          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 29232                            | 29232                            | 29232          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 6   | 1         | 20160                            | 20160                            | 20160          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 19040                            | 19040                            | 19040          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 18480                            | 18480                            | 18480          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 20160                            | 20160                            | 20160          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 20160                            | 20160                            | 20160          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 8   | 1         | 15624                            | 15624                            | 15624          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 14756                            | 14756                            | 14756          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 14322                            | 14322                            | 14322          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 15624                            | 15624                            | 15624          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 15624                            | 15624                            | 15624          | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.2 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$       | $K$      | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----------|----------|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|           |          |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| <b>10</b> | <b>2</b> | 1         | 2400                             | 2400                             | 2400           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 1860                             | 1860                             | 1860           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 1680                             | 1680                             | 1680           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 2220                             | 2220                             | 2220           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 2340                             | 2340                             | 2340           | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>4</b> | 1         | 1440                             | 1440                             | 1440           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 1116                             | 1116                             | 1116           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 1008                             | 1008                             | 1008           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 1332                             | 1332                             | 1332           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 1404                             | 1404                             | 1404           | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>6</b> | 1         | 1120                             | 1120                             | 1120           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 868                              | 868                              | 868            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 784                              | 784                              | 784            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 1036                             | 1036                             | 1036           | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 1092                             | 1092                             | 1092           | 0.00                   | 0.00  |                                |       |                                |       |
| <b>10</b> | <b>8</b> | 1         | 960                              | 960                              | 960            | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|           |          | 2         | 874                              | 874                              | 874            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 3         | 742                              | 742                              | 742            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 4         | 898                              | 898                              | 898            | 0.00                   | 0.00  |                                |       |                                |       |
|           |          | 5         | 996                              | 996                              | 996            | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.3** : Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 25  | 2   | 1         | 13520                            | 13520                            | 13520          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 10478                            | 10478                            | 10478          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 9464                             | 9464                             | 9464           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 12506                            | 12506                            | 12506          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 13182                            | 13182                            | 13182          | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 4   | 1         | 7280                             | 7280                             | 7280           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 5642                             | 5642                             | 5642           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 5096                             | 5096                             | 5096           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 6734                             | 6734                             | 6734           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 7098                             | 7098                             | 7098           | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 6   | 1         | 5200                             | 5200                             | 5200           | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 4030                             | 4030                             | 4030           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 3640                             | 3640                             | 3640           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 4810                             | 4810                             | 4810           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 5070                             | 5070                             | 5070           | 0.00                   | 0.00  |                                |       |                                |       |
| 25  | 8   | 1         | 4160                             | 4160                             | 4160           | 0.00                   | 0.00  | 0.33                           | 0.33  | 1.67                           | 1.67  |
|     |     | 2         | 3278                             | 3278                             | 3224           | 1.67                   | 1.67  |                                |       |                                |       |
|     |     | 3         | 2912                             | 2912                             | 2912           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 3848                             | 3848                             | 3848           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 4056                             | 4056                             | 4056           | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.3 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 40  | 2   | 1         | 33600                            | 33600                            | 33600          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 26040                            | 26040                            | 26040          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 23520                            | 23520                            | 23520          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 31080                            | 31080                            | 31080          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 32760                            | 32760                            | 32760          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 4   | 1         | 17600                            | 17600                            | 17600          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 13640                            | 13640                            | 13640          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 12320                            | 12320                            | 12320          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 16280                            | 16280                            | 16280          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 17160                            | 17160                            | 17160          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 6   | 1         | 12320                            | 12320                            | 12320          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 9548                             | 9548                             | 9548           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 8624                             | 8624                             | 8624           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 11396                            | 11396                            | 11396          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 12012                            | 12012                            | 12012          | 0.00                   | 0.00  |                                |       |                                |       |
| 40  | 8   | 1         | 9600                             | 9600                             | 9600           | 0.00                   | 0.00  | 0.02                           | 0.19  | 0.12                           | 0.95  |
|     |     | 2         | 7440                             | 7440                             | 7440           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 6728                             | 6784                             | 6720           | 0.12                   | 0.95  |                                |       |                                |       |
|     |     | 4         | 8880                             | 8880                             | 8880           | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 9360                             | 9360                             | 9360           | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.3 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 11]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | <i>LastPartialHR1</i><br>(LPHR1) | <i>LastPartialHR2</i><br>(LPHR2) | Lower<br>Bound | Lower Bound<br>Gap (%) |       | Average Lower<br>Bound Gap (%) |       | Maximum Lower<br>Bound Gap (%) |       |
|-----|-----|-----------|----------------------------------|----------------------------------|----------------|------------------------|-------|--------------------------------|-------|--------------------------------|-------|
|     |     |           |                                  |                                  |                | LPHR1                  | LPHR2 | LPHR1                          | LPHR2 | LPHR1                          | LPHR2 |
| 55  | 2   | 1         | 62720                            | 62720                            | 62720          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 48608                            | 48608                            | 48608          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 43904                            | 43904                            | 43904          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 58016                            | 58016                            | 58016          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 61152                            | 61152                            | 61152          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 4   | 1         | 32480                            | 32480                            | 32480          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 25172                            | 25172                            | 25172          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 22736                            | 22736                            | 22736          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 30044                            | 30044                            | 30044          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 31668                            | 31668                            | 31668          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 6   | 1         | 22400                            | 22400                            | 22400          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 17360                            | 17360                            | 17360          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 15680                            | 15680                            | 15680          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 20720                            | 20720                            | 20720          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 21840                            | 21840                            | 21840          | 0.00                   | 0.00  |                                |       |                                |       |
| 55  | 8   | 1         | 17360                            | 17360                            | 17360          | 0.00                   | 0.00  | 0.00                           | 0.00  | 0.00                           | 0.00  |
|     |     | 2         | 13454                            | 13454                            | 13454          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 3         | 12152                            | 12152                            | 12152          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 4         | 16058                            | 16058                            | 16058          | 0.00                   | 0.00  |                                |       |                                |       |
|     |     | 5         | 16926                            | 16926                            | 16926          | 0.00                   | 0.00  |                                |       |                                |       |

**Table C.3 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 11]$  and  $d_i \in [22, 48]$



| $n$ | $K$ | Ins. # | LPH1 | LPH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |      |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|------|------|
|     |     |        |      |      |             |         |                 | LPH1       | LPH2 | LPH1               | LPH2 | LPH1               | LPH2 | LPH1               | LPH2 | LPH1                       | LPH2 | LPH1                       | LPH2 |      |      |
| 10  | 2   | 1      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 2      | 1440 | 1440 | 1440        | 1440    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 3      | 1380 | 1380 | 1380        | 1380    |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 | 0.00 | 0.00 |
|     |     | 4      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 5      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
| 10  | 4   | 1      | 936  | 936  | 936         | 936     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 2      | 900  | 906  | 894         | 900     | 0.68            | 0.67       | 1.34 | 0.00               | 0.67 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 3      | 838  | 838  | 838         | 838     |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.13               | 0.27 | 0.67               | 1.34 | 0.00                       | 0.13 | 0.00                       | 0.67 |      |      |
|     |     | 4      | 956  | 956  | 956         | 956     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 5      | 966  | 966  | 966         | 966     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
| 10  | 6   | 1      | 898  | 898  | 898         | 898     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 2      | 920  | 920  | 912         | 920     | 0.25            | 0.88       | 0.88 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 3      | 812  | 812  | 804         | 812     | 0.25            | 1.00       | 1.00 | 0.00               | 0.00 | 0.37               | 0.37 | 1.00               | 1.00 | 0.00                       | 0.00 | 0.00                       | 0.00 |      |      |
|     |     | 4      | 938  | 938  | 938         | 938     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 5      | 988  | 988  | 988         | 988     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
| 10  | 8   | 1      | 1044 | 1044 | 1044        | 1044    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 2      | 1096 | 1096 | 1096        | 1096    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 3      | 992  | 992  | 992         | 992     |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 | 0.00 | 0.00 |
|     |     | 4      | 1064 | 1064 | 1064        | 1064    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |
|     |     | 5      | 1134 | 1134 | 1134        | 1134    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |      |      |

**Table C.4 :** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|
|     |     |           |      |      |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |
| 25  | 2   | 1         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 8112 | 8112 | 8112           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 7774 | 7774 | 7774           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |
|     |     | 4         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 25  | 4   | 1         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 4443 | 4443 | 4443           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 4186 | 4186 | 4186           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |
|     |     | 4         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 25  | 6   | 1         | 3606 | 3606 | 3580           |         |                       | 0.73       | 0.73 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 3647 | 3633 | 3595           |         |                       | 1.45       | 1.06 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 3266 | 3266 | 3240           |         |                       | 0.80       | 0.80 |                       |      | 0.74                  | 0.66 | 1.45                  | 1.06 |                                  |      |                                  |      |  |  |
|     |     | 4         | 3706 | 3706 | 3680           |         |                       | 0.71       | 0.71 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 3705 | 3705 | 3705           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 25  | 8   | 1         | 3281 | 3263 | 3229           |         |                       | 1.61       | 1.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 3502 | 3502 | 3396           |         |                       | 3.12       | 3.12 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 3116 | 3026 | 2992           |         |                       | 4.14       | 1.14 |                       |      | 2.03                  | 1.26 | 4.14                  | 3.12 |                                  |      |                                  |      |  |  |
|     |     | 4         | 3413 | 3413 | 3379           |         |                       | 1.01       | 1.01 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 3488 | 3479 | 3479           |         |                       | 0.26       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |

**Table C.4 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 4   | 1         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 10560 | 10560 | 10560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 10120 | 10120 | 10120          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 6   | 1         | 8280  | 8280  | 8248           |         |                       | 0.39       | 0.39 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 7908  | 7908  | 7832           |         |                       | 0.97       | 0.97 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7520  | 7520  | 7444           |         |                       | 1.02       | 1.02 |                       |      | 0.55                  | 0.55 | 1.02                  | 1.02 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 8520  | 8520  | 8488           |         |                       | 0.38       | 0.38 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 8408  | 8408  | 8408           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 8   | 1         | 7056  | 7056  | 6960           |         |                       | 1.38       | 1.38 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 6952  | 6896  | 6800           |         |                       | 2.24       | 1.41 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 6568  | 6496  | 6400           |         |                       | 2.63       | 1.50 |                       |      | 1.51                  | 1.12 | 2.63                  | 1.50 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 7376  | 7376  | 7280           |         |                       | 1.32       | 1.32 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 7200  | 7200  | 7200           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table C.4 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |  |
| 55  | 2   | 1         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 37632 | 37632 | 37632          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 36064 | 36064 | 36064          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 4   | 1         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 19488 | 19488 | 19488          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 18676 | 18676 | 18676          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 6   | 1         | 14954 | 14954 | 14890          |         |                       | 0.43       | 0.43 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 14196 | 14157 | 14045          |         |                       | 1.08       | 0.80 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 13408 | 13408 | 13320          |         |                       | 0.66       | 0.66 |                       |      | 0.52                  | 0.46 | 1.08                  | 0.80 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 15174 | 15174 | 15110          |         |                       | 0.42       | 0.42 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 14945 | 14945 | 14945          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 8   | 1         | 12475 | 12444 | 12274          |         |                       | 1.64       | 1.39 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 11977 | 11977 | 11791          |         |                       | 1.58       | 1.58 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 11268 | 11268 | 11082          |         |                       | 1.68       | 1.68 |                       |      | 1.22                  | 1.18 | 1.68                  | 1.68 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 12758 | 12760 | 12604          |         |                       | 1.22       | 1.24 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 12329 | 12329 | 12329          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table C.4 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$       | $K$      | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | LB Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      |
|-----------|----------|-----------|------|------|----------------|------------|------|-----------------------|------|-----------------------|------|
|           |          |           |      |      |                | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 |
| <b>10</b> | <b>2</b> | 1         | 2400 | 2400 | 2400           | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|           |          | 2         | 1860 | 1860 | 1860           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 3         | 1680 | 1680 | 1680           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 4         | 2220 | 2220 | 2220           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 5         | 2340 | 2340 | 2340           | 0.00       | 0.00 |                       |      |                       |      |
| <b>10</b> | <b>4</b> | 1         | 1440 | 1440 | 1440           | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|           |          | 2         | 1116 | 1116 | 1116           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 3         | 1008 | 1008 | 1008           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 4         | 1332 | 1332 | 1332           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 5         | 1404 | 1404 | 1404           | 0.00       | 0.00 |                       |      |                       |      |
| <b>10</b> | <b>6</b> | 1         | 1150 | 1150 | 1150           | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|           |          | 2         | 1038 | 1038 | 1038           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 3         | 902  | 902  | 894            | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 4         | 1136 | 1136 | 1136           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 5         | 1222 | 1222 | 1222           | 0.00       | 0.00 |                       |      |                       |      |
| <b>10</b> | <b>8</b> | 1         | 1240 | 1240 | 1240           | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|           |          | 2         | 1194 | 1194 | 1194           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 3         | 1062 | 1062 | 1062           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 4         | 1218 | 1218 | 1218           | 0.00       | 0.00 |                       |      |                       |      |
|           |          | 5         | 1316 | 1316 | 1316           | 0.00       | 0.00 |                       |      |                       |      |

**Table C.5 :** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | LB Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      |
|-----|-----|-----------|-------|-------|----------------|------------|------|-----------------------|------|-----------------------|------|
|     |     |           |       |       |                | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 |
| 25  | 2   | 1         | 13520 | 13520 | 13520          | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 10478 | 10478 | 10478          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 9464  | 9464  | 9464           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 12506 | 12506 | 12506          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 13182 | 13182 | 13182          | 0.00       | 0.00 |                       |      |                       |      |
| 25  | 4   | 1         | 7280  | 7280  | 7280           | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 5642  | 5642  | 5642           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 5096  | 5096  | 5096           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 6734  | 6734  | 6734           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 7098  | 7098  | 7098           | 0.00       | 0.00 |                       |      |                       |      |
| 25  | 6   | 1         | 5200  | 5200  | 5200           | 0.00       | 0.00 | 0.06                  | 0.06 | 0.30                  | 0.30 |
|     |     | 2         | 4408  | 4408  | 4330           | 0.30       | 0.30 |                       |      |                       |      |
|     |     | 3         | 3821  | 3821  | 3765           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 4835  | 4835  | 4835           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 5070  | 5070  | 5070           | 0.00       | 0.00 |                       |      |                       |      |
| 25  | 8   | 1         | 4371  | 4371  | 4335           | 0.85       | 0.85 | 0.67                  | 0.67 | 0.90                  | 0.90 |
|     |     | 2         | 4051  | 4051  | 3949           | 0.81       | 0.81 |                       |      |                       |      |
|     |     | 3         | 3523  | 3523  | 3387           | 0.90       | 0.90 |                       |      |                       |      |
|     |     | 4         | 4337  | 4384  | 4248           | 0.82       | 0.82 |                       |      |                       |      |
|     |     | 5         | 4506  | 4506  | 4506           | 0.00       | 0.00 |                       |      |                       |      |

**Table C.5 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | LB Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      |
|-----|-----|-----------|-------|-------|----------------|------------|------|-----------------------|------|-----------------------|------|
|     |     |           |       |       |                | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 |
| 40  | 2   | 1         | 33600 | 33600 | 33600          | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 26040 | 26040 | 26040          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 23520 | 23520 | 23520          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 31080 | 31080 | 31080          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 32760 | 32760 | 32760          | 0.00       | 0.00 |                       |      |                       |      |
| 40  | 4   | 1         | 17600 | 17600 | 17600          | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 13640 | 13640 | 13640          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 12320 | 12320 | 12320          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 16280 | 16280 | 16280          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 17160 | 17160 | 17160          | 0.00       | 0.00 |                       |      |                       |      |
| 40  | 6   | 1         | 12320 | 12320 | 12320          | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 9768  | 9768  | 9708           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 8912  | 8912  | 8784           | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 11436 | 11436 | 11436          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 12012 | 12012 | 12012          | 0.00       | 0.00 |                       |      |                       |      |
| 40  | 8   | 1         | 9792  | 9792  | 9760           | 0.36       | 0.36 | 0.44                  | 0.36 | 0.76                  | 0.57 |
|     |     | 2         | 8488  | 8440  | 8200           | 0.73       | 0.55 |                       |      |                       |      |
|     |     | 3         | 7816  | 7784  | 7400           | 0.76       | 0.57 |                       |      |                       |      |
|     |     | 4         | 9608  | 9608  | 9480           | 0.34       | 0.34 |                       |      |                       |      |
|     |     | 5         | 9800  | 9800  | 9800           | 0.00       | 0.00 |                       |      |                       |      |

**Table C.5 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | LB Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      |
|-----|-----|-----------|-------|-------|----------------|------------|------|-----------------------|------|-----------------------|------|
|     |     |           |       |       |                | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 |
| 55  | 2   | 1         | 62720 | 62720 | 62720          | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 48608 | 48608 | 48608          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 43904 | 43904 | 43904          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 58016 | 58016 | 58016          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 61152 | 61152 | 61152          | 0.00       | 0.00 |                       |      |                       |      |
| 55  | 4   | 1         | 32480 | 32480 | 32480          | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 25172 | 25172 | 25172          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 22736 | 22736 | 22736          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 30044 | 30044 | 30044          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 31668 | 31668 | 31668          | 0.00       | 0.00 |                       |      |                       |      |
| 55  | 6   | 1         | 22400 | 22400 | 22400          | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 |
|     |     | 2         | 17658 | 17658 | 17580          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 3         | 15949 | 15949 | 15845          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 4         | 20720 | 20720 | 20720          | 0.00       | 0.00 |                       |      |                       |      |
|     |     | 5         | 21840 | 21840 | 21840          | 0.00       | 0.00 |                       |      |                       |      |
| 55  | 8   | 1         | 17640 | 17640 | 17580          | 0.29       | 0.29 | 0.31                  | 0.27 | 0.59                  | 0.49 |
|     |     | 2         | 15001 | 14864 | 14444          | 0.59       | 0.49 |                       |      |                       |      |
|     |     | 3         | 13657 | 13409 | 12977          | 0.40       | 0.31 |                       |      |                       |      |
|     |     | 4         | 16985 | 16957 | 16773          | 0.28       | 0.28 |                       |      |                       |      |
|     |     | 5         | 17256 | 17256 | 17256          | 0.00       | 0.00 |                       |      |                       |      |

**Table C.5 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$



| $n$       | $K$      | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|
|           |          |           |      |      |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |
| <b>10</b> | <b>2</b> | 1         | 2400 | 2400 | 2400           | 2400    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1860 | 1860 | 1860           | 1860    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1680 | 1680 | 1680           | 1680    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 2220 | 2220 | 2220           | 2220    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 2340 | 2340 | 2340           | 2340    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>4</b> | 1         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1116 | 1116 | 1116           | 1116    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1008 | 1008 | 1008           | 1008    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1332 | 1332 | 1332           | 1332    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1404 | 1404 | 1404           | 1404    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>6</b> | 1         | 1150 | 1150 | 1150           | 1150    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1038 | 1038 | 1038           | 1038    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.18                  | 0.18 | 0.89                  | 0.89 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 902  | 902  | 894            | 902     | 0.10                  | 0.89       | 0.89 | 0.00                  | 0.00 | 0.18                  | 0.18 | 0.89                  | 0.89 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1136 | 1136 | 1136           | 1136    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1222 | 1222 | 1222           | 1222    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>8</b> | 1         | 1240 | 1240 | 1240           | 1240    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1194 | 1194 | 1194           | 1194    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1062 | 1062 | 1062           | 1062    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1218 | 1218 | 1218           | 1218    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1316 | 1316 | 1316           | 1316    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |

**Table C.6 :** Computational results for *Last Trip Partial Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |
| 25  | 2   | 1         | 13520 | 13520 | 13520          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 10478 | 10478 | 10478          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 9464  | 9464  | 9464           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 12506 | 12506 | 12506          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 13182 | 13182 | 13182          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 4   | 1         | 7280  | 7280  | 7280           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 5642  | 5642  | 5642           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 5096  | 5096  | 5096           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 6734  | 6734  | 6734           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 7098  | 7098  | 7098           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 6   | 1         | 5200  | 5200  | 5200           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 4408  | 4408  | 4330           |         |                       | 1.80       | 1.80 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 3821  | 3821  | 3765           |         |                       | 1.49       | 1.49 |                       |      | 0.66                  | 0.66 | 1.80                  | 1.80 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 4835  | 4835  | 4835           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 5070  | 5070  | 5070           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 8   | 1         | 4371  | 4371  | 4335           |         |                       | 0.83       | 0.83 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 4051  | 4051  | 3949           |         |                       | 2.58       | 2.58 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 3523  | 3523  | 3387           |         |                       | 4.02       | 4.02 |                       |      | 1.90                  | 2.13 | 4.02                  | 4.02 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 4337  | 4384  | 4248           |         |                       | 2.10       | 3.20 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 4506  | 4506  | 4506           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table C.6 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5, 15]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |  |
| 40  | 2   | 1         | 33600 | 33600 | 33600          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 26040 | 26040 | 26040          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 23520 | 23520 | 23520          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 31080 | 31080 | 31080          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 32760 | 32760 | 32760          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 40  | 4   | 1         | 17600 | 17600 | 17600          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 13640 | 13640 | 13640          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 16280 | 16280 | 16280          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 17160 | 17160 | 17160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 40  | 6   | 1         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 9768  | 9768  | 9708           |         |                       | 0.62       | 0.62 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 8912  | 8912  | 8784           |         |                       | 1.46       | 1.46 |                       |      | 0.42                  | 0.42 | 1.46                  | 1.46 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 11436 | 11436 | 11436          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 12012 | 12012 | 12012          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 40  | 8   | 1         | 9792  | 9792  | 9760           |         |                       | 0.33       | 0.33 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 8488  | 8440  | 8200           |         |                       | 3.51       | 2.93 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 7816  | 7784  | 7400           |         |                       | 5.62       | 5.19 |                       |      | 2.16                  | 1.96 | 5.62                  | 5.19 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 9608  | 9608  | 9480           |         |                       | 1.35       | 1.35 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 9800  | 9800  | 9800           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table C.6 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5, 15]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |  |
| 55  | 2   | 1         | 62720 | 62720 | 62720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 48608 | 48608 | 48608          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 43904 | 43904 | 43904          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 58016 | 58016 | 58016          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 61152 | 61152 | 61152          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 4   | 1         | 32480 | 32480 | 32480          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 25172 | 25172 | 25172          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 22736 | 22736 | 22736          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 30044 | 30044 | 30044          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 31668 | 31668 | 31668          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 6   | 1         | 22400 | 22400 | 22400          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 17658 | 17658 | 17580          |         |                       | 0.44       | 0.44 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 15949 | 15949 | 15845          |         |                       | 0.66       | 0.66 |                       |      | 0.22                  | 0.22 | 0.66                  | 0.66 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 20720 | 20720 | 20720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 8   | 1         | 17640 | 17640 | 17580          |         |                       | 0.34       | 0.34 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 15001 | 14864 | 14444          |         |                       | 3.86       | 2.91 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 13657 | 13409 | 12977          |         |                       | 5.24       | 3.33 |                       |      | 2.14                  | 1.54 | 5.24                  | 3.33 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 16985 | 16957 | 16773          |         |                       | 1.26       | 1.10 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 17256 | 17256 | 17256          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table C.6 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [5, 15]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | LPH1 | LPH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | LPH1       | LPH2 | LPH1               | LPH2 | LPH1               | LPH2 | LPH1               | LPH2 | LPH1                       | LPH2 | LPH1                       | LPH2 |
| 10  | 2   | 1      | 1838 | 1826 | 1810        | 1820    | 4.24            | 1.55       | 0.88 | 0.99               | 0.33 | 0.96               | 0.73 | 1.55               | 0.96 | 0.40                       | 0.18 | 0.99                       | 0.33 |
|     |     | 2      | 1730 | 1726 | 1710        | 1724    | 2.35            | 1.17       | 0.94 | 0.35               | 0.12 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 1680 | 1676 | 1660        | 1674    | 2.66            | 1.20       | 0.96 | 0.36               | 0.12 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 1846 | 1846 | 1830        | 1840    | 3.73            | 0.87       | 0.87 | 0.33               | 0.33 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 1810 | 1810 | 1810        | 1810    | 13.43           | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 4   | 1      | 1738 | 1738 | 1726        | 1736    | 4.05            | 0.70       | 0.70 | 0.12               | 0.12 | 0.56               | 0.56 | 0.73               | 0.73 | 0.09                       | 0.09 | 0.12                       | 0.12 |
|     |     | 2      | 1706 | 1706 | 1694        | 1704    | 2.38            | 0.71       | 0.71 | 0.12               | 0.12 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 1650 | 1650 | 1638        | 1648    | 4.75            | 0.73       | 0.73 | 0.12               | 0.12 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 1768 | 1768 | 1756        | 1766    | 3.42            | 0.68       | 0.68 | 0.11               | 0.11 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 1766 | 1766 | 1766        | 1766    | 1.79            | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 6   | 1      | 2106 | 2106 | 2098        | 2106    | 0.57            | 0.38       | 0.38 | 0.00               | 0.00 | 0.31               | 0.31 | 0.40               | 0.40 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 2120 | 2120 | 2112        | 2120    | 0.71            | 0.38       | 0.38 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 2012 | 2012 | 2004        | 2012    | 0.63            | 0.40       | 0.40 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 2146 | 2146 | 2138        | 2146    | 0.69            | 0.37       | 0.37 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 2188 | 2188 | 2188        | 2188    | 0.61            | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 8   | 1      | 2648 | 2648 | 2644        | 2648    | 0.14            | 0.15       | 0.15 | 0.00               | 0.00 | 0.12               | 0.12 | 0.15               | 0.15 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 2700 | 2700 | 2696        | 2700    | 0.17            | 0.15       | 0.15 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 2596 | 2596 | 2592        | 2596    | 0.20            | 0.15       | 0.15 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 2668 | 2668 | 2664        | 2668    | 0.16            | 0.15       | 0.15 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 2734 | 2734 | 2734        | 2734    | 0.16            | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |

**Table C.7 :** Computational results for *Last Trip Partial Problem* where  $p_j \in [25,35]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|
|     |     |           |      |      |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |
| 25  | 2   | 1         | 9451 | 9444 | 9388           |         |                       | 0.67       | 0.60 |                       |      | 0.71                  | 0.69 | 1.01                  | 1.12 |                                  |      |                                  |      |
|     |     | 2         | 8876 | 8885 | 8787           |         |                       | 1.01       | 1.12 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 8527 | 8543 | 8449           |         |                       | 0.92       | 1.11 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 9528 | 9498 | 9438           |         |                       | 0.95       | 0.64 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 9413 | 9413 | 9413           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 25  | 4   | 1         | 6726 | 6718 | 6632           |         |                       | 1.42       | 1.30 |                       |      | 2.31                  | 2.00 | 4.56                  | 3.75 |                                  |      |                                  |      |
|     |     | 2         | 6679 | 6639 | 6443           |         |                       | 3.66       | 3.04 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 6416 | 6366 | 6136           |         |                       | 4.56       | 3.75 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 6776 | 6776 | 6682           |         |                       | 1.41       | 1.41 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 6716 | 6716 | 6682           |         |                       | 0.51       | 0.51 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 25  | 6   | 1         | 6952 | 6693 | 6657           |         |                       | 4.43       | 0.54 |                       |      | 4.16                  | 0.72 | 5.76                  | 1.31 |                                  |      |                                  |      |
|     |     | 2         | 7115 | 6905 | 6833           |         |                       | 4.13       | 1.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 6807 | 6520 | 6436           |         |                       | 5.76       | 1.31 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 7031 | 6807 | 6771           |         |                       | 3.84       | 0.53 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 7032 | 6864 | 6852           |         |                       | 2.63       | 0.18 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 25  | 8   | 1         | 7281 | 7281 | 7229           |         |                       | 0.72       | 0.72 |                       |      | 0.97                  | 0.97 | 1.77                  | 1.77 |                                  |      |                                  |      |
|     |     | 2         | 7502 | 7502 | 7396           |         |                       | 1.43       | 1.43 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 7116 | 7116 | 6992           |         |                       | 1.77       | 1.77 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 7431 | 7431 | 7379           |         |                       | 0.70       | 0.70 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 7497 | 7497 | 7479           |         |                       | 0.24       | 0.24 |                       |      |                       |      |                       |      |                                  |      |                                  |      |

**Table C.7 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |
| 40  | 2   | 1         | 22922 | 22916 | 22800          |         |                       | 0.54       | 0.51 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 21404 | 21404 | 21200          |         |                       | 0.96       | 0.96 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 20588 | 20632 | 20400          |         |                       | 0.92       | 1.14 |                       |      | 0.75                  | 0.65 | 1.31                  | 1.14 |                                  |      |                                  |      |  |  |
|     |     | 4         | 23180 | 23028 | 22880          |         |                       | 1.31       | 0.65 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 22800 | 22800 | 22800          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 40  | 4   | 1         | 14664 | 14616 | 14400          |         |                       | 1.83       | 1.50 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 14192 | 14192 | 13680          |         |                       | 3.74       | 3.74 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 13800 | 13800 | 13200          |         |                       | 4.55       | 4.55 |                       |      | 2.48                  | 2.38 | 4.55                  | 4.55 |                                  |      |                                  |      |  |  |
|     |     | 4         | 14800 | 14792 | 14560          |         |                       | 1.65       | 1.59 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 14568 | 14552 | 14480          |         |                       | 0.61       | 0.50 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 40  | 6   | 1         | 13686 | 13368 | 13114          |         |                       | 4.36       | 1.94 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 13696 | 13386 | 13138          |         |                       | 4.25       | 1.89 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 13362 | 13154 | 12794          |         |                       | 4.44       | 2.81 |                       |      | 3.90                  | 1.52 | 4.44                  | 2.81 |                                  |      |                                  |      |  |  |
|     |     | 4         | 13904 | 13552 | 13464          |         |                       | 3.27       | 0.65 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 13922 | 13538 | 13494          |         |                       | 3.17       | 0.33 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 40  | 8   | 1         | 15072 | 14616 | 14384          |         |                       | 4.78       | 1.61 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 15328 | 14840 | 14496          |         |                       | 5.74       | 2.37 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 14960 | 14528 | 14208          |         |                       | 5.29       | 2.25 |                       |      | 4.55                  | 1.67 | 5.74                  | 2.37 |                                  |      |                                  |      |  |  |
|     |     | 4         | 15312 | 14912 | 14736          |         |                       | 3.91       | 1.19 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 15280 | 14968 | 14832          |         |                       | 3.02       | 0.92 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |

**Table C.7 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |
| 55  | 2   | 1         | 42268 | 42320 | 42088          |         |                       | 0.43       | 0.55 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 39366 | 39438 | 39062          |         |                       | 0.78       | 0.96 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 37900 | 37953 | 37549          |         |                       | 0.93       | 1.08 |                       |      | 0.64                  | 0.64 | 1.08                  | 1.08 |                                  |      |                                  |      |  |  |
|     |     | 4         | 42652 | 42454 | 42198          |         |                       | 1.08       | 0.61 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 42088 | 42088 | 42088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 55  | 4   | 1         | 25614 | 25592 | 25182          |         |                       | 1.72       | 1.63 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 24726 | 24678 | 23778          |         |                       | 3.99       | 3.79 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 24349 | 24023 | 22911          |         |                       | 6.28       | 4.85 |                       |      | 2.91                  | 2.48 | 6.28                  | 4.85 |                                  |      |                                  |      |  |  |
|     |     | 4         | 25928 | 25828 | 25402          |         |                       | 2.07       | 1.68 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 25369 | 25353 | 25237          |         |                       | 0.52       | 0.46 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 55  | 6   | 1         | 23065 | 22384 | 21774          |         |                       | 5.93       | 2.80 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 22971 | 22360 | 21878          |         |                       | 5.00       | 2.20 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 22506 | 21758 | 21080          |         |                       | 6.76       | 3.22 |                       |      | 5.41                  | 2.39 | 6.76                  | 3.22 |                                  |      |                                  |      |  |  |
|     |     | 4         | 23042 | 22472 | 22141          |         |                       | 4.07       | 1.49 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 23120 | 22445 | 21959          |         |                       | 5.29       | 2.21 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 55  | 8   | 1         | 24614 | 23749 | 23287          |         |                       | 5.70       | 1.98 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 24590 | 23884 | 23425          |         |                       | 4.97       | 1.96 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 23893 | 23251 | 22603          |         |                       | 5.71       | 2.87 |                       |      | 5.23                  | 1.93 | 5.71                  | 2.87 |                                  |      |                                  |      |  |  |
|     |     | 4         | 24844 | 23980 | 23651          |         |                       | 5.04       | 1.39 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 24560 | 23798 | 23456          |         |                       | 4.71       | 1.46 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |

**Table C.7 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$



| $n$ | $K$ | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|------|
|     |     |           |      |      |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |      |
| 10  | 2   | 1         | 2310 | 2310 | 2310           | 2310    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 2         | 2210 | 2210 | 2210           | 2210    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 3         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 | 0.00 |
|     |     | 4         | 2330 | 2330 | 2330           | 2330    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 5         | 2310 | 2310 | 2310           | 2310    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
| 10  | 4   | 1         | 1998 | 1998 | 1986           | 1996    | 2.48                  | 0.60       | 0.60 | 0.10                  | 0.10 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 2         | 1966 | 1966 | 1954           | 1964    | 6.03                  | 0.61       | 0.61 | 0.10                  | 0.10 | 0.49                  | 0.49 | 0.63                  | 0.63 | 0.08                             | 0.08 | 0.10                             | 0.10 |      |
|     |     | 3         | 1910 | 1910 | 1898           | 1908    | 6.45                  | 0.63       | 0.63 | 0.10                  | 0.10 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 4         | 2028 | 2028 | 2016           | 2026    | 6.87                  | 0.60       | 0.60 | 0.10                  | 0.10 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 5         | 2026 | 2026 | 2026           | 2026    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
| 10  | 6   | 1         | 2286 | 2286 | 2278           | 2286    | 0.34                  | 0.35       | 0.35 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 2         | 2300 | 2300 | 2292           | 2300    | 0.64                  | 0.35       | 0.35 | 0.00                  | 0.00 | 0.28                  | 0.28 | 0.37                  | 0.37 | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|     |     | 3         | 2192 | 2192 | 2184           | 2192    | 0.62                  | 0.37       | 0.37 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 4         | 2326 | 2326 | 2318           | 2326    | 0.58                  | 0.35       | 0.35 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 5         | 2368 | 2368 | 2368           | 2368    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
| 10  | 8   | 1         | 2784 | 2784 | 2784           | 2784    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 2         | 2840 | 2840 | 2836           | 2840    | 0.19                  | 0.14       | 0.14 | 0.00                  | 0.00 | 0.06                  | 0.06 | 0.15                  | 0.15 | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|     |     | 3         | 2736 | 2736 | 2732           | 2736    | 0.16                  | 0.15       | 0.15 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 4         | 2804 | 2804 | 2804           | 2804    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 5         | 2874 | 2874 | 2874           | 2874    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |

**Table C.8 :** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |
| 25  | 2   | 1         | 12518 | 12518 | 12518          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 11917 | 11917 | 11917          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 11579 | 11579 | 11579          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 12568 | 12568 | 12568          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 12543 | 12543 | 12543          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 4   | 1         | 8280  | 8270  | 8202           |         |                       | 0.95       | 0.83 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 8091  | 8091  | 8013           |         |                       | 0.97       | 0.97 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7784  | 7784  | 7706           |         |                       | 1.01       | 1.01 |                       |      | 0.78                  | 0.73 | 1.01                  | 1.01 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 8330  | 8320  | 8252           |         |                       | 0.95       | 0.82 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 8252  | 8252  | 8252           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 6   | 1         | 7694  | 7694  | 7630           |         |                       | 0.84       | 0.84 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 7787  | 7787  | 7645           |         |                       | 1.86       | 1.86 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7458  | 7458  | 7290           |         |                       | 2.30       | 2.30 |                       |      | 1.23                  | 1.23 | 2.30                  | 2.30 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 7794  | 7794  | 7730           |         |                       | 0.83       | 0.83 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 7781  | 7781  | 7755           |         |                       | 0.34       | 0.34 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 8   | 1         | 8071  | 8071  | 8019           |         |                       | 0.65       | 0.65 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 8292  | 8292  | 8186           |         |                       | 1.29       | 1.29 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7906  | 7906  | 7782           |         |                       | 1.59       | 1.59 |                       |      | 0.88                  | 0.88 | 1.59                  | 1.59 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 8221  | 8221  | 8169           |         |                       | 0.64       | 0.64 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 8287  | 8287  | 8269           |         |                       | 0.22       | 0.22 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table C.8 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |
| 40  | 2   | 1         | 30800 | 30800 | 30800          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 29200 | 29200 | 29200          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 28400 | 28400 | 28400          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 30880 | 30880 | 30880          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 30800 | 30800 | 30800          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 4   | 1         | 18624 | 18584 | 18400          |         |                       | 1.22       | 1.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 17880 | 17872 | 17680          |         |                       | 1.13       | 1.09 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 17400 | 17392 | 17200          |         |                       | 1.16       | 1.12 |                       |      | 0.89                  | 0.84 | 1.22                  | 1.12 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 18736 | 18744 | 18560          |         |                       | 0.95       | 0.99 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 18480 | 18480 | 18480          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 6   | 1         | 15904 | 15892 | 15728          |         |                       | 1.12       | 1.04 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 15716 | 15716 | 15312          |         |                       | 2.64       | 2.64 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 15404 | 15404 | 14924          |         |                       | 3.22       | 3.22 |                       |      | 1.71                  | 1.66 | 3.22                  | 3.22 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 16144 | 16132 | 15968          |         |                       | 1.10       | 1.03 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 15964 | 15944 | 15888          |         |                       | 0.48       | 0.35 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 8   | 1         | 16112 | 15496 | 15424          |         |                       | 4.46       | 0.47 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 16368 | 15752 | 15536          |         |                       | 5.36       | 1.39 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 16000 | 15464 | 15248          |         |                       | 4.93       | 1.42 |                       |      | 4.24                  | 0.78 | 5.36                  | 1.42 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 16352 | 15840 | 15776          |         |                       | 3.65       | 0.41 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 16320 | 15904 | 15872          |         |                       | 2.82       | 0.20 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table C.8 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |
| 55  | 2   | 1         | 57218 | 57218 | 57218          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 54192 | 54192 | 54192          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 52679 | 52679 | 52679          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 57328 | 57328 | 57328          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 57218 | 57218 | 57218          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 55  | 4   | 1         | 33068 | 33086 | 32752          |         |                       | 0.96       | 1.02 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 31688 | 31712 | 31348          |         |                       | 1.08       | 1.16 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 30821 | 30845 | 30481          |         |                       | 1.12       | 1.19 |                       |      | 0.85                  | 0.88 | 1.12                  | 1.19 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 33323 | 33306 | 32972          |         |                       | 1.06       | 1.01 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 32807 | 32807 | 32807          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 55  | 6   | 1         | 26875 | 26850 | 26540          |         |                       | 1.26       | 1.17 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 26481 | 26425 | 25695          |         |                       | 3.06       | 2.84 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 25978 | 25836 | 24970          |         |                       | 4.04       | 3.47 |                       |      | 2.01                  | 1.81 | 4.04                  | 3.47 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 27070 | 27070 | 26760          |         |                       | 1.16       | 1.16 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 26738 | 26707 | 26595          |         |                       | 0.54       | 0.42 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 55  | 8   | 1         | 26124 | 25181 | 24895          |         |                       | 4.94       | 1.15 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 26100 | 25280 | 24970          |         |                       | 4.53       | 1.24 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 25403 | 24759 | 24113          |         |                       | 5.35       | 2.68 |                       |      | 4.63                  | 1.20 | 5.35                  | 2.68 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 26354 | 25442 | 25287          |         |                       | 4.22       | 0.61 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 26070 | 25128 | 25043          |         |                       | 4.10       | 0.34 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table C.8 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|------|
|     |     |           |      |      |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |      |
| 10  | 2   | 1         | 2510 | 2510 | 2510           | 2510    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 2         | 2072 | 2072 | 2060           | 2072    | 5.77                  | 0.58       | 0.58 | 0.00                  | 0.00 | 0.62                  | 0.45 | 2.51                  | 1.68 | 0.16                             | 0.00 | 0.82                             | 0.00 |      |
|     |     | 3         | 1958 | 1942 | 1910           | 1942    | 4.06                  | 2.51       | 1.68 | 0.82                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 4         | 2380 | 2380 | 2380           | 2380    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 5         | 2460 | 2460 | 2460           | 2460    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
| 10  | 4   | 1         | 2114 | 2114 | 2090           | 2110    | 5.59                  | 1.15       | 1.15 | 0.19                  | 0.19 |                       |      |                       |      |                                  |      |                                  |      | 1.63 |
| 2   |     | 1912      | 1912 | 1876 | 1906           | 3.14    | 1.92                  | 1.92       | 0.31 | 0.31                  |      |                       |      |                       |      |                                  |      |                                  |      |      |
| 3   |     | 1816      | 1816 | 1768 | 1808           | 1.53    | 2.71                  | 2.71       | 0.44 | 0.44                  |      |                       |      |                       |      |                                  |      |                                  |      |      |
| 4   |     | 2090      | 2090 | 2042 | 2082           | 2.93    | 2.35                  | 2.35       | 0.38 | 0.38                  |      |                       |      |                       |      |                                  |      |                                  |      |      |
| 5   |     | 2104      | 2104 | 2104 | 2104           |         | 0.00                  | 0.00       | 0.00 | 0.00                  |      |                       |      |                       |      |                                  |      |                                  |      |      |
| 10  | 6   | 1         | 2366 | 2366 | 2350           | 2366    | 0.73                  | 0.68       | 0.68 | 0.00                  | 0.00 | 0.93                  | 0.93 | 1.53                  | 1.53 | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|     |     | 2         | 2262 | 2262 | 2238           | 2262    | 0.63                  | 1.07       | 1.07 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 3         | 2126 | 2126 | 2094           | 2126    | 0.75                  | 1.53       | 1.53 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 4         | 2368 | 2368 | 2336           | 2368    | 0.69                  | 1.37       | 1.37 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 5         | 2422 | 2422 | 2422           | 2422    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
| 10  | 8   | 1         | 2840 | 2840 | 2840           | 2840    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.21                  | 0.21 | 0.60                  | 0.60 | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|     |     | 2         | 2806 | 2806 | 2794           | 2806    | 0.19                  | 0.43       | 0.43 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 3         | 2678 | 2678 | 2662           | 2678    | 0.17                  | 0.60       | 0.60 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 4         | 2818 | 2818 | 2818           | 2818    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |
|     |     | 5         | 2916 | 2916 | 2916           | 2916    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |      |

**Table C.9 :** Computational results for *Last Trip Partial Problem* where  $p_j \in [25,35]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |
| 25  | 2   | 1         | 13770 | 13770 | 13770          |         |                       | 0.00       | 0.00 |                       |      | 0.22                  | 0.20 | 0.65                  | 0.72 |                                  |      |                                  |      |
|     |     | 2         | 11026 | 11008 | 10978          |         |                       | 0.44       | 0.27 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 10079 | 10086 | 10014          |         |                       | 0.65       | 0.72 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 12881 | 12881 | 12881          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 13482 | 13482 | 13482          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 25  | 4   | 1         | 8950  | 8950  | 8830           |         |                       | 1.36       | 1.36 |                       |      | 2.57                  | 2.44 | 4.77                  | 4.51 |                                  |      |                                  |      |
|     |     | 2         | 7776  | 7776  | 7542           |         |                       | 3.10       | 3.10 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 7251  | 7233  | 6921           |         |                       | 4.77       | 4.51 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 8714  | 8681  | 8409           |         |                       | 3.63       | 3.23 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 8723  | 8723  | 8723           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 25  | 6   | 1         | 8204  | 8204  | 8050           |         |                       | 1.91       | 1.91 |                       |      | 4.64                  | 4.64 | 9.55                  | 9.55 |                                  |      |                                  |      |
|     |     | 2         | 7834  | 7834  | 7330           |         |                       | 6.88       | 6.88 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 7411  | 7411  | 6765           |         |                       | 9.55       | 9.55 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 8091  | 8091  | 7835           |         |                       | 3.27       | 3.27 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 8200  | 8200  | 8070           |         |                       | 1.61       | 1.61 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 25  | 8   | 1         | 8457  | 8457  | 8335           |         |                       | 1.46       | 1.46 |                       |      | 3.24                  | 3.24 | 6.47                  | 6.47 |                                  |      |                                  |      |
|     |     | 2         | 8321  | 8321  | 7949           |         |                       | 4.68       | 4.68 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 7865  | 7865  | 7387           |         |                       | 6.47       | 6.47 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 8456  | 8456  | 8248           |         |                       | 2.52       | 2.52 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 8596  | 8596  | 8506           |         |                       | 1.06       | 1.06 |                       |      |                       |      |                       |      |                                  |      |                                  |      |

**Table C.9 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2  | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2  | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |
| 40  | 2   | 1         | 34000 | 34000 | 34000          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 26800 | 26800 | 26800          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 24684 | 24592 | 24400          |         |                       | 1.16       | 0.79  |                       |      | 0.23                  | 0.16 | 1.16                  | 0.79  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 31680 | 31680 | 31680          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 33200 | 33200 | 33200          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 40  | 4   | 1         | 20304 | 20288 | 20000          |         |                       | 1.52       | 1.44  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 17080 | 17080 | 16480          |         |                       | 3.64       | 3.64  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 16128 | 16000 | 15200          |         |                       | 6.11       | 5.26  |                       |      | 3.03                  | 2.78 | 6.11                  | 5.26  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 19696 | 19632 | 18960          |         |                       | 3.88       | 3.54  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 19680 | 19680 | 19680          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 40  | 6   | 1         | 17184 | 17120 | 16800          |         |                       | 2.29       | 1.90  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 15948 | 15948 | 14508          |         |                       | 9.93       | 9.93  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 15428 | 15428 | 13584          |         |                       | 13.57      | 13.57 |                       |      | 6.30                  | 6.19 | 13.57                 | 13.57 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 16892 | 16860 | 16236          |         |                       | 4.04       | 3.84  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 16972 | 16972 | 16692          |         |                       | 1.68       | 1.68  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 40  | 8   | 1         | 16608 | 16464 | 16160          |         |                       | 2.77       | 1.88  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 16328 | 15752 | 15224          |         |                       | 7.25       | 3.47  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 15848 | 15312 | 14728          |         |                       | 7.60       | 3.97  |                       |      | 5.11                  | 2.80 | 7.60                  | 3.97  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 16648 | 16392 | 15880          |         |                       | 4.84       | 3.22  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 16696 | 16440 | 16200          |         |                       | 3.06       | 1.48  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |

**Table C.9 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | LPH1  | LPH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | LPH1       | LPH2  | LPH1               | LPH2 | LPH1               | LPH2 | LPH1               | LPH2  | LPH1                       | LPH2 | LPH1                       | LPH2 |  |  |  |
| 55  | 2   | 1      | 63270 | 63270 | 63270       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 49653 | 49653 | 49653       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 45404 | 45322 | 45114       |         |                 | 0.64       | 0.46  |                    |      | 0.13               | 0.09 | 0.64               | 0.46  |                            |      |                            |      |  |  |  |
|     |     | 4      | 58841 | 58841 | 58841       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 61757 | 61757 | 61757       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 36336 | 36308 | 35780       |         |                 | 1.55       | 1.48  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 30211 | 30193 | 29077       |         |                 | 3.90       | 3.84  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 28264 | 28208 | 26696       |         |                 | 5.87       | 5.66  |                    |      | 2.94               | 2.91 | 5.87               | 5.66  |                            |      |                            |      |  |  |  |
|     |     | 4      | 34873 | 34937 | 33729       |         |                 | 3.39       | 3.58  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 35078 | 35078 | 35078       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 29409 | 29158 | 28560       |         |                 | 2.97       | 2.09  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 26679 | 26778 | 24180       |         |                 | 10.33      | 10.74 |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 25865 | 25773 | 22445       |         |                 | 15.24      | 14.83 |                    |      | 7.01               | 6.71 | 15.24              | 14.83 |                            |      |                            |      |  |  |  |
|     |     | 4      | 28505 | 28457 | 27265       |         |                 | 4.55       | 4.37  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 28657 | 28540 | 28110       |         |                 | 1.95       | 1.53  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 26984 | 26984 | 26380       |         |                 | 2.29       | 2.29  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 26127 | 25507 | 24482       |         |                 | 6.72       | 4.19  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 25288 | 24642 | 23358       |         |                 | 8.26       | 5.50  |                    |      | 4.87               | 3.58 | 8.26               | 5.50  |                            |      |                            |      |  |  |  |
|     |     | 4      | 26793 | 26565 | 25573       |         |                 | 4.77       | 3.88  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 26658 | 26596 | 26056       |         |                 | 2.31       | 2.07  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |

**Table C.9 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$



| $n$       | $K$      | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|           |          |           |      |      |                |         |                       | LPH1       | LPH2  | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2  | LPH1                             | LPH2 | LPH1                             | LPH2 |
| <b>10</b> | <b>2</b> | 1         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1380 | 1380 | 1380           | 1380    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>4</b> | 1         | 966  | 966  | 936            | 958     | 0.95                  | 3.21       | 3.21  | 0.84                  | 0.84 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 2         | 1070 | 1070 | 914            | 1048    | 2.12                  | 17.07      | 17.07 | 2.10                  | 2.10 | 6.48                  | 6.48 | 17.07                 | 17.07 | 1.04                             | 1.04 | 2.27                             | 2.27 |
|           |          | 3         | 900  | 900  | 828            | 880     | 0.64                  | 8.70       | 8.70  | 2.27                  | 2.27 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 4         | 1028 | 1028 | 1016           | 1028    | 2.83                  | 1.18       | 1.18  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 5         | 1090 | 1090 | 1066           | 1090    | 1.42                  | 2.25       | 2.25  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
| <b>10</b> | <b>6</b> | 1         | 1030 | 1030 | 998            | 1030    | 0.15                  | 3.21       | 3.21  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 2         | 1178 | 1178 | 1122           | 1178    | 0.19                  | 4.99       | 4.99  | 0.00                  | 0.00 | 5.62                  | 5.62 | 19.18                 | 19.18 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 994  | 994  | 834            | 994     | 0.16                  | 19.18      | 19.18 | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 4         | 1136 | 1136 | 1128           | 1136    | 0.15                  | 0.71       | 0.71  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 5         | 1318 | 1318 | 1318           | 1318    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
| <b>10</b> | <b>8</b> | 1         | 1428 | 1428 | 1424           | 1428    | 0.15                  | 0.28       | 0.28  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 2         | 1650 | 1650 | 1646           | 1650    | 0.12                  | 0.24       | 0.24  | 0.00                  | 0.00 | 0.22                  | 0.22 | 0.30                  | 0.30  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1336 | 1336 | 1332           | 1336    | 0.17                  | 0.30       | 0.30  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 4         | 1478 | 1478 | 1474           | 1478    | 0.10                  | 0.27       | 0.27  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |
|           |          | 5         | 1704 | 1704 | 1704           | 1704    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |

**Table C.10:** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | LPH1 | LPH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | LPH1       | LPH2  | LPH1               | LPH2 | LPH1               | LPH2  | LPH1               | LPH2  | LPH1                       | LPH2 | LPH1                       | LPH2 |
| 25  | 2   | 1      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00  | 0.00               | 0.00  |                            |      |                            |      |
|     |     | 2      | 8112 | 8112 | 8112        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 7774 | 7774 | 7774        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 25  | 4   | 1      | 4760 | 4760 | 4732        |         |                 | 0.59       | 0.59  |                    |      | 1.00               | 0.79  | 2.60               | 2.40  |                            |      |                            |      |
|     |     | 2      | 4610 | 4601 | 4493        |         |                 | 2.60       | 2.40  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 4214 | 4204 | 4186        |         |                 | 0.67       | 0.43  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 4786 | 4758 | 4732        |         |                 | 1.14       | 0.55  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 4732 | 4732 | 4732        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 25  | 6   | 1      | 3660 | 3612 | 3380        |         |                 | 8.28       | 6.86  |                    |      | 9.13               | 7.64  | 15.22              | 12.77 |                            |      |                            |      |
|     |     | 2      | 4324 | 4336 | 3845        | 4296(*) |                 | 12.46      | 12.77 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 3445 | 3361 | 2990        | 3289(*) |                 | 15.22      | 12.41 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 3867 | 3757 | 3705        |         |                 | 4.37       | 1.40  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 3954 | 3933 | 3755        |         |                 | 5.30       | 4.74  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 25  | 8   | 1      | 4310 | 4310 | 3079        | 4263    | 6898.34         | 39.98      | 39.98 | 1.10               | 1.10 | 29.44              | 29.44 | 41.89              | 41.89 | 0.91                       | 0.91 | 1.58                       | 1.58 |
|     |     | 2      | 5052 | 5052 | 3896        | 5014(-) | 50000.00        | 29.67      | 29.67 | 0.76               | 0.76 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 3997 | 3997 | 2817        | 3935    | 36647.46        | 41.89      | 41.89 | 1.58               | 1.58 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 4162 | 4162 | 3529        | 4130    | 12309.69        | 17.94      | 17.94 | 0.77               | 0.77 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 4537 | 4537 | 3854        | 4521    | 11960.39        | 17.72      | 17.72 | 0.35               | 0.35 |                    |       |                    |       |                            |      |                            |      |

**Table C.10 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,28]$

(-): The lower bound obtained by the linear relaxation is 5013.33. Best integer solution obtained is 5014.

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2  | LPH1                  | LPH2 | LPH1                  | LPH2  | LPH1                  | LPH2  | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |  |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
| 40  | 4   | 1         | 11488 | 11488 | 11440          |         |                       | 0.42       | 0.42  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 10672 | 10632 | 10560          |         |                       | 1.06       | 0.68  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 3         | 10200 | 10192 | 10120          |         |                       | 0.79       | 0.71  |                       |      | 0.55                  | 0.45  | 1.06                  | 0.71  |                                  |      |                                  |      |  |  |
|     |     | 4         | 11496 | 11488 | 11440          |         |                       | 0.49       | 0.42  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
| 40  | 6   | 1         | 8116  | 8116  | 8008           |         |                       | 1.35       | 1.35  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 8230  | 8020  | 7632           |         |                       | 7.84       | 5.08  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 3         | 7674  | 7464  | 7084           |         |                       | 8.33       | 5.36  |                       |      | 4.30                  | 2.78  | 8.33                  | 5.36  |                                  |      |                                  |      |  |  |
|     |     | 4         | 8548  | 8540  | 8408           |         |                       | 1.67       | 1.57  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 8358  | 8212  | 8168           |         |                       | 2.33       | 0.54  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
| 40  | 8   | 1         | 7680  | 7680  | 6280           |         |                       | 22.29      | 22.29 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 8640  | 8656  | 6800           |         |                       | 27.06      | 27.29 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 3         | 8208  | 8176  | 5880           |         |                       | 39.59      | 39.05 |                       |      | 25.27                 | 24.86 | 39.59                 | 39.05 |                                  |      |                                  |      |  |  |
|     |     | 4         | 8328  | 8240  | 7400           |         |                       | 12.54      | 11.35 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 8792  | 8752  | 7040           |         |                       | 24.89      | 24.32 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |

**Table C.10 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2  | LPH1                  | LPH2 | LPH1                  | LPH2  | LPH1                  | LPH2  | LPH1                             | LPH2 | LPH1                             | LPH2 |  |  |  |  |
| 55  | 2   | 1         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 37632 | 37632 | 37632          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 36064 | 36064 | 36064          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 55  | 4   | 1         | 21216 | 21202 | 21112          |         |                       | 0.49       | 0.43  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 19654 | 19640 | 19488          |         |                       | 0.85       | 0.78  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 18758 | 18758 | 18676          |         |                       | 0.44       | 0.44  |                       |      | 0.44                  | 0.41  | 0.85                  | 0.78  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 21202 | 21202 | 21112          |         |                       | 0.43       | 0.43  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 55  | 6   | 1         | 14774 | 14736 | 14560          |         |                       | 1.47       | 1.21  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 14398 | 14248 | 13770          |         |                       | 4.56       | 3.47  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 13324 | 13204 | 12880          |         |                       | 3.45       | 2.52  |                       |      | 2.42                  | 1.79  | 4.56                  | 3.47  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 15104 | 15004 | 14780          |         |                       | 2.19       | 1.52  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 14624 | 14598 | 14560          |         |                       | 0.44       | 0.26  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 55  | 8   | 1         | 13032 | 13107 | 11284          |         |                       | 15.49      | 16.16 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 13684 | 13684 | 11736          |         |                       | 16.60      | 16.60 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 12172 | 11772 | 9982           |         |                       | 21.94      | 17.93 |                       |      | 15.16                 | 13.95 | 21.94                 | 17.93 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 13530 | 13195 | 12384          |         |                       | 9.25       | 6.55  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 12881 | 12881 | 11449          |         |                       | 12.51      | 12.51 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |

**Table C.10 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | LPH1 | LPH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|
|     |     |           |      |      |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |
| 10  | 2   | 1         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 2040 | 2040 | 2040           | 2040    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 1980 | 1980 | 1980           | 1980    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
| 10  | 4   | 1         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.65                  | 0.58 | 1.35                  | 1.01 | 0.07                             | 0.00 | 0.33                             | 0.00 |
|     |     | 2         | 1236 | 1236 | 1224           | 1236    | 0.45                  | 0.98       | 0.98 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 1204 | 1200 | 1188           | 1200    | 0.16                  | 1.35       | 1.01 | 0.33                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 1308 | 1308 | 1296           | 1308    | 0.11                  | 0.93       | 0.93 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 1326 | 1326 | 1326           | 1326    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
| 10  | 6   | 1         | 1186 | 1186 | 1178           | 1186    | 0.16                  | 0.68       | 0.68 | 0.00                  | 0.00 | 1.96                  | 1.96 | 7.89                  | 7.89 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 1310 | 1310 | 1302           | 1310    | 0.17                  | 0.61       | 0.61 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 1094 | 1094 | 1014           | 1094    | 0.16                  | 7.89       | 7.89 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 1316 | 1316 | 1308           | 1316    | 0.14                  | 0.61       | 0.61 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 1498 | 1498 | 1498           | 1498    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
| 10  | 8   | 1         | 1564 | 1564 | 1564           | 1564    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.05                  | 0.05 | 0.27                  | 0.27 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 1786 | 1786 | 1786           | 1786    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 3         | 1476 | 1476 | 1472           | 1476    | 0.08                  | 0.27       | 0.27 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 1614 | 1614 | 1614           | 1614    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 1844 | 1844 | 1844           | 1844    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |

**Table C.11:** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |      |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|--|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2  | LPH1                  | LPH2 | LPH1                  | LPH2  | LPH1                  | LPH2  | LPH1                             | LPH2 | LPH1                             | LPH2 | LPH1 | LPH2 |  |  |
| 25  | 2   | 1         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 11492 | 11492 | 11492          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 11154 | 11154 | 11154          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
| 25  | 4   | 1         | 6562  | 6562  | 6552           |         |                       | 0.15       | 0.15  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 6224  | 6224  | 6188           |         |                       | 0.58       | 0.58  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 6016  | 6016  | 6006           |         |                       | 0.17       | 0.17  |                       |      | 0.21                  | 0.21  | 0.58                  | 0.58  |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 6562  | 6562  | 6552           |         |                       | 0.15       | 0.15  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
| 25  | 6   | 1         | 4720  | 4706  | 4680           |         |                       | 0.85       | 0.56  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 5037  | 5037  | 4895           |         |                       | 2.90       | 2.90  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 4386  | 4386  | 4290           |         |                       | 2.24       | 2.24  |                       |      | 1.43                  | 1.31  | 2.90                  | 2.90  |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 4795  | 4781  | 4755           |         |                       | 0.84       | 0.55  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 4819  | 4819  | 4805           |         |                       | 0.29       | 0.29  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
| 25  | 8   | 1         | 4580  | 4580  | 3869           |         |                       | 18.38      | 18.38 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 5322  | 5322  | 4686           |         |                       | 13.57      | 13.57 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 4267  | 4263  | 3607           |         |                       | 18.30      | 18.19 |                       |      | 12.15                 | 12.13 | 18.38                 | 18.38 |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 4488  | 4488  | 4319           |         |                       | 3.91       | 3.91  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 4951  | 4951  | 4644           |         |                       | 6.61       | 6.61  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |  |

**Table C.11 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |
| 40  | 2   | 1         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 28560 | 28560 | 28560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 27720 | 27720 | 27720          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |
|     |     | 4         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 40  | 4   | 1         | 15848 | 15848 | 15840          |         |                       | 0.05       | 0.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 14992 | 14992 | 14960          |         |                       | 0.21       | 0.21 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 14536 | 14536 | 14520          |         |                       | 0.11       | 0.11 |                       |      | 0.09                  | 0.09 | 0.21                  | 0.21 |                                  |      |                                  |      |  |
|     |     | 4         | 15848 | 15848 | 15840          |         |                       | 0.05       | 0.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 40  | 6   | 1         | 11140 | 11140 | 11088          |         |                       | 0.47       | 0.47 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 10640 | 10568 | 10472          |         |                       | 1.60       | 0.92 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 10248 | 10228 | 10164          |         |                       | 0.83       | 0.63 |                       |      | 0.73                  | 0.52 | 1.60                  | 0.92 |                                  |      |                                  |      |  |
|     |     | 4         | 11152 | 11152 | 11088          |         |                       | 0.58       | 0.58 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 11108 | 11088 | 11088          |         |                       | 0.18       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 40  | 8   | 1         | 9032  | 8720  | 8640           |         |                       | 4.54       | 0.93 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 9504  | 9224  | 8800           |         |                       | 8.00       | 4.82 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 8640  | 8528  | 7920           |         |                       | 9.09       | 7.68 |                       |      | 5.70                  | 3.52 | 9.09                  | 7.68 |                                  |      |                                  |      |  |
|     |     | 4         | 9512  | 9512  | 9400           |         |                       | 1.19       | 1.19 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 9552  | 9312  | 9040           |         |                       | 5.66       | 3.01 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |

**Table C.11 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                             | LPH2 | LPH1                             | LPH2 |  |
| 55  | 2   | 1         | 56448 | 56448 | 56448          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 53312 | 53312 | 53312          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 51744 | 51744 | 51744          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |
|     |     | 4         | 56448 | 56448 | 56448          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 56448 | 56448 | 56448          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 55  | 4   | 1         | 29254 | 29254 | 29232          |         |                       | 0.08       | 0.08 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 27652 | 27652 | 27608          |         |                       | 0.16       | 0.16 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 26810 | 26810 | 26796          |         |                       | 0.05       | 0.05 |                       |      | 0.07                  | 0.07 | 0.16                  | 0.16 |                                  |      |                                  |      |  |
|     |     | 4         | 29246 | 29246 | 29232          |         |                       | 0.05       | 0.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 29232 | 29232 | 29232          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 55  | 6   | 1         | 20286 | 20274 | 20160          |         |                       | 0.63       | 0.57 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 19246 | 19190 | 19040          |         |                       | 1.08       | 0.79 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 18570 | 18556 | 18480          |         |                       | 0.49       | 0.41 |                       |      | 0.55                  | 0.47 | 1.08                  | 0.79 |                                  |      |                                  |      |  |
|     |     | 4         | 20274 | 20274 | 20160          |         |                       | 0.57       | 0.57 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 55  | 8   | 1         | 15808 | 15778 | 15624          |         |                       | 1.18       | 0.99 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 16027 | 15880 | 15526          |         |                       | 3.23       | 2.28 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 14659 | 14596 | 14322          |         |                       | 2.35       | 1.91 |                       |      | 1.70                  | 1.34 | 3.23                  | 2.28 |                                  |      |                                  |      |  |
|     |     | 4         | 16374 | 16374 | 16174          |         |                       | 1.24       | 1.24 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 15700 | 15670 | 15624          |         |                       | 0.49       | 0.29 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |

**Table C.11 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [32, 38]$



| $n$ | $K$ | Ins. # | LPH1 | LPH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | LPH1       | LPH2  | LPH1               | LPH2 | LPH1               | LPH2 | LPH1               | LPH2  | LPH1                       | LPH2 | LPH1                       | LPH2 |
| 10  | 2   | 1      | 2400 | 2400 | 2400        | 2400    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1860 | 1860 | 1860        | 1860    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1680 | 1680 | 1680        | 1680    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 2220 | 2220 | 2220        | 2220    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 2340 | 2340 | 2340        | 2340    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
| 10  | 4   | 1      | 1440 | 1440 | 1440        | 1440    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 2.24               | 4.18 | 6.45               | 16.13 | 0.00                       | 1.82 | 0.00                       | 9.09 |
|     |     | 2      | 1188 | 1296 | 1116        | 1188    | 0.45            | 6.45       | 16.13 | 0.00               | 9.09 |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1056 | 1056 | 1008        | 1056    | 0.06            | 4.76       | 4.76  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 1332 | 1332 | 1332        | 1332    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1404 | 1404 | 1404        | 1404    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
| 10  | 6   | 1      | 1266 | 1266 | 1250        | 1266    | 0.25            | 1.28       | 1.28  | 0.00               | 0.00 | 3.98               | 3.98 | 14.29              | 14.29 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1272 | 1272 | 1248        | 1272    | 0.26            | 1.92       | 1.92  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1056 | 1056 | 924         | 1056    | 0.11            | 14.29      | 14.29 | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 1358 | 1358 | 1326        | 1358    | 0.18            | 2.41       | 2.41  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1552 | 1552 | 1552        | 1552    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
| 10  | 8   | 1      | 1620 | 1620 | 1620        | 1620    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.37               | 0.37 | 1.14               | 1.14  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1756 | 1756 | 1744        | 1756    | 0.10            | 0.69       | 0.69  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1418 | 1418 | 1402        | 1418    | 0.15            | 1.14       | 1.14  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 1628 | 1628 | 1628        | 1628    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1886 | 1886 | 1886        | 1886    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |

**Table C.12:** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | LPH1  | LPH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|------|
|     |     |        |       |       |             |         |                 | LPH1       | LPH2  | LPH1               | LPH2 | LPH1               | LPH2  | LPH1               | LPH2  | LPH1                       | LPH2 | LPH1                       | LPH2 | LPH1 |
| 25  | 2   | 1      | 13520 | 13520 | 13520       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 2      | 10478 | 10478 | 10478       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 3      | 9464  | 9464  | 9464        |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00  | 0.00               | 0.00  |                            |      |                            |      |      |
|     |     | 4      | 12506 | 12506 | 12506       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 5      | 13182 | 13182 | 13182       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
| 25  | 4   | 1      | 7280  | 7280  | 7280        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 2      | 5767  | 5774  | 5642        |         |                 | 2.22       | 2.34  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 3      | 5136  | 5136  | 5096        |         |                 | 0.78       | 0.78  |                    |      | 0.60               | 0.62  | 2.22               | 2.34  |                            |      |                            |      |      |
|     |     | 4      | 6734  | 6734  | 6734        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 5      | 7098  | 7098  | 7098        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
| 25  | 6   | 1      | 5252  | 5252  | 5200        |         |                 | 1.00       | 1.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 2      | 5280  | 5084  | 4580        | 5045(*) |                 | 15.28      | 11.00 |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 3      | 4086  | 4058  | 3640        | 4015    | 2965.63         | 12.25      | 11.48 | 1.77               | 1.07 | 6.37               | 5.13  | 15.28              | 11.48 |                            |      |                            |      |      |
|     |     | 4      | 5020  | 4964  | 4860        |         |                 | 3.29       | 2.14  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 5      | 5120  | 5120  | 5120        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
| 25  | 8   | 1      | 4714  | 4714  | 4185        | 4695    | 12449.50        | 12.64      | 12.64 | 0.40               | 0.40 |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 2      | 5365  | 5365  | 4449        | 5326    | 27821.13        | 20.59      | 20.59 | 0.73               | 0.73 |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 3      | 4282  | 4299  | 3212        | 4223    | 8393.50         | 33.31      | 33.84 | 1.40               | 1.80 | 15.39              | 15.50 | 33.31              | 33.84 |                            |      |                            |      |      |
|     |     | 4      | 4606  | 4606  | 4398        |         |                 | 4.73       | 4.73  |                    |      |                    |       |                    |       |                            |      |                            |      |      |
|     |     | 5      | 5158  | 5158  | 4881        |         |                 | 5.68       | 5.68  |                    |      |                    |       |                    |       |                            |      |                            |      |      |

**Table C.12 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | LPH1  | LPH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|--|
|     |     |        |       |       |             |         |                 | LPH1       | LPH2  | LPH1               | LPH2 | LPH1               | LPH2 | LPH1               | LPH2  | LPH1                       | LPH2 | LPH1                       | LPH2 |  |
| 40  | 2   | 1      | 33600 | 33600 | 33600       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 2      | 26040 | 26040 | 26040       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 3      | 23520 | 23520 | 23520       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |  |
|     |     | 4      | 31080 | 31080 | 31080       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 5      | 32760 | 32760 | 32760       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
| 40  | 4   | 1      | 17600 | 17600 | 17600       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 2      | 13840 | 13784 | 13640       |         |                 | 1.47       | 1.06  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 3      | 12480 | 12480 | 12320       |         |                 | 1.30       | 1.30  |                    |      | 0.59               | 0.51 | 1.47               | 1.30  |                            |      |                            |      |  |
|     |     | 4      | 16312 | 16312 | 16280       |         |                 | 0.20       | 0.20  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 5      | 17160 | 17160 | 17160       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
| 40  | 6   | 1      | 12400 | 12384 | 12320       |         |                 | 0.65       | 0.52  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 2      | 10112 | 10112 | 9548        |         |                 | 5.91       | 5.91  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 3      | 9356  | 9356  | 8624        |         |                 | 8.49       | 8.49  |                    |      | 3.46               | 3.43 | 8.49               | 8.49  |                            |      |                            |      |  |
|     |     | 4      | 11652 | 11652 | 11396       |         |                 | 2.25       | 2.25  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 5      | 12012 | 12012 | 12012       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
| 40  | 8   | 1      | 9792  | 9744  | 9600        |         |                 | 2.00       | 1.50  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 2      | 9544  | 9176  | 8200        |         |                 | 16.39      | 11.90 |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 3      | 8600  | 8776  | 6880        |         |                 | 25.00      | 27.56 |                    |      | 10.24              | 9.96 | 25.00              | 27.56 |                            |      |                            |      |  |
|     |     | 4      | 10048 | 10048 | 9600        |         |                 | 4.67       | 4.67  |                    |      |                    |      |                    |       |                            |      |                            |      |  |
|     |     | 5      | 9944  | 10040 | 9640        |         |                 | 3.15       | 4.15  |                    |      |                    |      |                    |       |                            |      |                            |      |  |

**Table C.12 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | LPH1  | LPH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|
|     |     |           |       |       |                |         |                       | LPH1       | LPH2  | LPH1                  | LPH2 | LPH1                  | LPH2 | LPH1                  | LPH2  | LPH1                             | LPH2 | LPH1                             | LPH2 | LPH1 |
| 55  | 2   | 1         | 62720 | 62720 | 62720          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 2         | 48608 | 48608 | 48608          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 3         | 43904 | 43904 | 43904          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |
|     |     | 4         | 58016 | 58016 | 58016          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 5         | 61152 | 61152 | 61152          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
| 55  | 4   | 1         | 32480 | 32480 | 32480          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 2         | 25370 | 25352 | 25172          |         |                       | 0.79       | 0.72  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 3         | 22912 | 22912 | 22736          |         |                       | 0.77       | 0.77  |                       |      | 0.33                  | 0.31 | 0.79                  | 0.77  |                                  |      |                                  |      |      |
|     |     | 4         | 30068 | 30068 | 30044          |         |                       | 0.08       | 0.08  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 5         | 31668 | 31668 | 31668          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
| 55  | 6   | 1         | 22580 | 22552 | 22400          |         |                       | 0.80       | 0.68  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 2         | 18228 | 18092 | 17360          |         |                       | 5.00       | 4.22  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 3         | 16198 | 16346 | 15680          |         |                       | 3.30       | 4.25  |                       |      | 2.35                  | 2.21 | 5.00                  | 4.25  |                                  |      |                                  |      |      |
|     |     | 4         | 21266 | 21120 | 20720          |         |                       | 2.64       | 1.93  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
| 55  | 8   | 1         | 17698 | 17698 | 17360          |         |                       | 1.95       | 1.95  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 2         | 15764 | 15589 | 14389          |         |                       | 9.56       | 8.34  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 3         | 13712 | 13394 | 12152          |         |                       | 12.84      | 10.22 |                       |      | 6.07                  | 5.25 | 12.84                 | 10.22 |                                  |      |                                  |      |      |
|     |     | 4         | 17404 | 17353 | 16553          |         |                       | 5.14       | 4.83  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |
|     |     | 5         | 17076 | 17076 | 16926          |         |                       | 0.89       | 0.89  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |

**Table C.12 (continued):** Computational results for *Last Trip Partial Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

# **Appendix D**

## Numerical Results for Fully Loaded Trips Problem

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |      |
| <b>10</b> | <b>2</b> | 1         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 2         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 1380 | 1380 | 1380           | 1380    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 | 0.00 |
|           |          | 4         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 5         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
| <b>10</b> | <b>4</b> | 1         | 936  | 936  | 936            | 936     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 2         | 864  | 864  | 864            | 864     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 828  | 828  | 828            | 828     |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 4         | 936  | 936  | 936            | 936     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 5         | 936  | 936  | 936            | 936     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
| <b>10</b> | <b>6</b> | 1         | 728  | 728  | 728            | 728     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 2         | 672  | 672  | 672            | 672     |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.55                  | 0.55  | 2.75                  | 2.75  | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 644  | 644  | 644            | 644     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 4         | 728  | 728  | 728            | 728     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 5         | 748  | 748  | 728            | 748     | 0.61                  | 2.75       | 2.75  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
| <b>10</b> | <b>8</b> | 1         | 724  | 724  | 624            | 724     | 0.25                  | 16.03      | 16.03 | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 2         | 776  | 776  | 576            | 776     | 0.20                  | 34.72      | 34.72 | 0.00                  | 0.00 | 24.43                 | 24.43 | 34.72                 | 34.72 | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 672  | 672  | 552            | 672     | 0.18                  | 21.74      | 21.74 | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 4         | 744  | 744  | 624            | 744     | 0.20                  | 19.23      | 19.23 | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 5         | 814  | 814  | 624            | 814     | 0.23                  | 30.45      | 30.45 | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |

**Table D.1** : Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |      |      |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 25  | 2   | 1         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 8112 | 8112 | 8112           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 7774 | 7774 | 7774           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 25  | 4   | 1         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 4368 | 4368 | 4368           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 4186 | 4186 | 4186           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 25  | 6   | 1         | 3380 | 3380 | 3380           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 3134 | 3134 | 3120           |         |                       | 0.45       | 0.45 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 2990 | 2990 | 2990           |         |                       | 0.00       | 0.00 |                       |      | 0.09                  | 0.09 | 0.45                  | 0.45 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 3380 | 3380 | 3380           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 3380 | 3380 | 3380           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 25  | 8   | 1         | 2722 | 2722 | 2704           |         |                       | 0.67       | 0.67 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 2630 | 2630 | 2496           |         |                       | 5.37       | 5.37 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 2410 | 2410 | 2392           |         |                       | 0.75       | 0.75 |                       |      | 1.49                  | 1.49 | 5.37                  | 5.37 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 2722 | 2722 | 2704           |         |                       | 0.67       | 0.67 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 2704 | 2704 | 2704           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table D.1 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 4   | 1         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 10560 | 10560 | 10560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 10120 | 10120 | 10120          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 6   | 1         | 8008  | 8008  | 8008           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 7392  | 7392  | 7392           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7084  | 7084  | 7084           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 8008  | 8008  | 8008           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 8008  | 8008  | 8008           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 8   | 1         | 6256  | 6256  | 6240           |         |                       | 0.26       | 0.26 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 5792  | 5792  | 5760           |         |                       | 0.56       | 0.56 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 5552  | 5552  | 5520           |         |                       | 0.58       | 0.58 |                       |      | 0.33                  | 0.33 | 0.58                  | 0.58 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 6256  | 6256  | 6240           |         |                       | 0.26       | 0.26 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 6240  | 6240  | 6240           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table D.1 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$



| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 55  | 2   | 1         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 37632 | 37632 | 37632          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 36064 | 36064 | 36064          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 4   | 1         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 19488 | 19488 | 19488          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 18676 | 18676 | 18676          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 6   | 1         | 14560 | 14560 | 14560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 13440 | 13440 | 13440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 12880 | 12880 | 12880          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 14560 | 14560 | 14560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 14560 | 14560 | 14560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 8   | 1         | 11298 | 11298 | 11284          |         |                       | 0.12       | 0.12 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 10446 | 10446 | 10416          |         |                       | 0.29       | 0.29 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 9996  | 9996  | 9982           |         |                       | 0.14       | 0.14 |                       |      | 0.14                  | 0.14 | 0.29                  | 0.29 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 11298 | 11298 | 11284          |         |                       | 0.12       | 0.12 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 11284 | 11284 | 11284          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table D.1 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |      |
| <b>10</b> | <b>2</b> | 1         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 2         | 2040 | 2040 | 2040           | 2040    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 1980 | 1980 | 1980           | 1980    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 | 0.00 |
|           |          | 4         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 5         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
| <b>10</b> | <b>4</b> | 1         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 2         | 1224 | 1224 | 1224           | 1224    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 1188 | 1188 | 1188           | 1188    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 | 0.00 |
|           |          | 4         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 5         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
| <b>10</b> | <b>6</b> | 1         | 1008 | 1008 | 1008           | 1008    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 2         | 952  | 952  | 952            | 952     |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 924  | 924  | 924            | 924     |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 4         | 1008 | 1008 | 1008           | 1008    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 5         | 1008 | 1008 | 1008           | 1008    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
| <b>10</b> | <b>8</b> | 1         | 864  | 864  | 864            | 864     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |      |
|           |          | 2         | 916  | 916  | 816            | 916     | 0.17                  | 12.25      | 12.25 | 0.00                  | 0.00 | 5.50                  | 5.50 | 12.25                 | 12.25 | 0.00                             | 0.00 | 0.00                             | 0.00 |      |
|           |          | 3         | 812  | 812  | 792            | 812     | 0.15                  | 2.53       | 2.53  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |      |
|           |          | 4         | 884  | 884  | 864            | 884     | 0.04                  | 2.31       | 2.31  | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |      |
|           |          | 5         | 954  | 954  | 864            | 954     | 0.18                  | 10.42      | 10.42 | 0.00                  | 0.00 |                       |      |                       |       |                                  |      |                                  |      |      |

**Table D.2:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |
| 25  | 2   | 1         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 11492 | 11492 | 11492          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 11154 | 11154 | 11154          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 4   | 1         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 6188  | 6188  | 6188           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 6006  | 6006  | 6006           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 6   | 1         | 4680  | 4680  | 4680           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 4420  | 4420  | 4420           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 4290  | 4290  | 4290           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 4680  | 4680  | 4680           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 4680  | 4680  | 4680           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 8   | 1         | 3744  | 3744  | 3744           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 3545  | 3554  | 3536           |         |                       | 0.25       | 0.51 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 3432  | 3432  | 3432           |         |                       | 0.00       | 0.00 |                       |      | 0.05                  | 0.10 | 0.25                  | 0.51 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 3744  | 3744  | 3744           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 3744  | 3744  | 3744           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table D.2 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |
| 40  | 2   | 1         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 2         | 28560 | 28560 | 28560          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |
|     |     | 3         | 27720 | 27720 | 27720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 40  | 4   | 1         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 2         | 14960 | 14960 | 14960          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |
|     |     | 3         | 14520 | 14520 | 14520          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 40  | 6   | 1         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 2         | 10472 | 10472 | 10472          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |
|     |     | 3         | 10164 | 10164 | 10164          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
| 40  | 8   | 1         | 8640  | 8640  | 8640           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 2         | 8160  | 8160  | 8160           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |
|     |     | 3         | 7920  | 7920  | 7920           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 4         | 8640  | 8640  | 8640           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |
|     |     | 5         | 8640  | 8640  | 8640           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |

**Table D.2 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |
| 55  | 2   | 1      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 53312 | 53312 | 53312       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 3      | 51744 | 51744 | 51744       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 4   | 1      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 27608 | 27608 | 27608       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 3      | 26796 | 26796 | 26796       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 6   | 1      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 19040 | 19040 | 19040       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 3      | 18480 | 18480 | 18480       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 8   | 1      | 15624 | 15624 | 15624       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 14756 | 14756 | 14756       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 3      | 14322 | 14322 | 14322       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 15624 | 15624 | 15624       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 15624 | 15624 | 15624       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |

**Table D.2 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |
| <b>10</b> | <b>2</b> | 1         | 2400 | 2400 | 2400           | 2400    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1860 | 1860 | 1860           | 1860    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1680 | 1680 | 1680           | 1680    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 2220 | 2220 | 2220           | 2220    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 2340 | 2340 | 2340           | 2340    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>4</b> | 1         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1116 | 1116 | 1116           | 1116    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1008 | 1008 | 1008           | 1008    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1332 | 1332 | 1332           | 1332    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1404 | 1404 | 1404           | 1404    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>6</b> | 1         | 1120 | 1120 | 1120           | 1120    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 868  | 868  | 868            | 868     |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 784  | 784  | 784            | 784     |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1036 | 1036 | 1036           | 1036    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1092 | 1092 | 1092           | 1092    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>8</b> | 1         | 960  | 960  | 960            | 960     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 874  | 874  | 744            | 874     | 0.17                  | 17.47      | 17.47 | 0.00                  | 0.00 | 7.09                  | 7.09 | 17.47                 | 17.47 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 742  | 742  | 672            | 742     | 0.21                  | 10.42      | 10.42 | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 898  | 898  | 888            | 898     | 0.10                  | 1.13       | 1.13  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 996  | 996  | 936            | 996     | 0.13                  | 6.41       | 6.41  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |

**Table D.3:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |
| 25  | 2   | 1      | 13520 | 13520 | 13520       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 10478 | 10478 | 10478       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 3      | 9464  | 9464  | 9464        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 12506 | 12506 | 12506       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 13182 | 13182 | 13182       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 4   | 1      | 7280  | 7280  | 7280        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 5642  | 5642  | 5642        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 3      | 5096  | 5096  | 5096        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 6734  | 6734  | 6734        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 7098  | 7098  | 7098        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 6   | 1      | 5200  | 5200  | 5200        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 4030  | 4030  | 4030        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 3      | 3640  | 3640  | 3640        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 4810  | 4810  | 4810        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 5070  | 5070  | 5070        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 8   | 1      | 4160  | 4160  | 4160        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 2      | 3278  | 3278  | 3224        |         |                 | 1.67       | 1.67 |                    |      | 0.33               | 0.33 | 1.67               | 1.67 |                            |      |                            |      |
|     |     | 3      | 2912  | 2912  | 2912        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 3848  | 3848  | 3848        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 4056  | 4056  | 4056        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |

**Table D.3 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |
| 40  | 2   | 1         | 33600 | 33600 | 33600          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 26040 | 26040 | 26040          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 23520 | 23520 | 23520          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 31080 | 31080 | 31080          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 32760 | 32760 | 32760          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 4   | 1         | 17600 | 17600 | 17600          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 13640 | 13640 | 13640          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 16280 | 16280 | 16280          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 17160 | 17160 | 17160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 6   | 1         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 9548  | 9548  | 9548           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 8624  | 8624  | 8624           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 11396 | 11396 | 11396          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 12012 | 12012 | 12012          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 8   | 1         | 9600  | 9600  | 9600           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 7440  | 7440  | 7440           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 6728  | 6784  | 6720           |         |                       | 0.12       | 0.95 |                       |      | 0.02                  | 0.19 | 0.12                  | 0.95 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 8880  | 8880  | 8880           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 9360  | 9360  | 9360           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table D.3 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$



| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 55  | 2   | 1         | 62720 | 62720 | 62720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 48608 | 48608 | 48608          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 43904 | 43904 | 43904          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 58016 | 58016 | 58016          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 61152 | 61152 | 61152          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 4   | 1         | 32480 | 32480 | 32480          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 25172 | 25172 | 25172          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 22736 | 22736 | 22736          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 30044 | 30044 | 30044          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 31668 | 31668 | 31668          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 6   | 1         | 22400 | 22400 | 22400          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 17360 | 17360 | 17360          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 15680 | 15680 | 15680          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 20720 | 20720 | 20720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 8   | 1         | 17360 | 17360 | 17360          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 13454 | 13454 | 13454          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 12152 | 12152 | 12152          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 16058 | 16058 | 16058          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 16926 | 16926 | 16926          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table D.3 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|     |     |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |
| 10  | 2   | 1         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 3         | 1380 | 1380 | 1380           | 1380    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 4         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 5         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| 10  | 4   | 1         | 936  | 936  | 936            | 936     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 900  | 906  | 864            | 900     | 16.86                 | 4.17       | 4.86  | 0.00                  | 0.67 | 2.14                  | 2.28  | 4.17                  | 4.86  | 0.00                             | 0.13 | 0.00                             | 4.86 |
|     |     | 3         | 838  | 838  | 828            | 838     | 14.64                 | 1.21       | 1.21  | 0.00                  | 0.00 | 2.14                  | 2.14  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 4         | 956  | 956  | 936            | 956     | 7.60                  | 2.14       | 2.14  | 0.00                  | 0.00 | 3.21                  | 3.21  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 5         | 966  | 966  | 936            | 966     | 4.27                  | 3.21       | 3.21  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
| 10  | 6   | 1         | 844  | 844  | 728            | 844     | 1.59                  | 15.93      | 15.93 | 0.00                  | 0.00 |                       |       |                       |       | 0.20                             | 1.58 | 0.52                             | 5.22 |
|     |     | 2         | 828  | 846  | 702            | 826     | 1.08                  | 17.95      | 20.51 | 0.24                  | 2.42 | 16.17                 | 17.78 | 17.95                 | 23.24 | 0.20                             | 1.58 | 0.52                             | 5.22 |
|     |     | 3         | 770  | 806  | 654            | 766     | 0.61                  | 17.74      | 23.24 | 0.52                  | 5.22 | 16.17                 | 17.78 | 17.95                 | 23.24 | 0.20                             | 1.58 | 0.52                             | 5.22 |
|     |     | 4         | 864  | 864  | 748            | 862     | 1.15                  | 15.51      | 15.51 | 0.23                  | 0.23 | 16.17                 | 17.78 | 17.95                 | 23.24 | 0.20                             | 1.58 | 0.52                             | 5.22 |
|     |     | 5         | 862  | 862  | 758            | 862     | 1.06                  | 13.72      | 13.72 | 0.00                  | 0.00 | 16.17                 | 17.78 | 17.95                 | 23.24 | 0.20                             | 1.58 | 0.52                             | 5.22 |
| 10  | 8   | 1         | 992  | 952  | 752            | 952     | 0.29                  | 31.91      | 26.60 | 4.20                  | 0.00 |                       |       |                       |       | 9.61                             | 1.63 | 14.53                            | 5.86 |
|     |     | 2         | 1056 | 976  | 800            | 922     | 0.45                  | 32.00      | 22.00 | 14.53                 | 5.86 | 31.47                 | 22.01 | 35.00                 | 26.60 | 9.61                             | 1.63 | 14.53                            | 5.86 |
|     |     | 3         | 972  | 892  | 720            | 872     | 0.36                  | 35.00      | 23.89 | 11.47                 | 2.29 | 31.47                 | 22.01 | 35.00                 | 26.60 | 9.61                             | 1.63 | 14.53                            | 5.86 |
|     |     | 4         | 1008 | 952  | 768            | 952     | 0.40                  | 31.25      | 23.96 | 5.88                  | 0.00 | 31.47                 | 22.01 | 35.00                 | 26.60 | 9.61                             | 1.63 | 14.53                            | 5.86 |
|     |     | 5         | 1048 | 936  | 824            | 936     | 0.26                  | 27.18      | 13.59 | 11.97                 | 0.00 | 31.47                 | 22.01 | 35.00                 | 26.60 | 9.61                             | 1.63 | 14.53                            | 5.86 |

**Table D.4 :** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | FTH1 | FTH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |      |      |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |
| 25  | 2   | 1      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 8112 | 8112 | 8112        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 7774 | 7774 | 7774        |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |  |  |  |
|     |     | 4      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 25  | 4   | 1      | 4732 | 4732 | 4732        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 4443 | 4443 | 4368        |         |                 | 1.72       | 1.72  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 4186 | 4186 | 4186        |         |                 | 0.00       | 0.00  |                    |      | 0.34               | 0.34 | 1.72               | 1.72  |                            |      |                            |      |  |  |  |
|     |     | 4      | 4732 | 4732 | 4732        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 4732 | 4732 | 4732        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 25  | 6   | 1      | 3606 | 3606 | 3380        |         |                 | 6.69       | 6.69  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 3647 | 3633 | 3336        | 3633(*) |                 |            | 9.32  | 8.90               |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 3266 | 3266 | 3000        |         |                 | 8.87       | 8.87  |                    |      | 8.31               | 8.23 | 9.32               | 8.90  |                            |      |                            |      |  |  |  |
|     |     | 4      | 3706 | 3706 | 3408        |         |                 | 8.74       | 8.74  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 3705 | 3705 | 3432        |         |                 | 7.95       | 7.95  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 25  | 8   | 1      | 3281 | 3263 | 3000        | 3263(*) |                 |            | 9.37  | 8.77               |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 3502 | 3502 | 3168        | 3430(*) |                 |            | 10.54 | 10.54              |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 3116 | 3026 | 2784        | 3026(*) |                 |            | 11.93 | 8.69               |      |                    | 9.61 | 8.79               | 11.93 | 10.54                      |      |                            |      |  |  |  |
|     |     | 4      | 3413 | 3413 | 3144        | 3413(*) |                 |            | 8.56  | 8.56               |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 3488 | 3479 | 3240        | 3479(*) |                 |            | 7.65  | 7.38               |      |                    |      |                    |       |                            |      |                            |      |  |  |  |

**Table D.4 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 40  | 4   | 1         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 10560 | 10560 | 10560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 10120 | 10120 | 10120          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |
|     |     | 4         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 40  | 6   | 1         | 8280  | 8280  | 8008           |         |                       | 3.40       | 3.40 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 7908  | 7908  | 7392           |         |                       | 6.98       | 6.98 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 7520  | 7520  | 7084           |         |                       | 6.15       | 6.15 |                       |      | 5.58                  | 5.58 | 6.98                  | 6.98 |                                  |      |                                  |      |  |
|     |     | 4         | 8520  | 8520  | 8008           |         |                       | 6.39       | 6.39 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 8408  | 8408  | 8008           |         |                       | 5.00       | 5.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
| 40  | 8   | 1         | 7056  | 7056  | 6960           |         |                       | 1.38       | 1.38 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 2         | 6952  | 6896  | 6800           |         |                       | 2.24       | 1.41 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 3         | 6568  | 6496  | 6400           |         |                       | 2.63       | 1.50 |                       |      | 1.51                  | 1.12 | 2.63                  | 1.50 |                                  |      |                                  |      |  |
|     |     | 4         | 7376  | 7376  | 7280           |         |                       | 1.32       | 1.32 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |
|     |     | 5         | 7200  | 7200  | 7200           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |

**Table D.4 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |
| 55  | 2   | 1      | 40768 | 40768 | 40768       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 37632 | 37632 | 37632       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 36064 | 36064 | 36064       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 40768 | 40768 | 40768       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 40768 | 40768 | 40768       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 21112 | 21112 | 21112       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 19488 | 19488 | 19488       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 18676 | 18676 | 18676       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 21112 | 21112 | 21112       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 21112 | 21112 | 21112       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 14954 | 14954 | 14560       |         |                 | 2.71       | 2.71 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 14196 | 14157 | 13554       |         |                 | 4.74       | 4.45 |                    |      | 3.65               | 3.59 | 4.74               | 4.45 |                            |      |                            |      |  |  |  |
|     |     | 3      | 13408 | 13408 | 12880       |         |                 | 4.10       | 4.10 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 15174 | 15174 | 14580       |         |                 | 4.07       | 4.07 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 14945 | 14945 | 14560       |         |                 | 2.64       | 2.64 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 12416 | 12432 | 11944       |         |                 | 3.95       | 4.09 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 11886 | 11886 | 11406       |         |                 | 4.21       | 4.21 |                    |      | 3.82               | 3.85 | 4.50               | 4.35 |                            |      |                            |      |  |  |  |
|     |     | 3      | 11236 | 11220 | 10752       |         |                 | 4.50       | 4.35 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 12691 | 12707 | 12219       |         |                 | 3.86       | 3.99 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 12311 | 12311 | 11999       |         |                 | 2.60       | 2.60 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |

**Table D.4 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |
| <b>10</b> | <b>2</b> | 1         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 2040 | 2040 | 2040           | 2040    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1980 | 1980 | 1980           | 1980    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>4</b> | 1         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1224 | 1224 | 1224           | 1224    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1188 | 1188 | 1188           | 1188    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>6</b> | 1         | 1078 | 1078 | 1008           | 1078    | 0.92                  | 6.94       | 6.94  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 2         | 1092 | 1092 | 952            | 1092    | 1.67                  | 14.71      | 14.71 | 0.00                  | 0.00 | 10.67                 | 10.67 | 14.71                 | 14.71 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 984  | 984  | 924            | 984     | 1.17                  | 6.49       | 6.49  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 4         | 1118 | 1118 | 1008           | 1118    | 0.88                  | 10.91      | 10.91 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 5         | 1152 | 1152 | 1008           | 1152    | 1.01                  | 14.29      | 14.29 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
| <b>10</b> | <b>8</b> | 1         | 1184 | 1184 | 864            | 1184    | 0.17                  | 37.04      | 37.04 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 2         | 1236 | 1236 | 880            | 1236    | 0.92                  | 40.45      | 40.45 | 0.00                  | 0.00 | 39.85                 | 39.85 | 41.50                 | 41.50 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1132 | 1132 | 800            | 1132    | 0.25                  | 41.50      | 41.50 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 4         | 1204 | 1204 | 864            | 1204    | 0.26                  | 39.35      | 39.35 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 5         | 1274 | 1274 | 904            | 1274    | 0.20                  | 40.93      | 40.93 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |

**Table D.5:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |
| 25  | 2   | 1      | 12168 | 12168 | 12168       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 11492 | 11492 | 11492       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |
|     |     | 3      | 11154 | 11154 | 11154       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 4      | 12168 | 12168 | 12168       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 12168 | 12168 | 12168       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
| 25  | 4   | 1      | 6552  | 6552  | 6552        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 6188  | 6188  | 6188        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |
|     |     | 3      | 6006  | 6006  | 6006        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 4      | 6552  | 6552  | 6552        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 6552  | 6552  | 6552        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
| 25  | 6   | 1      | 4680  | 4680  | 4680        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 4659  | 4659  | 4420        |         |                 | 5.41       | 5.41 |                    |      | 1.62               | 1.62 | 5.41               | 5.41 |                            |      |                            |      |  |  |
|     |     | 3      | 4290  | 4290  | 4290        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 4      | 4730  | 4730  | 4680        |         |                 | 1.07       | 1.07 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 4755  | 4755  | 4680        |         |                 | 1.60       | 1.60 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
| 25  | 8   | 1      | 4053  | 4053  | 3744        |         |                 | 8.25       | 8.25 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 4220  | 4220  | 3888        | 4220(*) |                 | 8.54       | 8.54 |                    |      | 8.45               | 8.45 | 8.90               | 8.90 |                            |      |                            |      |  |  |
|     |     | 3      | 3816  | 3816  | 3504        | 3807(*) |                 | 8.90       | 8.90 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 4      | 4203  | 4203  | 3864        | 4194(*) |                 | 8.77       | 8.77 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 4269  | 4269  | 3960        | 4269(*) |                 | 7.80       | 7.80 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |

**Table D.5 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |  |
| 40  | 2   | 1         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 28560 | 28560 | 28560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 27720 | 27720 | 27720          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
| 40  | 4   | 1         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 14960 | 14960 | 14960          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 14520 | 14520 | 14520          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
| 40  | 6   | 1         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 10512 | 10512 | 10472          |         |                       | 0.38       | 0.38 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 10164 | 10164 | 10164          |         |                       | 0.00       | 0.00 |                       |      | 0.22                  | 0.22 | 0.72                  | 0.72 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 11168 | 11168 | 11088          |         |                       | 0.72       | 0.72 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
| 40  | 8   | 1         | 8992  | 8992  | 8960           |         |                       | 0.36       | 0.36 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 8864  | 8848  | 8800           |         |                       | 0.73       | 0.55 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 8464  | 8448  | 8400           |         |                       | 0.76       | 0.57 |                       |      | 0.44                  | 0.36 | 0.76                  | 0.57 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 9312  | 9312  | 9280           |         |                       | 0.34       | 0.34 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 9200  | 9200  | 9200           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |

**Table D.5 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$



| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |
| 55  | 2   | 1      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 53312 | 53312 | 53312       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 51744 | 51744 | 51744       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 27608 | 27608 | 27608       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 26796 | 26796 | 26796       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 19095 | 19095 | 19040       |         |                 | 0.29       | 0.29 |                    |      | 0.06               | 0.06 | 0.29               | 0.29 |                            |      |                            |      |  |  |  |
|     |     | 3      | 18480 | 18480 | 18480       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 16110 | 16110 | 15734       |         |                 | 2.39       | 2.39 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 15673 | 15657 | 15196       |         |                 | 3.14       | 3.03 |                    |      | 2.60               | 2.56 | 3.14               | 3.03 |                            |      |                            |      |  |  |  |
|     |     | 3      | 14932 | 14918 | 14542       |         |                 | 2.68       | 2.59 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 16440 | 16440 | 16009       |         |                 | 2.69       | 2.69 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 16119 | 16119 | 15789       |         |                 | 2.09       | 2.09 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |

**Table D.5 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |
| <b>10</b> | <b>2</b> | 1         | 2400 | 2400 | 2400           | 2400    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1860 | 1860 | 1860           | 1860    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1680 | 1680 | 1680           | 1680    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 2220 | 2220 | 2220           | 2220    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 2340 | 2340 | 2340           | 2340    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>4</b> | 1         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1116 | 1116 | 1116           | 1116    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1008 | 1008 | 1008           | 1008    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 4         | 1332 | 1332 | 1332           | 1332    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 5         | 1404 | 1404 | 1404           | 1404    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| <b>10</b> | <b>6</b> | 1         | 1150 | 1150 | 1120           | 1150    | 1.08                  | 2.68       | 2.68  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 2         | 1028 | 1028 | 868            | 1028    | 1.25                  | 18.43      | 18.43 | 0.00                  | 0.00 | 11.54                 | 11.54 | 18.43                 | 18.43 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 902  | 902  | 784            | 902     | 0.70                  | 15.05      | 15.05 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 4         | 1136 | 1136 | 1036           | 1136    | 0.92                  | 9.65       | 9.65  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 5         | 1222 | 1222 | 1092           | 1222    | 1.29                  | 11.90      | 11.90 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
| <b>10</b> | <b>8</b> | 1         | 1240 | 1240 | 960            | 1240    | 0.24                  | 29.17      | 29.17 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 2         | 1164 | 1164 | 856            | 1164    | 0.28                  | 35.98      | 35.98 | 0.00                  | 0.00 | 36.53                 | 36.53 | 40.60                 | 40.60 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 3         | 1062 | 1062 | 760            | 1062    | 0.23                  | 39.74      | 39.74 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 4         | 1218 | 1218 | 888            | 1218    | 0.22                  | 37.16      | 37.16 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|           |          | 5         | 1316 | 1316 | 936            | 1316    | 0.23                  | 40.60      | 40.60 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |

**Table D.6:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |
| 25  | 2   | 1      | 13520 | 13520 | 13520       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 2      | 10478 | 10478 | 10478       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |
|     |     | 3      | 9464  | 9464  | 9464        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 12506 | 12506 | 12506       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 13182 | 13182 | 13182       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
| 25  | 4   | 1      | 7280  | 7280  | 7280        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 2      | 5642  | 5642  | 5642        |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |
|     |     | 3      | 5096  | 5096  | 5096        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 6734  | 6734  | 6734        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 7098  | 7098  | 7098        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
| 25  | 6   | 1      | 5200  | 5200  | 5200        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 2      | 4408  | 4408  | 4030        |         |                 | 9.38       | 9.38  |                    |      | 2.97               | 2.97 | 9.38               | 9.38  |                            |      |                            |      |
|     |     | 3      | 3821  | 3821  | 3640        |         |                 | 4.97       | 4.97  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 4835  | 4835  | 4810        |         |                 | 0.52       | 0.52  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 5070  | 5070  | 5070        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
| 25  | 8   | 1      | 4371  | 4371  | 4160        |         |                 | 5.07       | 5.07  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 2      | 4051  | 4051  | 3672        |         |                 | 10.32      | 10.32 |                    |      | 9.11               | 9.35 | 12.05              | 25.65 |                            |      |                            |      |
|     |     | 3      | 3523  | 3523  | 3144        |         |                 | 12.05      | 12.05 |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 4337  | 4384  | 3936        |         |                 | 10.19      | 11.38 |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 4506  | 4506  | 4176        |         |                 | 7.90       | 7.90  |                    |      |                    |      |                    |       |                            |      |                            |      |

**Table D.6 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |  |
| 40  | 2   | 1      | 33600 | 33600 | 33600       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 2      | 26040 | 26040 | 26040       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 3      | 23520 | 23520 | 23520       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |
|     |     | 4      | 31080 | 31080 | 31080       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 5      | 32760 | 32760 | 32760       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
| 40  | 4   | 1      | 17600 | 17600 | 17600       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 2      | 13640 | 13640 | 13640       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 3      | 12320 | 12320 | 12320       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |
|     |     | 4      | 16280 | 16280 | 16280       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 5      | 17160 | 17160 | 17160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
| 40  | 6   | 1      | 12320 | 12320 | 12320       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 2      | 9768  | 9768  | 9548        |         |                 | 2.30       | 2.30 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 3      | 8912  | 8912  | 8624        |         |                 | 3.34       | 3.34 |                    |      | 1.20               | 1.20 | 3.34               | 3.34 |                            |      |                            |      |  |
|     |     | 4      | 11436 | 11436 | 11396       |         |                 | 0.35       | 0.35 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 5      | 12012 | 12012 | 12012       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
| 40  | 8   | 1      | 9792  | 9792  | 9760        |         |                 | 0.33       | 0.33 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 2      | 8488  | 8440  | 8200        |         |                 | 3.51       | 2.93 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 3      | 7816  | 7784  | 7400        |         |                 | 5.62       | 5.19 |                    |      | 2.16               | 1.96 | 5.62               | 5.19 |                            |      |                            |      |  |
|     |     | 4      | 9608  | 9608  | 9480        |         |                 | 1.35       | 1.35 |                    |      |                    |      |                    |      |                            |      |                            |      |  |
|     |     | 5      | 9800  | 9800  | 9800        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |

**Table D.6 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |  |
| 55  | 2   | 1         | 62720 | 62720 | 62720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 48608 | 48608 | 48608          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 43904 | 43904 | 43904          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 58016 | 58016 | 58016          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 61152 | 61152 | 61152          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
| 55  | 4   | 1         | 32480 | 32480 | 32480          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 25172 | 25172 | 25172          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 22736 | 22736 | 22736          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 30044 | 30044 | 30044          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 31668 | 31668 | 31668          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
| 55  | 6   | 1         | 22400 | 22400 | 22400          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 17658 | 17658 | 17360          |         |                       | 1.72       | 1.72 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 15949 | 15949 | 15680          |         |                       | 1.72       | 1.72 |                       |      | 0.69                  | 0.69 | 1.72                  | 1.72 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 20720 | 20720 | 20720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
| 55  | 8   | 1         | 17640 | 17640 | 17360          |         |                       | 1.61       | 1.61 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 2         | 14815 | 14767 | 14059          |         |                       | 5.38       | 5.04 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 3         | 13409 | 13409 | 12647          |         |                       | 6.03       | 6.03 |                       |      | 3.69                  | 3.62 | 6.03                  | 6.03 |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 4         | 16960 | 16957 | 16388          |         |                       | 3.49       | 3.47 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |
|     |     | 5         | 17256 | 17256 | 16926          |         |                       | 1.95       | 1.95 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |

**Table D.6 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [5, 15]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|     |     |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |
| 10  | 2   | 1         | 1826 | 1826 | 1810           | 1820    | 784.62                | 0.88       | 0.88  | 0.33                  | 0.33 | 0.83                  | 0.73  | 1.20                  | 0.96  | 0.27                             | 0.18 | 0.36                             | 0.33 |
|     |     | 2         | 1730 | 1726 | 1710           | 1724    | 587.18                | 1.17       | 0.94  | 0.35                  | 0.12 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 1680 | 1676 | 1660           | 1674    | 759.24                | 1.20       | 0.96  | 0.36                  | 0.12 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 1846 | 1846 | 1830           | 1840    | 458.32                | 0.87       | 0.87  | 0.33                  | 0.33 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 1810 | 1810 | 1810           | 1810    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
| 10  | 4   | 1         | 1482 | 1482 | 1256           | 1452    | 21.96                 | 17.99      | 17.99 | 2.07                  | 2.07 | 19.23                 | 19.23 | 21.77                 | 21.77 | 3.15                             | 3.15 | 4.57                             | 4.57 |
|     |     | 2         | 1510 | 1510 | 1240           | 1444    | 91.09                 | 21.77      | 21.77 | 4.57                  | 4.57 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 1428 | 1428 | 1200           | 1380    | 40.62                 | 19.00      | 19.00 | 3.48                  | 3.48 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 1502 | 1502 | 1280           | 1472    | 23.32                 | 17.34      | 17.34 | 2.04                  | 2.04 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 1546 | 1546 | 1288           | 1492    | 31.23                 | 20.03      | 20.03 | 3.62                  | 3.62 |                       |       |                       |       |                                  |      |                                  |      |
| 10  | 6   | 1         | 1826 | 1826 | 1518           | 1792    | 1.36                  | 20.29      | 20.29 | 1.90                  | 1.90 | 21.53                 | 21.53 | 24.48                 | 24.48 | 2.06                             | 2.06 | 2.49                             | 2.49 |
|     |     | 2         | 1868 | 1868 | 1502           | 1824    | 2.17                  | 24.37      | 24.37 | 2.41                  | 2.41 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 1810 | 1810 | 1454           | 1766    | 1.84                  | 24.48      | 24.48 | 2.49                  | 2.49 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 1844 | 1844 | 1548           | 1812    | 1.58                  | 19.12      | 19.12 | 1.77                  | 1.77 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 1860 | 1860 | 1558           | 1828    | 1.81                  | 19.38      | 19.38 | 1.75                  | 1.75 |                       |       |                       |       |                                  |      |                                  |      |
| 10  | 8   | 1         | 2322 | 2322 | 2032           | 2220    | 0.8                   | 14.27      | 14.27 | 4.59                  | 4.59 | 14.39                 | 14.39 | 15.40                 | 15.40 | 4.77                             | 4.77 | 5.48                             | 5.48 |
|     |     | 2         | 2390 | 2390 | 2080           | 2270    | 0.66                  | 14.90      | 14.90 | 5.29                  | 5.29 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 2308 | 2308 | 2000           | 2188    | 0.62                  | 15.40      | 15.40 | 5.48                  | 5.48 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 2342 | 2342 | 2048           | 2240    | 0.46                  | 14.36      | 14.36 | 4.55                  | 4.55 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 2378 | 2378 | 2104           | 2288    | 0.42                  | 13.02      | 13.02 | 3.93                  | 3.93 |                       |       |                       |       |                                  |      |                                  |      |

**Table D.7:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | FTH1 | FTH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |
| 25  | 2   | 1      | 9451 | 9444 | 8788        |         |                 | 7.54       | 7.46 |                    |      | 7.78               | 7.80 | 8.16               | 8.33 |                            |      |                            |      |
|     |     | 2      | 8801 | 8809 | 8137        |         |                 | 8.16       | 8.26 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 8460 | 8476 | 7824        |         |                 | 8.13       | 8.33 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 9486 | 9476 | 8788        |         |                 | 7.94       | 7.83 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 9412 | 9412 | 8788        |         |                 | 7.10       | 7.10 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 4   | 1      | 6348 | 6332 | 6192        |         |                 | 2.52       | 2.26 |                    |      | 3.63               | 3.34 | 5.46               | 5.06 |                            |      |                            |      |
|     |     | 2      | 6353 | 6329 | 6024        |         |                 | 5.46       | 5.06 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 6048 | 6024 | 5736        |         |                 | 5.44       | 5.02 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 6396 | 6404 | 6240        |         |                 | 2.50       | 2.63 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 6380 | 6348 | 6240        |         |                 | 2.24       | 1.73 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 6   | 1      | 6604 | 6454 | 6258        |         |                 | 5.53       | 3.13 |                    |      | 5.73               | 3.34 | 7.24               | 4.60 |                            |      |                            |      |
|     |     | 2      | 6799 | 6715 | 6420        |         |                 | 5.90       | 4.60 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 6486 | 6288 | 6048        |         |                 | 7.24       | 3.97 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 6688 | 6508 | 6366        |         |                 | 5.06       | 2.23 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 6754 | 6616 | 6438        |         |                 | 4.91       | 2.76 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 8   | 1      | 7020 | 6996 | 6840        |         |                 | 2.63       | 2.28 |                    |      | 3.05               | 3.06 | 5.04               | 4.58 |                            |      |                            |      |
|     |     | 2      | 7361 | 7329 | 7008        |         |                 | 5.04       | 4.58 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 6840 | 6904 | 6624        |         |                 | 3.26       | 4.23 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 7124 | 7124 | 6984        |         |                 | 2.00       | 2.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 7244 | 7236 | 7080        |         |                 | 2.32       | 2.20 |                    |      |                    |      |                    |      |                            |      |                            |      |

**Table D.7 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 40  | 2   | 1         | 22922 | 22916 | 22800          |         |                       | 0.54       | 0.51  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 21376 | 21404 | 21200          |         |                       | 0.83       | 0.96  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 20588 | 20632 | 20400          |         |                       | 0.92       | 1.14  |                       |      | 0.57                  | 0.65  | 0.92                  | 1.14  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 23008 | 23028 | 22880          |         |                       | 0.56       | 0.65  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 22800 | 22800 | 22800          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 4   | 1         | 14664 | 14616 | 14400          |         |                       | 1.83       | 1.50  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 14192 | 14192 | 13680          |         |                       | 3.74       | 3.74  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 13800 | 13800 | 13200          |         |                       | 4.55       | 4.55  |                       |      | 2.48                  | 2.38  | 4.55                  | 4.55  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 14800 | 14792 | 14560          |         |                       | 1.65       | 1.59  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 14568 | 14552 | 14480          |         |                       | 0.61       | 0.50  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 6   | 1         | 12714 | 12456 | 11248          |         |                       | 13.03      | 10.74 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 12996 | 12708 | 11288          |         |                       | 15.13      | 12.58 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 12684 | 12522 | 10994          |         |                       | 15.37      | 13.90 |                       |      | 13.52                 | 11.34 | 15.37                 | 13.90 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 12844 | 12580 | 11536          |         |                       | 11.34      | 9.05  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 13040 | 12776 | 11570          |         |                       | 12.71      | 10.42 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 8   | 1         | 15072 | 14616 | 14384          |         |                       | 4.78       | 1.61  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 15328 | 14840 | 14496          |         |                       | 5.74       | 2.37  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 14960 | 14528 | 14208          |         |                       | 5.29       | 2.25  |                       |      | 4.55                  | 1.67  | 5.74                  | 2.37  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 15312 | 14912 | 14736          |         |                       | 3.91       | 1.19  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 15280 | 14968 | 14832          |         |                       | 3.02       | 0.92  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |

**Table D.7 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$



| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |  |
| 55  | 2   | 1      | 42268 | 42320 | 40768       |         |                 | 3.68       | 3.81 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 2      | 39315 | 39371 | 37692       |         |                 | 4.31       | 4.45 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 3      | 37744 | 37832 | 36234       |         |                 | 4.17       | 4.41 |                    |      | 3.87               | 4.00 | 4.31               | 4.45 |                            |      |                            |      |  |  |  |  |
|     |     | 4      | 42390 | 42436 | 40768       |         |                 | 3.98       | 4.09 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 5      | 42088 | 42088 | 40768       |         |                 | 3.24       | 3.24 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
| 55  | 4   | 1      | 24931 | 24923 | 23807       |         |                 | 4.72       | 4.69 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 2      | 23900 | 23956 | 22348       |         |                 | 6.94       | 7.20 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 3      | 23298 | 23286 | 21536       |         |                 | 8.18       | 8.13 |                    |      | 5.61               | 5.62 | 8.18               | 8.13 |                            |      |                            |      |  |  |  |  |
|     |     | 4      | 25104 | 25096 | 23972       |         |                 | 4.72       | 4.69 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 5      | 24635 | 24619 | 23807       |         |                 | 3.48       | 3.41 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
| 55  | 6   | 1      | 22498 | 21934 | 21114       |         |                 | 6.55       | 3.88 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 2      | 22507 | 21985 | 21222       |         |                 | 6.06       | 3.60 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 3      | 21990 | 21402 | 20448       |         |                 | 7.54       | 4.67 |                    |      | 6.18               | 3.65 | 7.54               | 4.67 |                            |      |                            |      |  |  |  |  |
|     |     | 4      | 22498 | 22072 | 21474       |         |                 | 4.77       | 2.78 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 5      | 22570 | 22006 | 21294       |         |                 | 5.99       | 3.34 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
| 55  | 8   | 1      | 23884 | 23356 | 22201       |         |                 | 7.58       | 5.20 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 2      | 23906 | 23490 | 22308       |         |                 | 7.16       | 5.30 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 3      | 23192 | 22880 | 21534       |         |                 | 7.70       | 6.25 |                    |      | 7.19               | 5.09 | 7.70               | 6.25 |                            |      |                            |      |  |  |  |  |
|     |     | 4      | 24055 | 23447 | 22534       |         |                 | 6.75       | 4.05 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |
|     |     | 5      | 23859 | 23387 | 22346       |         |                 | 6.77       | 4.66 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |  |

**Table D.7 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | FTH1 | FTH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2  | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |
| 10  | 2   | 1      | 2310 | 2310 | 2310        | 2310    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00  | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 2210 | 2210 | 2210        | 2210    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 2160 | 2160 | 2160        | 2160    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 2330 | 2330 | 2330        | 2330    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 2310 | 2310 | 2310        | 2310    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
| 10  | 4   | 1      | 1750 | 1750 | 1446        | 1750    | 35.64           | 21.02      | 21.02 | 0.00               | 0.00 | 20.66              | 20.42 | 21.64              | 21.02 | 0.19                       | 0.00 | 0.97                       | 0.00 |
|     |     | 2      | 1682 | 1682 | 1394        | 1682    | 35.67           | 20.14      | 20.14 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 1664 | 1648 | 1368        | 1648    | 59.81           | 21.64      | 20.47 | 0.97               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1770 | 1770 | 1466        | 1770    | 33.15           | 20.74      | 20.74 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1734 | 1734 | 1446        | 1734    | 19.95           | 19.75      | 19.75 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
| 10  | 6   | 1      | 1926 | 1926 | 1698        | 1912    | 1.24            | 13.43      | 13.43 | 0.73               | 0.73 | 14.52              | 14.52 | 17.00              | 17.00 | 0.90                       | 0.90 | 1.27                       | 1.27 |
|     |     | 2      | 1968 | 1968 | 1682        | 1944    | 1.78            | 17.00      | 17.00 | 1.23               | 1.23 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 1910 | 1910 | 1634        | 1886    | 1.55            | 16.89      | 16.89 | 1.27               | 1.27 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1944 | 1944 | 1728        | 1932    | 1.34            | 12.50      | 12.50 | 0.62               | 0.62 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1960 | 1960 | 1738        | 1948    | 1.13            | 12.77      | 12.77 | 0.62               | 0.62 |                    |       |                    |       |                            |      |                            |      |
| 10  | 8   | 1      | 2422 | 2422 | 1014        | 2320    | 0.55            | 14.68      | 14.68 | 4.40               | 4.40 | 14.79              | 14.79 | 15.77              | 15.77 | 4.57                       | 4.57 | 5.24                       | 5.24 |
|     |     | 2      | 2490 | 2490 | 986         | 2370    | 1.02            | 15.28      | 15.28 | 5.06               | 5.06 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 2408 | 2408 | 972         | 2288    | 1.15            | 15.77      | 15.77 | 5.24               | 5.24 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 2442 | 2442 | 1034        | 2340    | 0.91            | 14.76      | 14.76 | 4.36               | 4.36 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 2478 | 2478 | 1014        | 2388    | 0.95            | 13.46      | 13.46 | 3.77               | 3.77 |                    |       |                    |       |                            |      |                            |      |

**Table D.8:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |
| 25  | 2   | 1         | 12518 | 12518 | 12168          |         |                       | 2.88       | 2.88 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 11917 | 11917 | 11492          |         |                       | 3.70       | 3.70 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 11579 | 11579 | 11154          |         |                       | 3.81       | 3.81 |                       |      | 3.35                  | 3.35 | 3.81                  | 3.81 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 12568 | 12568 | 12168          |         |                       | 3.29       | 3.29 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 12543 | 12543 | 12168          |         |                       | 3.08       | 3.08 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 4   | 1         | 7928  | 7936  | 6552           |         |                       | 3.88       | 3.98 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 7676  | 7604  | 6188           |         |                       | 2.84       | 1.88 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7338  | 7482  | 6006           |         |                       | 2.26       | 4.26 |                       |      | 2.88                  | 3.13 | 3.88                  | 4.26 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 7928  | 7936  | 6552           |         |                       | 3.23       | 3.33 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 7848  | 7848  | 6552           |         |                       | 2.19       | 2.19 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 6   | 1         | 7308  | 7284  | 4680           |         |                       | 2.18       | 1.85 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 7448  | 7376  | 4420           |         |                       | 3.79       | 2.79 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7110  | 7062  | 4290           |         |                       | 3.95       | 3.25 |                       |      | 2.94                  | 2.20 | 3.95                  | 3.25 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 7404  | 7380  | 4680           |         |                       | 2.15       | 1.82 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 7464  | 7368  | 4680           |         |                       | 2.64       | 1.32 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 8   | 1         | 7744  | 7672  | 3744           |         |                       | 2.43       | 1.48 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 8004  | 7884  | 3548           |         |                       | 3.57       | 2.02 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7562  | 7514  | 3435           |         |                       | 2.97       | 2.31 |                       |      | 2.68                  | 1.68 | 3.57                  | 2.31 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 7864  | 7816  | 3744           |         |                       | 2.08       | 1.45 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 7984  | 7888  | 3744           |         |                       | 2.36       | 1.13 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table D.8 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 40  | 2   | 1         | 30800 | 30800 | 30800          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 29200 | 29200 | 29200          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 28400 | 28400 | 28400          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 30880 | 30880 | 30880          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 30800 | 30800 | 30800          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 4   | 1         | 18576 | 18584 | 18400          |         |                       | 0.96       | 1.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 17880 | 17872 | 17680          |         |                       | 1.13       | 1.09  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 17400 | 17392 | 17200          |         |                       | 1.16       | 1.12  |                       |      | 0.84                  | 0.84 | 1.16                  | 1.12  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 18736 | 18744 | 18560          |         |                       | 0.95       | 0.99  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 18480 | 18480 | 18480          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 6   | 1         | 14704 | 14692 | 13648          |         |                       | 7.74       | 7.65  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 14452 | 14452 | 13192          |         |                       | 9.55       | 9.55  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 14164 | 14164 | 12844          |         |                       | 10.28      | 10.28 |                       |      | 8.42                  | 8.39 | 10.28                 | 10.28 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 14864 | 14852 | 13808          |         |                       | 7.65       | 7.56  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 14676 | 14676 | 13728          |         |                       | 6.91       | 6.91  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 8   | 1         | 16112 | 15496 | 15424          |         |                       | 4.46       | 0.47  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 16368 | 15752 | 15536          |         |                       | 5.36       | 1.39  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 16000 | 15464 | 15248          |         |                       | 4.93       | 1.42  |                       |      | 4.24                  | 0.78 | 5.36                  | 1.42  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 16352 | 15840 | 15776          |         |                       | 3.65       | 0.41  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 16320 | 15904 | 15872          |         |                       | 2.82       | 0.20  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |  |

**Table D.8 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |
| 55  | 2   | 1         | 57218 | 57218 | 56448          |         |                       | 1.36       | 1.36 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 54192 | 54192 | 53312          |         |                       | 1.65       | 1.65 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 52679 | 52679 | 51744          |         |                       | 1.81       | 1.81 |                       |      | 1.55                  | 1.55 | 1.81                  | 1.81 |                                  |      |                                  |      |  |  |
|     |     | 4         | 57328 | 57328 | 56448          |         |                       | 1.56       | 1.56 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 57218 | 57218 | 56448          |         |                       | 1.36       | 1.36 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 55  | 4   | 1         | 32641 | 32665 | 31377          |         |                       | 4.03       | 4.10 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 31154 | 31178 | 29918          |         |                       | 4.13       | 4.21 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 30316 | 30340 | 29106          |         |                       | 4.16       | 4.24 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 4         | 32798 | 32830 | 31542          |         |                       | 3.98       | 4.08 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 32313 | 32313 | 31377          |         |                       | 2.98       | 2.98 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 55  | 6   | 1         | 26112 | 26082 | 20350          |         |                       | 1.59       | 1.47 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 25784 | 25664 | 19914          |         |                       | 3.58       | 3.09 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 25170 | 25080 | 19278          |         |                       | 4.04       | 3.67 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 4         | 26328 | 26286 | 20483          |         |                       | 1.57       | 1.41 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 26028 | 25938 | 20445          |         |                       | 1.05       | 0.70 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
| 55  | 8   | 1         | 25394 | 24458 | 23735          |         |                       | 6.99       | 3.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 2         | 25320 | 24520 | 23818          |         |                       | 6.31       | 2.95 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 3         | 24702 | 23894 | 23044          |         |                       | 7.19       | 3.69 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 4         | 25565 | 24621 | 24044          |         |                       | 6.33       | 2.40 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |
|     |     | 5         | 25369 | 24529 | 23856          |         |                       | 6.34       | 2.82 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |

**Table D.8 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins. # | FTH1 | FTH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|--|
|     |     |        |      |      |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2  | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |  |
| 10  | 2   | 1      | 2510 | 2510 | 2510        | 2510    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 2      | 2072 | 2072 | 2060        | 2072    | 892.25          | 0.58       | 0.58  | 0.00               | 0.00 | 0.45               | 0.45  | 1.68               | 1.68  | 0.00                       | 0.00 | 0.00                       | 0.00 |  |
|     |     | 3      | 1942 | 1942 | 1910        | 1942    | 1025.38         | 1.68       | 1.68  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 4      | 2380 | 2380 | 2380        | 2380    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 5      | 2460 | 2460 | 2460        | 2460    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |  |
|     |     |        |      |      |             |         |                 |            |       |                    |      |                    |       |                    |       |                            |      |                            |      |  |
| 10  | 4   | 1      | 1902 | 1902 | 1550        | 1902    | 76.85           | 22.71      | 22.71 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 2      | 1648 | 1804 | 1352        | 1648    | 74.13           | 21.89      | 33.43 | 0.00               | 9.47 | 22.81              | 26.37 | 24.84              | 33.43 | 0.15                       | 3.05 | 0.76                       | 9.47 |  |
|     |     | 3      | 1598 | 1678 | 1280        | 1586    | 37.91           | 24.84      | 31.09 | 0.76               | 5.80 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 4      | 1852 | 1852 | 1492        | 1852    | 35.51           | 24.13      | 24.13 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 5      | 1836 | 1836 | 1524        | 1836    | 19.91           | 20.47      | 20.47 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |  |
|     |     |        |      |      |             |         |                 |            |       |                    |      |                    |       |                    |       |                            |      |                            |      |  |
| 10  | 6   | 1      | 1972 | 1972 | 1770        | 1966    | 1.62            | 11.41      | 11.41 | 0.31               | 0.31 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 2      | 1950 | 1950 | 1628        | 1918    | 1.65            | 19.78      | 19.78 | 1.67               | 1.67 | 15.36              | 15.36 | 21.63              | 21.63 | 0.95                       | 0.95 | 1.84                       | 1.84 |  |
|     |     | 3      | 1878 | 1878 | 1544        | 1844    | 1.50            | 21.63      | 21.63 | 1.84               | 1.84 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 4      | 1972 | 1972 | 1746        | 1960    | 1.21            | 12.94      | 12.94 | 0.61               | 0.61 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 5      | 1990 | 1990 | 1792        | 1984    | 1.05            | 11.05      | 11.05 | 0.30               | 0.30 |                    |       |                    |       |                            |      |                            |      |  |
|     |     |        |      |      |             |         |                 |            |       |                    |      |                    |       |                    |       |                            |      |                            |      |  |
| 10  | 8   | 1      | 2470 | 2470 | 2144        | 2362    | 0.90            | 15.21      | 15.21 | 4.57               | 4.57 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 2      | 2476 | 2476 | 2136        | 2344    | 1.12            | 15.92      | 15.92 | 5.63               | 5.63 | 15.48              | 15.48 | 16.76              | 16.76 | 5.03                       | 5.03 | 6.15                       | 6.15 |  |
|     |     | 3      | 2382 | 2382 | 2040        | 2244    | 0.89            | 16.76      | 16.76 | 6.15               | 6.15 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 4      | 2476 | 2476 | 2136        | 2356    | 0.58            | 15.92      | 15.92 | 5.09               | 5.09 |                    |       |                    |       |                            |      |                            |      |  |
|     |     | 5      | 2508 | 2508 | 2208        | 2418    | 0.33            | 13.59      | 13.59 | 3.72               | 3.72 |                    |       |                    |       |                            |      |                            |      |  |
|     |     |        |      |      |             |         |                 |            |       |                    |      |                    |       |                    |       |                            |      |                            |      |  |

**Table D.9:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |
| 25  | 2   | 1      | 13770 | 13770 | 13520       |         |                 | 1.85       | 1.85  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 11008 | 11008 | 10478       |         |                 | 5.06       | 5.06  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 10079 | 10086 | 9464        |         |                 | 6.50       | 6.57  |                    |      | 3.74               | 3.75 | 6.50               | 6.57  |                            |      |                            |      |  |  |  |
|     |     | 4      | 12881 | 12881 | 12506       |         |                 | 3.00       | 3.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 13482 | 13482 | 13182       |         |                 | 2.28       | 2.28  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 25  | 4   | 1      | 8864  | 8864  | 8208        |         |                 | 7.99       | 7.99  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 7382  | 7622  | 7032        |         |                 | 4.98       | 8.39  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 6896  | 7208  | 6456        |         |                 | 6.82       | 11.65 |                    |      | 6.36               | 8.09 | 7.99               | 11.65 |                            |      |                            |      |  |  |  |
|     |     | 4      | 8386  | 8418  | 7824        |         |                 | 7.18       | 7.59  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 8502  | 8502  | 8112        |         |                 | 4.81       | 4.81  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 25  | 6   | 1      | 7760  | 7736  | 7536        |         |                 | 2.97       | 2.65  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 7490  | 7418  | 6888        |         |                 | 8.74       | 7.69  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 7064  | 7016  | 6360        |         |                 | 11.07      | 10.31 |                    |      | 6.25               | 5.51 | 11.07              | 10.31 |                            |      |                            |      |  |  |  |
|     |     | 4      | 7682  | 7658  | 7344        |         |                 | 4.60       | 4.28  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 7854  | 7758  | 7560        |         |                 | 3.89       | 2.62  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 25  | 8   | 1      | 8096  | 8024  | 7848        |         |                 | 3.16       | 2.24  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 8006  | 7886  | 7512        |         |                 | 6.58       | 4.98  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 7488  | 7440  | 6984        |         |                 | 7.22       | 6.53  |                    |      | 4.75               | 3.75 | 7.22               | 6.53  |                            |      |                            |      |  |  |  |
|     |     | 4      | 8058  | 8010  | 7776        |         |                 | 3.63       | 3.01  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 8270  | 8174  | 8016        |         |                 | 3.17       | 1.97  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |

**Table D.9 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2  | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |
| 40  | 2   | 1      | 34000 | 34000 | 34000       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 2      | 26800 | 26800 | 26800       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 3      | 24684 | 24592 | 24400       |         |                 | 1.16       | 0.79  |                    |      | 0.23               | 0.16  | 1.16               | 0.79  |                            |      |                            |      |  |  |
|     |     | 4      | 31680 | 31680 | 31680       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 5      | 33200 | 33200 | 33200       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
| 40  | 4   | 1      | 20304 | 20288 | 20000       |         |                 | 1.52       | 1.44  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 2      | 17080 | 17080 | 16480       |         |                 | 3.64       | 3.64  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 3      | 16128 | 16000 | 15200       |         |                 | 6.11       | 5.26  |                    |      | 2.93               | 2.78  | 6.11               | 5.26  |                            |      |                            |      |  |  |
|     |     | 4      | 19600 | 19632 | 18960       |         |                 | 3.38       | 3.54  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 5      | 19680 | 19680 | 19680       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
| 40  | 6   | 1      | 16172 | 16052 | 14720       |         |                 | 9.86       | 9.05  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 2      | 14716 | 14716 | 12468       |         |                 | 18.03      | 18.03 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 3      | 14204 | 14204 | 11716       |         |                 | 21.24      | 21.24 |                    |      | 13.81              | 13.65 | 21.24              | 21.24 |                            |      |                            |      |  |  |
|     |     | 4      | 15684 | 15684 | 14076       |         |                 | 11.42      | 11.42 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 5      | 15768 | 15768 | 14532       |         |                 | 8.51       | 8.51  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
| 40  | 8   | 1      | 16608 | 16464 | 16160       |         |                 | 2.77       | 1.88  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 2      | 16328 | 15752 | 15224       |         |                 | 7.25       | 3.47  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 3      | 15848 | 15312 | 14728       |         |                 | 7.60       | 3.97  |                    |      | 5.11               | 2.80  | 7.60               | 3.97  |                            |      |                            |      |  |  |
|     |     | 4      | 16648 | 16392 | 15880       |         |                 | 4.84       | 3.22  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |
|     |     | 5      | 16696 | 16440 | 16200       |         |                 | 3.06       | 1.48  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |

**Table D.9 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$



| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |
| 55  | 2   | 1         | 63270 | 63270 | 62720          |         |                       | 0.88       | 0.88  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 49653 | 49653 | 48608          |         |                       | 2.15       | 2.15  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 45404 | 45322 | 43904          |         |                       | 3.42       | 3.23  |                       |      | 1.77                  | 1.73 | 3.42                  | 3.23  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 58841 | 58841 | 58016          |         |                       | 1.42       | 1.42  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 61757 | 61757 | 61152          |         |                       | 0.99       | 0.99  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 55  | 4   | 1         | 36021 | 36005 | 34405          |         |                       | 4.70       | 4.65  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 29629 | 29629 | 27647          |         |                       | 7.17       | 7.17  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 27657 | 27737 | 25321          |         |                       | 9.23       | 9.54  |                       |      | 6.15                  | 6.24 | 9.23                  | 9.54  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 34445 | 34509 | 32299          |         |                       | 6.64       | 6.84  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 34662 | 34662 | 33648          |         |                       | 3.01       | 3.01  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 55  | 6   | 1         | 28406 | 28328 | 27648          |         |                       | 2.74       | 2.46  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 26276 | 25964 | 23436          |         |                       | 12.12      | 10.79 |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 25244 | 24974 | 21762          |         |                       | 16.00      | 14.76 |                       |      | 7.54                  | 6.88 | 16.00                 | 14.76 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 27566 | 27608 | 26406          |         |                       | 4.39       | 4.55  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 27888 | 27714 | 27216          |         |                       | 2.47       | 1.83  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 55  | 8   | 1         | 26246 | 26054 | 24950          |         |                       | 5.19       | 4.42  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 25347 | 24563 | 23365          |         |                       | 8.48       | 5.13  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 24587 | 23859 | 22289          |         |                       | 10.31      | 7.04  |                       |      | 7.21                  | 5.12 | 10.31                 | 7.04  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 26004 | 25556 | 24291          |         |                       | 7.05       | 5.21  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 25950 | 25654 | 24717          |         |                       | 4.99       | 3.79  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |

**Table D.9 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |       | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |       | Maximum<br>Optimality<br>Gap (%) |       |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|-------|-----------------------|-------|-----------------------|-------|----------------------------------|-------|----------------------------------|-------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2  | FTH1                             | FTH2  |
| <b>10</b> | <b>2</b> | 1         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00  | 0.00                             | 0.00  |
|           |          | 2         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 3         | 1380 | 1380 | 1380           | 1380    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 4         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 5         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
| <b>10</b> | <b>4</b> | 1         | 966  | 966  | 936            | 958     | 9.01                  | 3.21       | 3.21  | 0.84                  | 0.84  | 11.57                 | 11.57 | 19.68                 | 19.68 | 0.70                             | 0.70  | 2.27                             | 2.27  |
|           |          | 2         | 1034 | 1034 | 864            | 1030    | 33.52                 | 19.68      | 19.68 | 0.39                  | 0.39  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 3         | 900  | 900  | 828            | 880     | 15.40                 | 8.70       | 8.70  | 2.27                  | 2.27  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 4         | 1028 | 1028 | 936            | 1028    | 9.07                  | 9.83       | 9.83  | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 5         | 1090 | 1090 | 936            | 1090    | 11.11                 | 16.45      | 16.45 | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
| <b>10</b> | <b>6</b> | 1         | 1030 | 1030 | 728            | 1030    | 0.90                  | 41.48      | 41.48 | 0.00                  | 0.00  | 50.31                 | 50.31 | 63.16                 | 63.16 | 0.90                             | 0.90  | 4.49                             | 4.49  |
|           |          | 2         | 1178 | 1178 | 722            | 1178    | 1.21                  | 63.16      | 63.16 | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 3         | 994  | 994  | 644            | 994     | 1.80                  | 54.35      | 54.35 | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 4         | 1136 | 1136 | 808            | 1136    | 1.13                  | 40.59      | 40.59 | 0.00                  | 0.00  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 5         | 1304 | 1304 | 858            | 1248    | 1.01                  | 51.98      | 51.98 | 4.49                  | 4.49  |                       |       |                       |       |                                  |       |                                  |       |
| <b>10</b> | <b>8</b> | 1         | 1428 | 1428 | 1056           | 1252    | 0.46                  | 35.23      | 35.23 | 14.06                 | 14.06 | 34.19                 | 33.06 | 35.23                 | 35.23 | 13.98                            | 12.98 | 18.50                            | 15.71 |
|           |          | 2         | 1650 | 1650 | 1240           | 1426    | 0.52                  | 33.06      | 33.06 | 15.71                 | 15.71 |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 3         | 1336 | 1336 | 992            | 1218    | 0.39                  | 34.68      | 34.68 | 9.69                  | 9.69  |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 4         | 1478 | 1478 | 1096           | 1320    | 0.33                  | 34.85      | 34.85 | 11.97                 | 11.97 |                       |       |                       |       |                                  |       |                                  |       |
|           |          | 5         | 1704 | 1632 | 1280           | 1438    | 0.46                  | 33.13      | 27.50 | 18.50                 | 13.49 |                       |       |                       |       |                                  |       |                                  |       |

**Table D.10:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|     |     |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |
| 25  | 2   | 1         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |
|     |     | 2         | 8112 | 8112 | 8112           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 7774 | 7774 | 7774           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
| 25  | 4   | 1         | 4760 | 4760 | 4732           |         |                       | 0.59       | 0.59  |                       |      | 1.51                  | 1.38  | 5.54                  | 5.33  |                                  |      |                                  |      |
|     |     | 2         | 4610 | 4601 | 4368           |         |                       | 5.54       | 5.33  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 4214 | 4204 | 4186           |         |                       | 0.67       | 0.43  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 4768 | 4758 | 4732           |         |                       | 0.76       | 0.55  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
| 25  | 6   | 1         | 3660 | 3612 | 3380           |         |                       | 8.28       | 6.86  |                       |      | 14.14                 | 12.60 | 20.92                 | 21.25 |                                  |      |                                  |      |
|     |     | 2         | 4324 | 4336 | 3576           |         |                       | 20.92      | 21.25 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 3445 | 3361 | 2990           |         |                       | 15.22      | 12.41 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 3867 | 3757 | 3432           |         |                       | 12.67      | 9.47  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 3954 | 3933 | 3480           |         |                       | 13.62      | 13.02 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
| 25  | 8   | 1         | 4282 | 4167 | 2856           |         |                       | 49.93      | 45.90 |                       |      | 38.52                 | 35.99 | 52.79                 | 47.90 |                                  |      |                                  |      |
|     |     | 2         | 5008 | 4872 | 3648           |         |                       | 37.28      | 33.55 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 3997 | 3869 | 2616           |         |                       | 52.79      | 47.90 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 4162 | 4162 | 3288           |         |                       | 26.58      | 26.58 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 4537 | 4537 | 3600           |         |                       | 26.03      | 26.03 |                       |      |                       |       |                       |       |                                  |      |                                  |      |

**Table D.10 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 4   | 1         | 11488 | 11488 | 11440          |         |                       | 0.42       | 0.42  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 10672 | 10632 | 10560          |         |                       | 1.06       | 0.68  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 10200 | 10192 | 10120          |         |                       | 0.79       | 0.71  |                       |      | 0.55                  | 0.45  | 1.06                  | 0.71  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 11496 | 11488 | 11440          |         |                       | 0.49       | 0.42  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 6   | 1         | 8116  | 8116  | 8008           |         |                       | 1.35       | 1.35  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 8052  | 8020  | 7392           |         |                       | 8.93       | 8.50  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 7674  | 7460  | 7084           |         |                       | 8.33       | 5.31  |                       |      | 5.66                  | 4.87  | 8.93                  | 8.50  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 8548  | 8540  | 8008           |         |                       | 6.74       | 6.64  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 8244  | 8212  | 8008           |         |                       | 2.95       | 2.55  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 40  | 8   | 1         | 7680  | 7680  | 6280           |         |                       | 22.29      | 22.29 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 8640  | 8656  | 6800           |         |                       | 27.06      | 27.29 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 8208  | 8176  | 5880           |         |                       | 39.59      | 39.05 |                       |      | 25.27                 | 24.86 | 39.59                 | 39.05 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 8328  | 8240  | 7400           |         |                       | 12.54      | 11.35 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 8792  | 8752  | 7040           |         |                       | 24.89      | 24.32 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |

**Table D.10 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2  | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |
| 55  | 2   | 1      | 40768 | 40768 | 40768       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 37632 | 37632 | 37632       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00  | 0.00               | 0.00  |                            |      |                            |      |  |  |  |
|     |     | 3      | 36064 | 36064 | 36064       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 40768 | 40768 | 40768       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 40768 | 40768 | 40768       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 21216 | 21202 | 21112       |         |                 | 0.49       | 0.43  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 19654 | 19640 | 19488       |         |                 | 0.85       | 0.78  |                    |      | 0.44               | 0.41  | 0.85               | 0.78  |                            |      |                            |      |  |  |  |
|     |     | 3      | 18758 | 18758 | 18676       |         |                 | 0.44       | 0.44  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 21202 | 21202 | 21112       |         |                 | 0.43       | 0.43  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 21112 | 21112 | 21112       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 14851 | 14736 | 14560       |         |                 | 2.00       | 1.21  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 14284 | 14248 | 13440       |         |                 | 6.28       | 6.01  |                    |      | 3.06               | 2.61  | 6.28               | 6.01  |                            |      |                            |      |  |  |  |
|     |     | 3      | 13324 | 13204 | 12880       |         |                 | 3.45       | 2.52  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 15030 | 15004 | 14560       |         |                 | 3.23       | 3.05  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 14612 | 14598 | 14560       |         |                 | 0.36       | 0.26  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 13032 | 13071 | 11284       |         |                 | 15.49      | 15.84 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 13684 | 13684 | 11241       |         |                 | 21.73      | 21.73 |                    |      | 16.39              | 16.03 | 21.73              | 21.73 |                            |      |                            |      |  |  |  |
|     |     | 3      | 11893 | 11772 | 9982        |         |                 | 19.14      | 17.93 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 13310 | 13195 | 11944       |         |                 | 11.44      | 10.47 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 12881 | 12881 | 11284       |         |                 | 14.15      | 14.15 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |

**Table D.10 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |       | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |       |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|-------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|-------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2  |
| <b>10</b> | <b>2</b> | 1         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 2         | 2040 | 2040 | 2040           | 2040    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 3         | 1980 | 1980 | 1980           | 1980    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 4         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 5         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
| <b>10</b> | <b>4</b> | 1         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 2         | 1236 | 1236 | 1224           | 1236    | 8.61                  | 0.98       | 0.98  | 0.00                  | 0.00  | 1.05                  | 1.05  | 2.31                  | 2.31  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 3         | 1200 | 1200 | 1188           | 1200    | 8.71                  | 1.01       | 1.01  | 0.00                  | 0.00  | 1.05                  | 1.05  | 2.31                  | 2.31  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 4         | 1308 | 1308 | 1296           | 1308    | 10.14                 | 0.93       | 0.93  | 0.00                  | 0.00  | 1.05                  | 1.05  | 2.31                  | 2.31  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 5         | 1326 | 1326 | 1296           | 1326    | 4.28                  | 2.31       | 2.31  | 0.00                  | 0.00  | 1.05                  | 1.05  | 2.31                  | 2.31  | 0.00                             | 0.00 | 0.00                             | 0.00  |
| <b>10</b> | <b>6</b> | 1         | 1186 | 1186 | 1008           | 1186    | 0.97                  | 17.66      | 17.66 | 0.00                  | 0.00  |                       |       |                       |       | 0.59                             | 0.59 | 2.63                             | 2.63  |
|           |          | 2         | 1310 | 1310 | 952            | 1310    | 1.07                  | 37.61      | 37.61 | 0.00                  | 0.00  | 27.90                 | 27.90 | 37.61                 | 37.61 | 0.59                             | 0.59 | 2.63                             | 2.63  |
|           |          | 3         | 1094 | 1094 | 924            | 1094    | 0.81                  | 18.40      | 18.40 | 0.00                  | 0.00  | 27.90                 | 27.90 | 37.61                 | 37.61 | 0.59                             | 0.59 | 2.63                             | 2.63  |
|           |          | 4         | 1316 | 1316 | 1008           | 1312    | 0.98                  | 30.56      | 30.56 | 0.30                  | 0.30  | 27.90                 | 27.90 | 37.61                 | 37.61 | 0.59                             | 0.59 | 2.63                             | 2.63  |
|           |          | 5         | 1404 | 1404 | 1038           | 1368    | 1.03                  | 35.26      | 35.26 | 2.63                  | 2.63  | 27.90                 | 27.90 | 37.61                 | 37.61 | 0.59                             | 0.59 | 2.63                             | 2.63  |
| <b>10</b> | <b>8</b> | 1         | 1564 | 1528 | 1136           | 1412    | 0.33                  | 37.68      | 34.51 | 10.76                 | 8.22  |                       |       |                       |       | 12.34                            | 8.95 | 19.90                            | 14.51 |
|           |          | 2         | 1786 | 1768 | 1320           | 1544    | 1.02                  | 35.30      | 33.94 | 15.67                 | 14.51 | 36.70                 | 32.75 | 37.69                 | 37.69 | 12.34                            | 8.95 | 19.90                            | 14.51 |
|           |          | 3         | 1476 | 1476 | 1072           | 1402    | 0.87                  | 37.69      | 37.69 | 5.28                  | 5.28  | 36.70                 | 32.75 | 37.69                 | 37.69 | 12.34                            | 8.95 | 19.90                            | 14.51 |
|           |          | 4         | 1614 | 1584 | 1176           | 1466    | 0.41                  | 37.24      | 34.69 | 10.10                 | 8.05  | 36.70                 | 32.75 | 37.69                 | 37.69 | 12.34                            | 8.95 | 19.90                            | 14.51 |
|           |          | 5         | 1844 | 1672 | 1360           | 1538    | 0.32                  | 35.59      | 22.94 | 19.90                 | 8.71  | 36.70                 | 32.75 | 37.69                 | 37.69 | 12.34                            | 8.95 | 19.90                            | 14.51 |

**Table D.11:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |
| 25  | 2   | 1         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 11492 | 11492 | 11492          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |  |  |
|     |     | 3         | 11154 | 11154 | 11154          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 4         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
| 25  | 4   | 1         | 6562  | 6562  | 6552           |         |                       | 0.15       | 0.15  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 6224  | 6224  | 6188           |         |                       | 0.58       | 0.58  |                       |      | 0.21                  | 0.21  | 0.58                  | 0.58  |                                  |      |                                  |      |  |  |
|     |     | 3         | 6016  | 6016  | 6006           |         |                       | 0.17       | 0.17  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 4         | 6562  | 6562  | 6552           |         |                       | 0.15       | 0.15  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
| 25  | 6   | 1         | 4720  | 4706  | 4680           |         |                       | 0.85       | 0.56  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 5037  | 5037  | 4536           |         |                       | 11.04      | 11.04 |                       |      | 3.91                  | 3.79  | 11.04                 | 11.04 |                                  |      |                                  |      |  |  |
|     |     | 3         | 4386  | 4386  | 4290           |         |                       | 2.24       | 2.24  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 4         | 4795  | 4781  | 4680           |         |                       | 2.46       | 2.16  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 4819  | 4819  | 4680           |         |                       | 2.97       | 2.97  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
| 25  | 8   | 1         | 4580  | 4580  | 3744           |         |                       | 22.33      | 22.33 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 2         | 5322  | 5322  | 4368           |         |                       | 21.84      | 21.84 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 3         | 4267  | 4255  | 3432           |         |                       | 24.33      | 23.98 |                       |      | 19.02                 | 18.95 | 24.33                 | 23.98 |                                  |      |                                  |      |  |  |
|     |     | 4         | 4488  | 4488  | 4008           |         |                       | 11.98      | 11.98 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |
|     |     | 5         | 4951  | 4951  | 4320           |         |                       | 14.61      | 14.61 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |

**Table D.11 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 40  | 2   | 1         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 28560 | 28560 | 28560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 27720 | 27720 | 27720          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 40  | 4   | 1         | 15848 | 15848 | 15840          |         |                       | 0.05       | 0.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 14992 | 14992 | 14960          |         |                       | 0.21       | 0.21 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 14536 | 14536 | 14520          |         |                       | 0.11       | 0.11 |                       |      | 0.09                  | 0.09 | 0.21                  | 0.21 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 15848 | 15848 | 15840          |         |                       | 0.05       | 0.05 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 40  | 6   | 1         | 11140 | 11140 | 11088          |         |                       | 0.47       | 0.47 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 10640 | 10568 | 10472          |         |                       | 1.60       | 0.92 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 10248 | 10228 | 10164          |         |                       | 0.83       | 0.63 |                       |      | 0.70                  | 0.52 | 1.60                  | 0.92 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 11152 | 11152 | 11088          |         |                       | 0.58       | 0.58 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 40  | 8   | 1         | 9032  | 8720  | 8640           |         |                       | 4.54       | 0.93 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 9504  | 9224  | 8800           |         |                       | 8.00       | 4.82 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 8640  | 8528  | 7920           |         |                       | 9.09       | 7.68 |                       |      | 5.70                  | 3.52 | 9.09                  | 7.68 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 9512  | 9512  | 9400           |         |                       | 1.19       | 1.19 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 9552  | 9312  | 9040           |         |                       | 5.66       | 3.01 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table D.11 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$



| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2 | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |
| 55  | 2   | 1      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 53312 | 53312 | 53312       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 51744 | 51744 | 51744       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 29254 | 29254 | 29232       |         |                 | 0.08       | 0.08 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 27652 | 27652 | 27608       |         |                 | 0.16       | 0.16 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 3      | 26810 | 26810 | 26796       |         |                 | 0.05       | 0.05 |                    |      | 0.07               | 0.07 | 0.16               | 0.16 |                            |      |                            |      |  |  |  |
|     |     | 4      | 29246 | 29246 | 29232       |         |                 | 0.05       | 0.05 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 20286 | 20274 | 20160       |         |                 | 0.63       | 0.57 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 19246 | 19190 | 19040       |         |                 | 1.08       | 0.79 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 3      | 18570 | 18556 | 18480       |         |                 | 0.49       | 0.41 |                    |      | 0.55               | 0.47 | 1.08               | 0.79 |                            |      |                            |      |  |  |  |
|     |     | 4      | 20274 | 20274 | 20160       |         |                 | 0.57       | 0.57 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 15808 | 15778 | 15624       |         |                 | 1.18       | 0.99 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 15919 | 15807 | 15031       |         |                 | 5.91       | 5.16 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 3      | 14659 | 14596 | 14322       |         |                 | 2.35       | 1.91 |                    |      | 2.76               | 2.44 | 5.91               | 5.16 |                            |      |                            |      |  |  |  |
|     |     | 4      | 16374 | 16342 | 15734       |         |                 | 4.07       | 3.86 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 15670 | 15670 | 15624       |         |                 | 0.29       | 0.29 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |

**Table D.11 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$       | $K$      | Ins.<br># | FTH1 | FTH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |       | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |       |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|-------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|-------|
|           |          |           |      |      |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2  |
| <b>10</b> | <b>2</b> | 1         | 2400 | 2400 | 2400           | 2400    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 2         | 1860 | 1860 | 1860           | 1860    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 3         | 1680 | 1680 | 1680           | 1680    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 4         | 2220 | 2220 | 2220           | 2220    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 5         | 2340 | 2340 | 2340           | 2340    |                       | 0.00       | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00  |
| <b>10</b> | <b>4</b> | 1         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00  |
|           |          | 2         | 1188 | 1264 | 1116           | 1188    | 25.37                 | 6.45       | 13.26 | 0.00                  | 6.40  | 2.24                  | 3.60  | 6.45                  | 13.26 | 0.00                             | 1.28 | 0.00                             | 6.40  |
|           |          | 3         | 1056 | 1056 | 1008           | 1056    | 14.32                 | 4.76       | 4.76  | 0.00                  | 0.00  | 2.24                  | 3.60  | 6.45                  | 13.26 | 0.00                             | 1.28 | 0.00                             | 6.40  |
|           |          | 4         | 1332 | 1332 | 1332           | 1332    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       |                                  |      |                                  |       |
|           |          | 5         | 1404 | 1404 | 1404           | 1404    |                       | 0.00       | 0.00  | 0.00                  | 0.00  |                       |       |                       |       |                                  |      |                                  |       |
| <b>10</b> | <b>6</b> | 1         | 1266 | 1266 | 1120           | 1266    | 0.92                  | 13.04      | 13.04 | 0.00                  | 0.00  |                       |       |                       |       |                                  |      |                                  |       |
|           |          | 2         | 1272 | 1272 | 868            | 1272    | 1.34                  | 46.54      | 46.54 | 0.00                  | 0.00  | 31.33                 | 31.33 | 46.54                 | 46.54 | 0.67                             | 0.67 | 1.99                             | 1.99  |
|           |          | 3         | 1056 | 1056 | 784            | 1056    | 1.07                  | 34.69      | 34.69 | 0.00                  | 0.00  | 31.33                 | 31.33 | 46.54                 | 46.54 | 0.67                             | 0.67 | 1.99                             | 1.99  |
|           |          | 4         | 1358 | 1358 | 1036           | 1340    | 1.04                  | 31.08      | 31.08 | 1.34                  | 1.34  |                       |       |                       |       |                                  |      |                                  |       |
|           |          | 5         | 1434 | 1434 | 1092           | 1406    | 0.93                  | 31.32      | 31.32 | 1.99                  | 1.99  |                       |       |                       |       |                                  |      |                                  |       |
| <b>10</b> | <b>8</b> | 1         | 1620 | 1496 | 1168           | 1480    | 0.78                  | 38.70      | 28.08 | 9.46                  | 1.08  |                       |       |                       |       |                                  |      |                                  |       |
|           |          | 2         | 1756 | 1748 | 1296           | 1516    | 0.39                  | 35.49      | 34.88 | 15.83                 | 15.30 | 37.07                 | 31.31 | 38.70                 | 37.40 | 11.85                            | 6.98 | 20.28                            | 15.30 |
|           |          | 3         | 1418 | 1418 | 1032           | 1358    | 0.37                  | 37.40      | 37.40 | 4.42                  | 4.42  |                       |       |                       |       |                                  |      |                                  |       |
|           |          | 4         | 1628 | 1620 | 1184           | 1490    | 0.50                  | 37.50      | 36.82 | 9.26                  | 8.72  |                       |       |                       |       |                                  |      |                                  |       |
|           |          | 5         | 1886 | 1652 | 1384           | 1568    | 0.27                  | 36.27      | 19.36 | 20.28                 | 5.36  |                       |       |                       |       |                                  |      |                                  |       |

**Table D.12:** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |  |
| 25  | 2   | 1         | 13520 | 13520 | 13520          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 10478 | 10478 | 10478          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 9464  | 9464  | 9464           |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 12506 | 12506 | 12506          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 13182 | 13182 | 13182          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 25  | 4   | 1         | 7280  | 7280  | 7280           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 5767  | 5774  | 5642           |         |                       | 2.22       | 2.34  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 5136  | 5136  | 5096           |         |                       | 0.78       | 0.78  |                       |      | 0.60                  | 0.62  | 2.22                  | 2.34  |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 6734  | 6734  | 6734           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 7098  | 7098  | 7098           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 25  | 6   | 1         | 5252  | 5252  | 5200           |         |                       | 1.00       | 1.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 5084  | 5084  | 4248           |         |                       | 19.68      | 19.68 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 4086  | 4058  | 3640           |         |                       | 12.25      | 11.48 |                       |      | 7.66                  | 7.27  | 19.68                 | 19.68 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 5020  | 4964  | 4810           |         |                       | 4.37       | 3.20  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 5120  | 5120  | 5070           |         |                       | 0.99       | 0.99  |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
| 25  | 8   | 1         | 4714  | 4714  | 4160           |         |                       | 13.32      | 13.32 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 5365  | 5365  | 4152           |         |                       | 29.21      | 29.21 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 4279  | 4299  | 2976           |         |                       | 43.78      | 44.46 |                       |      | 22.58                 | 22.72 | 43.78                 | 44.46 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 4606  | 4606  | 4080           |         |                       | 12.89      | 12.89 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 5158  | 5158  | 4536           |         |                       | 13.71      | 13.71 |                       |      |                       |       |                       |       |                                  |      |                                  |      |  |  |  |  |

**Table D.12 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | FTH1  | FTH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality<br>Gap (%) |      | Maximum<br>Optimality<br>Gap (%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | FTH1       | FTH2  | FTH1                  | FTH2 | FTH1                  | FTH2 | FTH1                  | FTH2  | FTH1                             | FTH2 | FTH1                             | FTH2 |  |  |  |
| 40  | 2   | 1         | 33600 | 33600 | 33600          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 26040 | 26040 | 26040          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 23520 | 23520 | 23520          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 31080 | 31080 | 31080          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 32760 | 32760 | 32760          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 40  | 4   | 1         | 17600 | 17600 | 17600          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 13840 | 13784 | 13640          |         |                       | 1.47       | 1.06  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 12480 | 12480 | 12320          |         |                       | 1.30       | 1.30  |                       |      | 0.59                  | 0.51 | 1.47                  | 1.30  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 16312 | 16312 | 16280          |         |                       | 0.20       | 0.20  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 17160 | 17160 | 17160          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 40  | 6   | 1         | 12400 | 12384 | 12320          |         |                       | 0.65       | 0.52  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 10112 | 10112 | 9548           |         |                       | 5.91       | 5.91  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 9316  | 9316  | 8624           |         |                       | 8.02       | 8.02  |                       |      | 3.37                  | 3.34 | 8.02                  | 8.02  |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 11652 | 11652 | 11396          |         |                       | 2.25       | 2.25  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 12012 | 12012 | 12012          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
| 40  | 8   | 1         | 9792  | 9744  | 9600           |         |                       | 2.00       | 1.50  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 9544  | 9176  | 8200           |         |                       | 16.39      | 11.90 |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 8600  | 8776  | 6880           |         |                       | 25.00      | 27.56 |                       |      | 10.24                 | 9.96 | 25.00                 | 27.56 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 10048 | 10048 | 9600           |         |                       | 4.67       | 4.67  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 9944  | 10040 | 9640           |         |                       | 3.15       | 4.15  |                       |      |                       |      |                       |       |                                  |      |                                  |      |  |  |  |

**Table D.12 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | FTH1  | FTH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | FTH1       | FTH2  | FTH1               | FTH2 | FTH1               | FTH2 | FTH1               | FTH2  | FTH1                       | FTH2 | FTH1                       | FTH2 |  |  |  |
| 55  | 2   | 1      | 62720 | 62720 | 62720       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 48608 | 48608 | 48608       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 43904 | 43904 | 43904       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |  |  |  |
|     |     | 4      | 58016 | 58016 | 58016       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 61152 | 61152 | 61152       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 32480 | 32480 | 32480       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 25370 | 25352 | 25172       |         |                 | 0.79       | 0.72  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 22912 | 22912 | 22736       |         |                 | 0.77       | 0.77  |                    |      | 0.33               | 0.31 | 0.79               | 0.77  |                            |      |                            |      |  |  |  |
|     |     | 4      | 30068 | 30068 | 30044       |         |                 | 0.08       | 0.08  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 31668 | 31668 | 31668       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 22580 | 22552 | 22400       |         |                 | 0.80       | 0.68  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 18228 | 18092 | 17360       |         |                 | 5.00       | 4.22  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 16198 | 16346 | 15680       |         |                 | 3.30       | 4.25  |                    |      | 2.35               | 2.21 | 5.00               | 4.25  |                            |      |                            |      |  |  |  |
|     |     | 4      | 21266 | 21120 | 20720       |         |                 | 2.64       | 1.93  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 21840 | 21840 | 21840       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 17698 | 17698 | 17360       |         |                 | 1.95       | 1.95  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 15730 | 15514 | 13894       |         |                 | 13.21      | 11.66 |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 13712 | 13394 | 12152       |         |                 | 12.84      | 10.22 |                    |      | 7.40               | 6.29 | 13.21              | 11.66 |                            |      |                            |      |  |  |  |
|     |     | 4      | 17357 | 17197 | 16113       |         |                 | 7.72       | 6.73  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 17145 | 17076 | 16926       |         |                 | 1.29       | 0.89  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |

**Table D.12 (continued):** Computational results for *Fully Loaded Trips Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

# **Appendix E**

## **Numerical Results for No Wait Problem**

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 10  | 2   | 1      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1440 | 1440 | 1440        | 1440    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 1380 | 1380 | 1380        | 1380    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 4   | 1      | 936  | 936  | 936         | 936     |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 864  | 864  | 864         | 864     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 828  | 828  | 828         | 828     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 936  | 936  | 936         | 936     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 936  | 936  | 936         | 936     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 6   | 1      | 728  | 728  | 728         | 728     |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 672  | 672  | 672         | 672     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 644  | 644  | 644         | 644     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 728  | 728  | 728         | 728     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 780  | 780  | 780         | 780     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 8   | 1      | 696  | 696  | 676         | 696     | 67.87           | 2.96       | 2.96 | 0.00               | 0.00 | 1.26               | 1.26 | 3.34               | 3.34 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 672  | 672  | 672         | 672     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 618  | 618  | 598         | 618     | 92.17           | 3.34       | 3.34 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 728  | 728  | 728         | 728     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 780  | 780  | 780         | 780     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |

**Table E.1:** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | NWH1 | NWH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |  |  |  |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |      |      |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 |  |  |  |
| 25  | 2   | 1         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 8112 | 8112 | 8112           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7774 | 7774 | 7774           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 4   | 1         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 4368 | 4368 | 4368           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 4186 | 4186 | 4186           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 6   | 1         | 3380 | 3380 | 3380           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 3134 | 3134 | 3120           |         |                       | 0.45       | 0.45 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 2990 | 2990 | 2990           |         |                       | 0.00       | 0.00 |                       |      | 0.09                  | 0.09 | 0.45                  | 0.45 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 3380 | 3380 | 3380           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 3380 | 3380 | 3380           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 8   | 1         | 2722 | 2722 | 2704           |         |                       | 0.67       | 0.67 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 2676 | 2676 | 2496           |         |                       | 7.21       | 7.21 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 2410 | 2410 | 2392           |         |                       | 0.75       | 0.75 |                       |      | 1.86                  | 1.86 | 7.21                  | 7.21 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 2722 | 2722 | 2704           |         |                       | 0.67       | 0.67 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 2704 | 2704 | 2704           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table E.1 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$



| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 |  |  |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 4   | 1         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 10560 | 10560 | 10560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 10120 | 10120 | 10120          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 6   | 1         | 8008  | 8008  | 8008           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 7392  | 7392  | 7392           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 7084  | 7084  | 7084           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 8008  | 8008  | 8008           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 8008  | 8008  | 8008           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 40  | 8   | 1         | 6256  | 6256  | 6240           |         |                       | 0.26       | 0.26 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 5792  | 5792  | 5760           |         |                       | 0.56       | 0.56 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 5552  | 5552  | 5520           |         |                       | 0.58       | 0.58 |                       |      | 0.33                  | 0.33 | 0.58                  | 0.58 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 6256  | 6256  | 6240           |         |                       | 0.26       | 0.26 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 6240  | 6240  | 6240           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table E.1 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 |  |  |  |  |
| 55  | 2   | 1         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 37632 | 37632 | 37632          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 36064 | 36064 | 36064          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 4   | 1         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 19488 | 19488 | 19488          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 18676 | 18676 | 18676          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 6   | 1         | 14560 | 14560 | 14560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 13440 | 13440 | 13440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 12880 | 12880 | 12880          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 14560 | 14560 | 14560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 14560 | 14560 | 14560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
| 55  | 8   | 1         | 11298 | 11298 | 11284          |         |                       | 0.12       | 0.12 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 2         | 10446 | 10446 | 10416          |         |                       | 0.29       | 0.29 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 3         | 9996  | 9996  | 9982           |         |                       | 0.14       | 0.14 |                       |      | 0.14                  | 0.14 | 0.29                  | 0.29 |                                  |      |                                  |      |  |  |  |  |
|     |     | 4         | 11298 | 11298 | 11284          |         |                       | 0.12       | 0.12 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |
|     |     | 5         | 11284 | 11284 | 11284          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |

**Table E.1 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 10  | 2   | 1      | 2160 | 2160 | 2160        | 2160    |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 2040 | 2040 | 2040        | 2040    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 1980 | 1980 | 1980        | 1980    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 2160 | 2160 | 2160        | 2160    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 2160 | 2160 | 2160        | 2160    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 4   | 1      | 1296 | 1296 | 1296        | 1296    |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1224 | 1224 | 1224        | 1224    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 1188 | 1188 | 1188        | 1188    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 1296 | 1296 | 1296        | 1296    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 1296 | 1296 | 1296        | 1296    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 6   | 1      | 1008 | 1008 | 1008        | 1008    |                 | 0.00       | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 952  | 952  | 952         | 952     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 924  | 924  | 924         | 924     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 1008 | 1008 | 1008        | 1008    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 1008 | 1008 | 1008        | 1008    |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
| 10  | 8   | 1      | 864  | 864  | 864         | 864     | 51.64           | 0.00       | 0.00 | 0.00               | 0.00 | 1.67               | 1.67 | 8.33               | 8.33 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 884  | 884  | 884         | 884     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 858  | 858  | 792         | 858     |                 | 8.33       | 8.33 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 936  | 936  | 936         | 936     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 936  | 936  | 936         | 936     |                 | 0.00       | 0.00 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |

**Table E.2:** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |  |
| 25  | 2   | 1      | 12168 | 12168 | 12168       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 11492 | 11492 | 11492       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 11154 | 11154 | 11154       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 12168 | 12168 | 12168       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 12168 | 12168 | 12168       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 25  | 4   | 1      | 6552  | 6552  | 6552        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 6188  | 6188  | 6188        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 6006  | 6006  | 6006        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 6552  | 6552  | 6552        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 6552  | 6552  | 6552        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 25  | 6   | 1      | 4680  | 4680  | 4680        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 4420  | 4420  | 4420        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 4290  | 4290  | 4290        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 4680  | 4680  | 4680        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 4680  | 4680  | 4680        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 25  | 8   | 1      | 3744  | 3744  | 3744        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 3554  | 3554  | 3536        |         |                 | 0.51       | 0.51 |                    |      | 0.10               | 0.10 | 0.51               | 0.51 |                            |      |                            |      |  |  |  |
|     |     | 3      | 3432  | 3432  | 3432        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 3744  | 3744  | 3744        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 3744  | 3744  | 3744        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |

**Table E.2 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |  |  |  |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|--|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 |  |  |  |  |  |  |
| 40  | 2   | 1         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 2         | 28560 | 28560 | 28560          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 3         | 27720 | 27720 | 27720          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 4         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 5         | 30240 | 30240 | 30240          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
| 40  | 4   | 1         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 2         | 14960 | 14960 | 14960          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 3         | 14520 | 14520 | 14520          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 4         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 5         | 15840 | 15840 | 15840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
| 40  | 6   | 1         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 2         | 10472 | 10472 | 10472          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 3         | 10164 | 10164 | 10164          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 4         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 5         | 11088 | 11088 | 11088          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
| 40  | 8   | 1         | 8640  | 8640  | 8640           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 2         | 8160  | 8160  | 8160           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 3         | 7920  | 7920  | 7920           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 4         | 8640  | 8640  | 8640           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |
|     |     | 5         | 8640  | 8640  | 8640           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |  |  |  |

**Table E.2 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 55  | 2   | 1      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 53312 | 53312 | 53312       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 51744 | 51744 | 51744       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 4   | 1      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 27608 | 27608 | 27608       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 26796 | 26796 | 26796       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 6   | 1      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 19040 | 19040 | 19040       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 18480 | 18480 | 18480       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 8   | 1      | 15624 | 15624 | 15624       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 14756 | 14756 | 14756       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 14322 | 14322 | 14322       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 15624 | 15624 | 15624       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 15624 | 15624 | 15624       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |

**Table E.2 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 10  | 2   | 1      | 2400 | 2400 | 2400        | 2400    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1860 | 1860 | 1860        | 1860    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 3      | 1680 | 1680 | 1680        | 1680    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 4      | 2220 | 2220 | 2220        | 2220    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 5      | 2340 | 2340 | 2340        | 2340    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
| 10  | 4   | 1      | 1440 | 1440 | 1440        | 1440    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1116 | 1116 | 1116        | 1116    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 3      | 1008 | 1008 | 1008        | 1008    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 4      | 1332 | 1332 | 1332        | 1332    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 5      | 1404 | 1404 | 1404        | 1404    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
| 10  | 6   | 1      | 1120 | 1120 | 1120        | 1120    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 868  | 868  | 868         | 868     |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 3      | 784  | 784  | 784         | 784     |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 4      | 1036 | 1036 | 1036        | 1036    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 5      | 1092 | 1092 | 1092        | 1092    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
| 10  | 8   | 1      | 960  | 960  | 960         | 960     |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 2      | 866  | 866  | 744         | 866     | 187.97          | 16.40      | 16.40 | 0.00               | 0.00 | 6.61               | 6.61 | 16.40              | 16.40 | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 3      | 728  | 728  | 672         | 728     | 37.31           | 8.33       | 8.33  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 962  | 962  | 888         | 962     | 169.15          | 8.33       | 8.33  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1014 | 1014 | 1014        | 1014    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |

**Table E.3:** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |  |
| 25  | 2   | 1      | 13520 | 13520 | 13520       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 10478 | 10478 | 10478       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 9464  | 9464  | 9464        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 12506 | 12506 | 12506       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 13182 | 13182 | 13182       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 25  | 4   | 1      | 7280  | 7280  | 7280        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 5642  | 5642  | 5642        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 5096  | 5096  | 5096        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 6734  | 6734  | 6734        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 7098  | 7098  | 7098        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 25  | 6   | 1      | 5200  | 5200  | 5200        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 4030  | 4030  | 4030        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 3640  | 3640  | 3640        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 4810  | 4810  | 4810        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 5070  | 5070  | 5070        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 25  | 8   | 1      | 4160  | 4160  | 4160        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 3278  | 3278  | 3224        |         |                 | 1.67       | 1.67 |                    |      | 0.33               | 0.33 | 1.67               | 1.67 |                            |      |                            |      |  |  |  |
|     |     | 3      | 2912  | 2912  | 2912        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 3848  | 3848  | 3848        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 4056  | 4056  | 4056        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |

**Table E.3 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$



| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|------|------|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |  |
| 40  | 2   | 1         | 33600 | 33600 | 33600          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 26040 | 26040 | 26040          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 23520 | 23520 | 23520          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 31080 | 31080 | 31080          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 32760 | 32760 | 32760          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
| 40  | 4   | 1         | 17600 | 17600 | 17600          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 13640 | 13640 | 13640          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 16280 | 16280 | 16280          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 17160 | 17160 | 17160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
| 40  | 6   | 1         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 9548  | 9548  | 9548           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 8624  | 8624  | 8624           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 11396 | 11396 | 11396          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 12012 | 12012 | 12012          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
| 40  | 8   | 1         | 9600  | 9600  | 9600           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 7440  | 7440  | 7440           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 6776  | 6776  | 6720           |         |                       | 0.83       | 0.83 |                       |      | 0.17                  | 0.17 | 0.83                  | 0.83 |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 8880  | 8880  | 8880           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 9360  | 9360  | 9360           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |  |

**Table E.3 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |  |
| 55  | 2   | 1      | 62720 | 62720 | 62720       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 48608 | 48608 | 48608       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 43904 | 43904 | 43904       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 58016 | 58016 | 58016       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 61152 | 61152 | 61152       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 32480 | 32480 | 32480       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 25172 | 25172 | 25172       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 22736 | 22736 | 22736       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 30044 | 30044 | 30044       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 31668 | 31668 | 31668       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 22400 | 22400 | 22400       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 17360 | 17360 | 17360       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 15680 | 15680 | 15680       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 20720 | 20720 | 20720       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 21840 | 21840 | 21840       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 17360 | 17360 | 17360       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 13454 | 13454 | 13454       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 12152 | 12152 | 12152       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 16058 | 16058 | 16058       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 16926 | 16926 | 16926       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |

**Table E.3 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | NWH1 | NWH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|     |     |           |      |      |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 |
| 10  | 2   | 1         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 3         | 1380 | 1380 | 1380           | 1380    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 4         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 5         | 1560 | 1560 | 1560           | 1560    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
| 10  | 4   | 1         | 936  | 936  | 936            | 936     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 944  | 944  | 864            | 944     | 7270.61               | 9.26       | 9.26  | 0.00                  | 0.00 | 2.33                  | 2.33 | 9.26                  | 9.26  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 3         | 848  | 848  | 828            | 848     | 2702.13               | 2.42       | 2.42  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 4         | 1040 | 1040 | 1040           | 1040    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 5         | 1040 | 1040 | 1040           | 1040    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
| 10  | 6   | 1         | 844  | 844  | 832            | 844     | 433.45                | 1.44       | 1.44  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 848  | 848  | 768            | 848     | 3067.61               | 10.42      | 10.42 | 0.00                  | 0.00 | 4.46                  | 4.46 | 10.42                 | 10.42 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 3         | 802  | 802  | 736            | 802     | 1082.22               | 8.97       | 8.97  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 4         | 950  | 950  | 936            | 950     | 2251.22               | 1.50       | 1.50  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 5         | 936  | 936  | 936            | 936     |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
| 10  | 8   | 1         | 844  | 844  | 832            | 844     | 433.45                | 1.44       | 1.44  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 2         | 848  | 848  | 768            | 848     | 4770.48               | 10.42      | 10.42 | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 3         | 802  | 802  | 736            | 802     | 1252.86               | 8.97       | 8.97  | 0.00                  | 0.00 | 5.66                  | 5.66 | 10.42                 | 10.42 | 1.18                             | 1.18 | 5.88                             | 5.88 |
|     |     | 4         | 898  | 898  | 884            | 898     | 2367.39               | 1.58       | 1.58  | 0.00                  | 0.00 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 5         | 936  | 936  | 884            | 884     | 1513.15               | 5.88       | 5.88  | 5.88                  | 5.88 |                       |      |                       |       | 0.00                             | 0.00 | 0.00                             | 0.00 |

**Table E.4:** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 25  | 2   | 1      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 8112 | 8112 | 8112        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 7774 | 7774 | 7774        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 8788 | 8788 | 8788        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 4   | 1      | 4732 | 4732 | 4732        |         |                 | 0.00       | 0.00 |                    |      | 0.92               | 0.92 | 4.58               | 4.58 |                            |      |                            |      |
|     |     | 2      | 4568 | 4568 | 4368        |         |                 | 4.58       | 4.58 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 4186 | 4186 | 4186        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 4732 | 4732 | 4732        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 4732 | 4732 | 4732        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 6   | 1      | 3814 | 3814 | 3796        |         |                 | 0.47       | 0.47 |                    |      | 2.78               | 2.85 | 6.74               | 6.74 |                            |      |                            |      |
|     |     | 2      | 3722 | 3734 | 3504        |         |                 | 6.22       | 6.56 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 3388 | 3388 | 3174        |         |                 | 6.74       | 6.74 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 3814 | 3814 | 3796        |         |                 | 0.47       | 0.47 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 3796 | 3796 | 3796        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 25  | 8   | 1      | 3380 | 3370 | 3328        |         |                 | 1.56       | 1.26 |                    |      | 3.39               | 3.33 | 7.36               | 7.36 |                            |      |                            |      |
|     |     | 2      | 3298 | 3298 | 3072        |         |                 | 7.36       | 7.36 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 2996 | 2996 | 2806        |         |                 | 6.77       | 6.77 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 3370 | 3370 | 3328        |         |                 | 1.26       | 1.26 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 3328 | 3328 | 3328        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |

**Table E.4 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|------|------|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
| 40  | 4   | 1         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 10560 | 10560 | 10560          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 10120 | 10120 | 10120          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
| 40  | 6   | 1         | 8354  | 8354  | 8320           |         |                       | 0.41       | 0.41 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 8034  | 8034  | 7680           |         |                       | 4.61       | 4.61 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 7804  | 7794  | 7360           |         |                       | 6.03       | 5.90 |                       |      | 2.29                  | 2.27 | 6.03                  | 5.90 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 8668  | 8668  | 8632           |         |                       | 0.42       | 0.42 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 8632  | 8632  | 8632           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
| 40  | 8   | 1         | 7128  | 7112  | 7020           |         |                       | 1.54       | 1.31 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 6876  | 6876  | 6480           |         |                       | 6.11       | 6.11 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 6686  | 6686  | 6210           |         |                       | 7.67       | 7.67 |                       |      | 3.33                  | 3.33 | 7.67                  | 7.67 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 7376  | 7392  | 7280           |         |                       | 1.32       | 1.54 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 7280  | 7280  | 7280           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |      |      |  |

**Table E.4 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 |  |  |  |
| 55  | 2   | 1         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 37632 | 37632 | 37632          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 36064 | 36064 | 36064          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 55  | 4   | 1         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 19488 | 19488 | 19488          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 18676 | 18676 | 18676          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 55  | 6   | 1         | 15096 | 15096 | 15028          |         |                       | 0.45       | 0.45 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 14368 | 14392 | 13872          |         |                       | 3.58       | 3.75 |                       |      | 1.78                  | 1.77 | 3.75                  | 3.75 |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 13792 | 13780 | 13294          |         |                       | 3.75       | 3.66 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 15556 | 15538 | 15496          |         |                       | 0.39       | 0.27 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 15138 | 15138 | 15028          |         |                       | 0.73       | 0.73 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 55  | 8   | 1         | 12480 | 12460 | 12324          |         |                       | 1.27       | 1.10 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 11940 | 11952 | 11376          |         |                       | 4.96       | 5.06 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 11386 | 11386 | 10902          |         |                       | 4.44       | 4.44 |                       |      | 2.57                  | 2.52 | 4.96                  | 5.06 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 12850 | 12828 | 12688          |         |                       | 1.28       | 1.10 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 12434 | 12434 | 12324          |         |                       | 0.89       | 0.89 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table E.4 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$       | $K$      | Ins.<br># | NWH1 | NWH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |
|-----------|----------|-----------|------|------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|
|           |          |           |      |      |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 |
| <b>10</b> | <b>2</b> | 1         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 2040 | 2040 | 2040           | 2040    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 3         | 1980 | 1980 | 1980           | 1980    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 4         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 5         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
| <b>10</b> | <b>4</b> | 1         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                  | 0.00 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1224 | 1224 | 1224           | 1224    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 3         | 1188 | 1188 | 1188           | 1188    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 4         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 5         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
| <b>10</b> | <b>6</b> | 1         | 1080 | 1080 | 1080           | 1080    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 1.94                  | 1.94 | 7.84                  | 7.84 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1100 | 1100 | 1020           | 1100    | 857.61                | 7.84       | 7.84 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 3         | 990  | 990  | 990            | 990     |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 4         | 1100 | 1100 | 1080           | 1100    | 466.39                | 1.85       | 1.85 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 5         | 1152 | 1152 | 1152           | 1152    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
| <b>10</b> | <b>8</b> | 1         | 1080 | 1080 | 1080           | 1080    |                       | 0.00       | 0.00 | 0.00                  | 0.00 | 1.94                  | 1.94 | 7.84                  | 7.84 | 0.00                             | 0.00 | 0.00                             | 0.00 |
|           |          | 2         | 1100 | 1100 | 1020           | 1100    | 857.61                | 7.84       | 7.84 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 3         | 990  | 990  | 990            | 990     |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 4         | 1100 | 1100 | 1080           | 1100    | 466.39                | 1.85       | 1.85 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |
|           |          | 5         | 1152 | 1152 | 1152           | 1152    |                       | 0.00       | 0.00 | 0.00                  | 0.00 |                       |      |                       |      |                                  |      |                                  |      |

**Table E.5:** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |      | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |      | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|------|-----------------------|------|-----------------------|------|-----------------------|------|----------------------------------|------|----------------------------------|------|--|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                             | NWH2 | NWH1                             | NWH2 |  |  |  |
| 25  | 2   | 1         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 11492 | 11492 | 11492          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 11154 | 11154 | 11154          |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 4   | 1         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 6188  | 6188  | 6188           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 6006  | 6006  | 6006           |         |                       | 0.00       | 0.00 |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 6   | 1         | 4680  | 4680  | 4680           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 4742  | 4742  | 4692           |         |                       | 1.07       | 1.07 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 4290  | 4290  | 4290           |         |                       | 0.00       | 0.00 |                       |      | 0.21                  | 0.21 | 1.07                  | 1.07 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 4968  | 4968  | 4968           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 4968  | 4968  | 4968           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
| 25  | 8   | 1         | 4198  | 4198  | 4176           |         |                       | 0.53       | 0.53 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 2         | 4222  | 4222  | 4148           |         |                       | 1.78       | 1.78 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 3         | 3850  | 3850  | 3828           |         |                       | 0.57       | 0.57 |                       |      | 0.69                  | 0.69 | 1.78                  | 1.78 |                                  |      |                                  |      |  |  |  |
|     |     | 4         | 4416  | 4416  | 4392           |         |                       | 0.55       | 0.55 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |
|     |     | 5         | 4392  | 4392  | 4392           |         |                       | 0.00       | 0.00 |                       |      |                       |      |                       |      |                                  |      |                                  |      |  |  |  |

**Table E.5 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$



| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |  |
| 40  | 2   | 1      | 30240 | 30240 | 30240       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 28560 | 28560 | 28560       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 27720 | 27720 | 27720       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 30240 | 30240 | 30240       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 30240 | 30240 | 30240       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 40  | 4   | 1      | 15840 | 15840 | 15840       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 14960 | 14960 | 14960       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |  |
|     |     | 3      | 14520 | 14520 | 14520       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 15840 | 15840 | 15840       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 15840 | 15840 | 15840       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 40  | 6   | 1      | 11088 | 11088 | 11088       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 10552 | 10552 | 10472       |         |                 | 0.76       | 0.76 |                    |      | 0.15               | 0.15 | 0.76               | 0.76 |                            |      |                            |      |  |  |  |
|     |     | 3      | 10164 | 10164 | 10164       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 4      | 11520 | 11520 | 11520       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 11088 | 11088 | 11088       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
| 40  | 8   | 1      | 9396  | 9396  | 9360        |         |                 | 0.38       | 0.38 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 2      | 8956  | 8956  | 8840        |         |                 | 1.31       | 1.31 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 3      | 8668  | 8684  | 8250        |         |                 | 5.07       | 5.26 |                    |      | 1.40               | 1.44 | 5.07               | 5.26 |                            |      |                            |      |  |  |  |
|     |     | 4      | 9742  | 9742  | 9720        |         |                 | 0.23       | 0.23 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |
|     |     | 5      | 9360  | 9360  | 9360        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |  |

**Table E.5 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 55  | 2   | 1      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 53312 | 53312 | 53312       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 51744 | 51744 | 51744       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 4   | 1      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 27608 | 27608 | 27608       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 26796 | 26796 | 26796       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 6   | 1      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      | 0.12               | 0.12 | 0.58               | 0.58 |                            |      |                            |      |
|     |     | 2      | 19150 | 19150 | 19040       |         |                 | 0.58       | 0.58 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 18480 | 18480 | 18480       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 8   | 1      | 16610 | 16610 | 16560       |         |                 | 0.30       | 0.30 |                    |      | 1.03               | 1.02 | 3.60               | 3.48 |                            |      |                            |      |
|     |     | 2      | 15784 | 15800 | 15640       |         |                 | 0.92       | 1.02 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 15248 | 15230 | 14718       |         |                 | 3.60       | 3.48 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 16610 | 16610 | 16560       |         |                 | 0.30       | 0.30 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 16560 | 16560 | 16560       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |

**Table E.5 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 10  | 2   | 1      | 2400 | 2400 | 2400        | 2400    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1860 | 1860 | 1860        | 1860    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 3      | 1680 | 1680 | 1680        | 1680    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 4      | 2220 | 2220 | 2220        | 2220    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 5      | 2340 | 2340 | 2340        | 2340    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
| 10  | 4   | 1      | 1440 | 1440 | 1440        | 1440    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1116 | 1116 | 1116        | 1116    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 3      | 1008 | 1008 | 1008        | 1008    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 4      | 1332 | 1332 | 1332        | 1332    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 5      | 1404 | 1404 | 1404        | 1404    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00 | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
| 10  | 6   | 1      | 1180 | 1180 | 1120        | 1180    | 342.91          | 5.36       | 5.36  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 2      | 1028 | 1028 | 930         | 1028    | 2477.41         | 10.54      | 10.54 | 0.00               | 0.00 | 8.36               | 8.36 | 17.35              | 17.35 | 0.35                       | 0.35 | 1.76                       | 1.76 |
|     |     | 3      | 920  | 920  | 784         | 920     | 412.89          | 17.35      | 17.35 | 0.00               | 0.00 | 8.36               | 8.36 | 17.35              | 17.35 | 0.35                       | 0.35 | 1.76                       | 1.76 |
|     |     | 4      | 1110 | 1110 | 1110        | 1110    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1270 | 1270 | 1170        | 1248    | 2364.57         | 8.55       | 8.55  | 1.76               | 1.76 |                    |      |                    |       |                            |      |                            |      |
| 10  | 8   | 1      | 1180 | 1180 | 1120        | 1180    | 342.91          | 5.36       | 5.36  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 2      | 1028 | 1028 | 930         | 1028    | 3213.26         | 10.54      | 10.54 | 0.00               | 0.00 | 8.36               | 8.36 | 17.35              | 17.35 | 0.35                       | 0.35 | 1.76                       | 1.76 |
|     |     | 3      | 920  | 920  | 784         | 920     | 310.35          | 17.35      | 17.35 | 0.00               | 0.00 | 8.36               | 8.36 | 17.35              | 17.35 | 0.35                       | 0.35 | 1.76                       | 1.76 |
|     |     | 4      | 1110 | 1110 | 1110        | 1110    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1270 | 1270 | 1170        | 1248    | 2364.57         | 8.55       | 8.55  | 1.76               | 1.76 |                    |      |                    |       |                            |      |                            |      |

**Table E.6:** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |
| 25  | 2   | 1         | 13520 | 13520 | 13520          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 10478 | 10478 | 10478          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |
|     |     | 3         | 9464  | 9464  | 9464           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 12506 | 12506 | 12506          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 13182 | 13182 | 13182          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
| 25  | 4   | 1         | 7280  | 7280  | 7280           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 5642  | 5642  | 5642           |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |
|     |     | 3         | 5096  | 5096  | 5096           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 6734  | 6734  | 6734           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 7098  | 7098  | 7098           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
| 25  | 6   | 1         | 5200  | 5200  | 5200           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 4580  | 4580  | 4030           |         |                       | 13.65      | 13.65 |                       |      | 5.14                  | 5.14 | 13.65                 | 13.65 |                                  |      |                                  |      |      |      |
|     |     | 3         | 3928  | 3928  | 3640           |         |                       | 7.91       | 7.91  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 5010  | 5010  | 4810           |         |                       | 4.16       | 4.16  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 5070  | 5070  | 5070           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
| 25  | 8   | 1         | 4440  | 4440  | 4400           |         |                       | 0.91       | 0.91  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 4094  | 4094  | 3596           |         |                       | 13.85      | 13.85 |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 3         | 3576  | 3576  | 2912           |         |                       | 22.80      | 22.80 |                       |      | 8.44                  | 8.44 | 22.80                 | 22.80 |                                  |      |                                  |      |      |      |
|     |     | 4         | 4492  | 4492  | 4292           |         |                       | 4.66       | 4.66  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 4524  | 4524  | 4524           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |

**Table E.6 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|--|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |  |  |
| 40  | 2   | 1         | 33600 | 33600 | 33600          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 2         | 26040 | 26040 | 26040          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 3         | 23520 | 23520 | 23520          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 4         | 31080 | 31080 | 31080          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 5         | 32760 | 32760 | 32760          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
| 40  | 4   | 1         | 17600 | 17600 | 17600          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 2         | 13640 | 13640 | 13640          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 3         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 4         | 16280 | 16280 | 16280          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 5         | 17160 | 17160 | 17160          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
| 40  | 6   | 1         | 12320 | 12320 | 12320          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 2         | 9986  | 9986  | 9548           |         |                       | 4.59       | 4.59  |                       |      | 2.41                  | 2.41 | 4.64                  | 4.64  |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 3         | 9024  | 9024  | 8624           |         |                       | 4.64       | 4.64  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 4         | 11716 | 11716 | 11396          |         |                       | 2.81       | 2.81  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 5         | 12012 | 12012 | 12012          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
| 40  | 8   | 1         | 10036 | 10036 | 10000          |         |                       | 0.36       | 0.36  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 2         | 8598  | 8532  | 7750           |         |                       | 10.94      | 10.09 |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 3         | 7744  | 7808  | 6720           |         |                       | 15.24      | 16.19 |                       |      | 6.79                  | 6.81 | 15.24                 | 16.19 |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 4         | 9940  | 9940  | 9620           |         |                       | 3.33       | 3.33  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |
|     |     | 5         | 10150 | 10150 | 9750           |         |                       | 4.10       | 4.10  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |  |

**Table E.6 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |  |
| 55  | 2   | 1      | 62720 | 62720 | 62720       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 48608 | 48608 | 48608       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |  |  |  |
|     |     | 3      | 43904 | 43904 | 43904       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 58016 | 58016 | 58016       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 61152 | 61152 | 61152       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 4   | 1      | 32480 | 32480 | 32480       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 25172 | 25172 | 25172       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |  |  |  |
|     |     | 3      | 22736 | 22736 | 22736       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 30044 | 30044 | 30044       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 31668 | 31668 | 31668       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 6   | 1      | 22400 | 22400 | 22400       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 17966 | 17966 | 17360       |         |                 | 3.49       | 3.49  |                    |      | 1.33               | 1.33 | 3.49               | 3.49  |                            |      |                            |      |  |  |  |
|     |     | 3      | 16176 | 16176 | 15680       |         |                 | 3.16       | 3.16  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 20720 | 20720 | 20720       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 21840 | 21840 | 21840       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 55  | 8   | 1      | 17904 | 17904 | 17840       |         |                 | 0.36       | 0.36  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 15006 | 14958 | 13826       |         |                 | 8.53       | 8.19  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 13592 | 13592 | 12152       |         |                 | 11.85      | 11.85 |                    |      | 4.31               | 4.24 | 11.85              | 11.85 |                            |      |                            |      |  |  |  |
|     |     | 4      | 17156 | 17156 | 17020       |         |                 | 0.80       | 0.80  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 17394 | 17394 | 17394       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |

**Table E.6 (continued):** Computational results for *No Wait Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 10  | 2   | 1      | 1834 | 1834 | 1820        | 1716(*) |                 | 0.77       | 0.77  |                    |      | 2.03               | 2.12 | 6.58               | 6.83  |                            |      |                            |      |
|     |     | 2      | 1710 | 1714 | 1680        |         |                 | 1.79       | 2.02  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1716 | 1720 | 1610        |         |                 | 6.58       | 6.83  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 1838 | 1838 | 1820        |         |                 | 0.99       | 0.99  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1820 | 1820 | 1820        |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
| 10  | 4   | 1      | 1522 | 1434 | 1404        | 1434    | 34608.51        | 8.40       | 2.14  | 6.14               | 0.00 | 10.34              | 9.09 | 16.20              | 16.20 |                            |      |                            |      |
|     |     | 2      | 1506 | 1506 | 1296        | 1388    | 103433.02       | 16.20      | 16.20 | 8.50               | 8.50 |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1354 | 1354 | 1242        | 1354    | 127726.17       | 9.02       | 9.02  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 1540 | 1540 | 1404        | 1446    | 34851.46        | 9.69       | 9.69  | 6.50               | 6.50 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1522 | 1522 | 1404        |         |                 | 8.40       | 8.40  | ---                | ---  |                    |      |                    |       |                            |      |                            |      |
| 10  | 6   | 1      | 1522 | 1434 | 1352        | 1434    | 34608.51        | 12.57      | 6.07  | 6.14               | 0.00 | 11.18              | 9.88 | 16.20              | 16.20 |                            |      |                            |      |
|     |     | 2      | 1506 | 1506 | 1296        | 1388    | 103433.02       | 16.20      | 16.20 | 8.50               | 8.50 |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1354 | 1354 | 1242        | 1354    | 127726.17       | 9.02       | 9.02  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 1540 | 1540 | 1404        | 1446    | 34851.46        | 9.69       | 9.69  | 6.50               | 6.50 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1522 | 1522 | 1404        |         |                 | 8.40       | 8.40  | ---                | ---  |                    |      |                    |       |                            |      |                            |      |
| 10  | 8   | 1      | 1522 | 1434 | 1352        | 1434    | 34608.51        | 12.57      | 6.07  | 6.14               | 0.00 | 11.18              | 9.88 | 16.20              | 16.20 |                            |      |                            |      |
|     |     | 2      | 1506 | 1506 | 1296        | 1388    | 103433.02       | 16.20      | 16.20 | 8.50               | 8.50 |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 1354 | 1354 | 1242        | 1354    | 127726.17       | 9.02       | 9.02  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 1540 | 1540 | 1404        | 1446    | 34851.46        | 9.69       | 9.69  | 6.50               | 6.50 |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 1522 | 1522 | 1404        | 1522(*) |                 | 8.40       | 8.40  |                    |      |                    |      |                    |       |                            |      |                            |      |

**Table E.7:** Computational results for *No Wait Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2  | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 25  | 2   | 1      | 9460 | 9464 | 9412        |         |                 | 0.51       | 0.55  |                    |      | 1.21               | 1.30  | 3.63               | 3.77  |                            |      |                            |      |
|     |     | 2      | 8802 | 8818 | 8688        |         |                 | 1.31       | 1.50  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 8628 | 8640 | 8326        |         |                 | 3.63       | 3.77  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 9468 | 9476 | 9412        |         |                 | 0.59       | 0.68  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 9412 | 9412 | 9412        |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 25  | 4   | 1      | 6310 | 6310 | 5980        |         |                 | 5.52       | 5.52  |                    |      | 7.47               | 6.39  | 16.30              | 14.53 |                            |      |                            |      |
|     |     | 2      | 6420 | 6322 | 5520        |         |                 | 16.30      | 14.53 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 5820 | 5770 | 5290        |         |                 | 10.02      | 9.07  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 6106 | 6106 | 5980        |         |                 | 2.11       | 2.11  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 6184 | 6022 | 5980        |         |                 | 3.41       | 0.70  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 25  | 6   | 1      | 5584 | 5532 | 5200        |         |                 | 7.38       | 6.38  |                    |      | 13.73              | 11.72 | 20.71              | 18.35 |                            |      |                            |      |
|     |     | 2      | 5968 | 5758 | 4944        |         |                 | 20.71      | 16.46 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 5520 | 5444 | 4600        |         |                 | 20.00      | 18.35 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 5744 | 5744 | 5200        |         |                 | 10.46      | 10.46 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 5838 | 5672 | 5304        |         |                 | 10.07      | 6.94  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 25  | 8   | 1      | 5584 | 5532 | 5096        |         |                 | 9.58       | 8.56  |                    |      | 15.80              | 13.76 | 23.10              | 20.76 |                            |      |                            |      |
|     |     | 2      | 5968 | 5758 | 4848        |         |                 | 23.10      | 18.77 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 5520 | 5444 | 4508        |         |                 | 22.45      | 20.76 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 5744 | 5744 | 5096        |         |                 | 12.72      | 12.72 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 5838 | 5672 | 5252        |         |                 | 11.16      | 8.00  |                    |      |                    |       |                    |       |                            |      |                            |      |

**Table E.7 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$



| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2  | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 40  | 2   | 1      | 22974 | 22990 | 22880       |         |                 | 0.41       | 0.48  |                    |      | 0.92               | 1.06  | 2.67               | 2.92  |                            |      |                            |      |
|     |     | 2      | 21332 | 21380 | 21120       |         |                 | 1.00       | 1.23  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 20780 | 20832 | 20240       |         |                 | 2.67       | 2.92  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 22994 | 23034 | 22880       |         |                 | 0.50       | 0.67  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 22880 | 22880 | 22880       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 40  | 4   | 1      | 13746 | 13738 | 13468       |         |                 | 2.06       | 2.00  |                    |      | 4.09               | 3.96  | 8.39               | 8.39  |                            |      |                            |      |
|     |     | 2      | 13184 | 13240 | 12432       |         |                 | 6.05       | 6.50  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 12914 | 12914 | 11914       |         |                 | 8.39       | 8.39  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 13754 | 13754 | 13468       |         |                 | 2.12       | 2.12  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 13714 | 13572 | 13468       |         |                 | 1.83       | 0.77  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 40  | 6   | 1      | 12134 | 11814 | 10972       |         |                 | 10.59      | 7.67  |                    |      | 15.56              | 14.19 | 23.26              | 19.35 |                            |      |                            |      |
|     |     | 2      | 12136 | 12088 | 10128       |         |                 | 19.83      | 19.35 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 11964 | 11578 | 9706        |         |                 | 23.26      | 19.29 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 12294 | 12348 | 10972       |         |                 | 12.05      | 12.54 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 12298 | 12298 | 10972       |         |                 | 12.09      | 12.09 |                    |      |                    |       |                    |       |                            |      |                            |      |
| 40  | 8   | 1      | 12134 | 11814 | 10296       |         |                 | 17.85      | 14.74 |                    |      | 24.22              | 22.73 | 34.07              | 29.81 |                            |      |                            |      |
|     |     | 2      | 12136 | 12088 | 9312        |         |                 | 30.33      | 29.81 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 11964 | 11578 | 8924        |         |                 | 34.07      | 29.74 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 12294 | 12348 | 10296       |         |                 | 19.41      | 19.93 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 12298 | 12298 | 10296       |         |                 | 19.44      | 19.44 |                    |      |                    |       |                    |       |                            |      |                            |      |

**Table E.7 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25,35]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2  | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 55  | 2   | 1      | 42352 | 42396 | 42172       |         |                 | 0.43       | 0.53  |                    |      | 0.79               | 0.95  | 2.15               | 2.44  |                            |      |                            |      |
|     |     | 2      | 39290 | 39374 | 38928       |         |                 | 0.93       | 1.15  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 38108 | 38216 | 37306       |         |                 | 2.15       | 2.44  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 42364 | 42436 | 42172       |         |                 | 0.46       | 0.63  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 42172 | 42172 | 42172       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 55  | 4   | 1      | 24414 | 24884 | 23920       |         |                 | 2.07       | 4.03  |                    |      | 4.58               | 5.02  | 7.85               | 7.55  |                            |      |                            |      |
|     |     | 2      | 23300 | 23412 | 22080       |         |                 | 5.53       | 6.03  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 22822 | 22758 | 21160       |         |                 | 7.85       | 7.55  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 24998 | 24998 | 23920       |         |                 | 4.51       | 4.51  |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 24620 | 24628 | 23920       |         |                 | 2.93       | 2.96  |                    |      |                    |       |                    |       |                            |      |                            |      |
| 55  | 6   | 1      | 20872 | 20552 | 18720       |         |                 | 11.50      | 9.79  |                    |      | 15.42              | 14.78 | 22.69              | 20.88 |                            |      |                            |      |
|     |     | 2      | 20770 | 20876 | 17280       |         |                 | 20.20      | 20.81 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 20318 | 20018 | 16560       |         |                 | 22.69      | 20.88 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 20872 | 20872 | 18720       |         |                 | 11.50      | 11.50 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 20820 | 20768 | 18720       |         |                 | 11.22      | 10.94 |                    |      |                    |       |                    |       |                            |      |                            |      |
| 55  | 8   | 1      | 20872 | 20552 | 16952       |         |                 | 23.12      | 21.24 |                    |      | 28.29              | 27.59 | 37.60              | 35.57 |                            |      |                            |      |
|     |     | 2      | 20770 | 20876 | 15408       |         |                 | 34.80      | 35.49 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 20318 | 20018 | 14766       |         |                 | 37.60      | 35.57 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 20872 | 20872 | 16952       |         |                 | 23.12      | 23.12 |                    |      |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 20820 | 20768 | 16952       |         |                 | 22.82      | 22.51 |                    |      |                    |       |                    |       |                            |      |                            |      |

**Table E.7 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25,35]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |
| 10  | 2   | 1      | 2520 | 2520 | 2520        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 2380 | 2380 | 2380        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 3      | 2310 | 2310 | 2310        |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |
|     |     | 4      | 2520 | 2520 | 2520        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 2520 | 2520 | 2520        |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
| 10  | 4   | 1      | 1818 | 1818 | 1800        |         |                 | 1.00       | 1.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 1854 | 1854 | 1700        | 1790(*) |                 |            | 9.06 | 9.06               |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 3      | 1800 | 1800 | 1650        | 1740    | 104625.72       |            |      | 9.09               | 9.09 | 3.45               | 3.45 | 7.16               | 5.63 | 9.09                       | 9.09 |                            |      |  |  |
|     |     | 4      | 1956 | 1818 | 1800        |         |                 |            |      | 8.67               | 1.00 |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 1944 | 1944 | 1800        | 1818    | 55740.93        |            |      | 8.00               | 8.00 | 6.93               | 6.93 |                    |      |                            |      |                            |      |  |  |
| 10  | 6   | 1      | 1756 | 1756 | 1728        | 1756    | 27679.80        | 1.62       | 1.62 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 1834 | 1766 | 1632        | 1722    | 59274.44        | 12.38      | 8.21 | 6.50               | 2.56 |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 3      | 1794 | 1728 | 1584        | 1684    | 70499.34        | 13.26      | 9.09 | 6.53               | 2.61 | 9.06               | 5.08 | 13.26              | 9.09 | 5.65                       | 1.79 | 7.90                       | 3.78 |  |  |
|     |     | 4      | 1884 | 1756 | 1728        | 1756    | 64088.75        | 9.03       | 1.62 | 7.29               | 0.00 |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 1884 | 1812 | 1728        | 1746    | 28243.47        | 9.03       | 4.86 | 7.90               | 3.78 |                    |      |                    |      |                            |      |                            |      |  |  |
| 10  | 8   | 1      | 1756 | 1756 | 1728        | 1756    | 27679.80        | 1.62       | 1.62 | 0.00               | 0.00 |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 1834 | 1766 | 1632        | 1722    | 59274.44        | 12.38      | 8.21 | 6.50               | 2.56 |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 3      | 1794 | 1728 | 1584        | 1684    | 70499.34        | 13.26      | 9.09 | 6.53               | 2.61 | 9.06               | 5.08 | 13.26              | 9.09 | 5.65                       | 1.79 | 7.90                       | 3.78 |  |  |
|     |     | 4      | 1884 | 1756 | 1728        | 1756    | 64088.75        | 9.03       | 1.62 | 7.29               | 0.00 |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 1884 | 1812 | 1728        | 1746    | 28243.47        | 9.03       | 4.86 | 7.90               | 3.78 |                    |      |                    |      |                            |      |                            |      |  |  |

**Table E.8:** Computational results for *No Wait Problem* where  $p_j \in [25,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |
| 25  | 2   | 1         | 13032 | 13032 | 13032          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 12308 | 12308 | 12308          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 11946 | 11946 | 11946          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 13032 | 13032 | 13032          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 13032 | 13032 | 13032          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
| 25  | 4   | 1         | 7928  | 7936  | 7848           |         |                       | 1.02       | 1.12  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 7920  | 7920  | 7412           |         |                       | 6.85       | 6.85  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 7690  | 7690  | 7194           |         |                       | 6.89       | 6.89  |                       |      | 3.16                  | 3.20 | 6.89                  | 6.89  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 7928  | 7936  | 7848           |         |                       | 1.02       | 1.12  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 7848  | 7848  | 7848           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
| 25  | 6   | 1         | 6800  | 6800  | 6696           |         |                       | 1.55       | 1.55  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 6830  | 6830  | 6324           |         |                       | 8.00       | 8.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 6678  | 6678  | 6138           |         |                       | 8.80       | 8.80  |                       |      | 4.10                  | 4.10 | 8.80                  | 8.80  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 6800  | 6800  | 6696           |         |                       | 1.55       | 1.55  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 6736  | 6736  | 6696           |         |                       | 0.60       | 0.60  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
| 25  | 8   | 1         | 6654  | 6436  | 6264           |         |                       | 6.23       | 2.75  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 6830  | 6692  | 6052           |         |                       | 12.86      | 10.58 |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 6544  | 6410  | 5874           |         |                       | 11.41      | 9.12  |                       |      | 7.44                  | 5.38 | 12.86                 | 10.58 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 6654  | 6508  | 6408           |         |                       | 3.84       | 1.56  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 6592  | 6592  | 6408           |         |                       | 2.87       | 2.87  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |

**Table E.8 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |
| 40  | 2   | 1         | 31680 | 31680 | 31680          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 29920 | 29920 | 29920          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |
|     |     | 3         | 29040 | 29040 | 29040          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 31680 | 31680 | 31680          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 31680 | 31680 | 31680          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
| 40  | 4   | 1         | 18184 | 18208 | 18000          |         |                       | 1.02       | 1.16  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 17206 | 17222 | 17000          |         |                       | 1.21       | 1.31  |                       |      | 1.63                  | 1.00 | 4.90                  | 1.39  |                                  |      |                                  |      |      |      |
|     |     | 3         | 17308 | 16730 | 16500          |         |                       | 4.90       | 1.39  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 18184 | 18208 | 18000          |         |                       | 1.02       | 1.16  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 18000 | 18000 | 18000          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
| 40  | 6   | 1         | 14836 | 14544 | 14328          |         |                       | 3.55       | 1.51  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 14082 | 14082 | 13532          |         |                       | 4.06       | 4.06  |                       |      | 3.79                  | 2.56 | 8.18                  | 4.98  |                                  |      |                                  |      |      |      |
|     |     | 3         | 14208 | 13788 | 13134          |         |                       | 8.18       | 4.98  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 14628 | 14544 | 14328          |         |                       | 2.09       | 1.51  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 14482 | 14432 | 14328          |         |                       | 1.07       | 0.73  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
| 40  | 8   | 1         | 14388 | 13390 | 12816          |         |                       | 12.27      | 4.48  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 13798 | 13442 | 12376          |         |                       | 11.49      | 8.61  |                       |      | 9.29                  | 6.23 | 14.22                 | 10.72 |                                  |      |                                  |      |      |      |
|     |     | 3         | 13720 | 13300 | 12012          |         |                       | 14.22      | 10.72 |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 13610 | 13538 | 13104          |         |                       | 3.86       | 3.31  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 13708 | 13634 | 13104          |         |                       | 4.61       | 4.04  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |

**Table E.8 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 55  | 2   | 1      | 58392 | 58392 | 58392       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |      |                            |      |
|     |     | 2      | 55148 | 55148 | 55148       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 53526 | 53526 | 53526       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 58392 | 58392 | 58392       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 58392 | 58392 | 58392       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
| 55  | 4   | 1      | 32520 | 32560 | 32184       |         |                 | 1.04       | 1.17  |                    |      | 0.92               | 1.01 | 1.27               | 1.38  |                            |      |                            |      |
|     |     | 2      | 30772 | 30796 | 30396       |         |                 | 1.24       | 1.32  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 29878 | 29910 | 29502       |         |                 | 1.27       | 1.38  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 32520 | 32560 | 32184       |         |                 | 1.04       | 1.17  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 32184 | 32184 | 32184       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |
| 55  | 6   | 1      | 25588 | 25088 | 24696       |         |                 | 3.61       | 1.59  |                    |      | 3.18               | 2.45 | 5.42               | 4.68  |                            |      |                            |      |
|     |     | 2      | 24418 | 24220 | 23324       |         |                 | 4.69       | 3.84  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 23866 | 23698 | 22638       |         |                 | 5.42       | 4.68  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 25088 | 25088 | 24696       |         |                 | 1.59       | 1.59  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 24836 | 24836 | 24696       |         |                 | 0.57       | 0.57  |                    |      |                    |      |                    |       |                            |      |                            |      |
| 55  | 8   | 1      | 22992 | 22698 | 21384       |         |                 | 7.52       | 6.14  |                    |      | 9.42               | 8.17 | 13.37              | 12.29 |                            |      |                            |      |
|     |     | 2      | 22898 | 22754 | 20604       |         |                 | 11.13      | 10.43 |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 3      | 22222 | 22012 | 19602       |         |                 | 13.37      | 12.29 |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 4      | 22992 | 22552 | 21384       |         |                 | 7.52       | 5.46  |                    |      |                    |      |                    |       |                            |      |                            |      |
|     |     | 5      | 23000 | 22782 | 21384       |         |                 | 7.56       | 6.54  |                    |      |                    |      |                    |       |                            |      |                            |      |

**Table E.8 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |  |
| 10  | 2   | 1      | 2800 | 2800 | 2800        | 2800    |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 2170 | 2170 | 2170        | 2170    |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 1984 | 1984 | 1960        |         |                 |            | 1.22  | 1.22               |      |                    | 0.24 | 0.24               | 1.22  | 1.22                       |      |                            |      |  |  |  |
|     |     | 4      | 2590 | 2590 | 2590        | 2590    |                 |            | 0.00  | 0.00               |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 2730 | 2730 | 2730        | 2730    |                 |            | 0.00  | 0.00               |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
| 10  | 4   | 1      | 2036 | 2036 | 2000        |         |                 | 1.80       | 1.80  |                    |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 1740 | 1728 | 1550        | 1728    | 61045.96        | 12.26      | 11.48 | 0.69               | 0.00 |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 1600 | 1600 | 1400        | 1600    | 88992.59        | 14.29      | 14.29 | 0.00               | 0.00 | 6.45               | 6.29 | 14.29              | 14.29 |                            |      |                            |      |  |  |  |
|     |     | 4      | 1922 | 1922 | 1850        |         |                 |            | 3.89  | 3.89               |      |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 1950 | 1950 | 1950        | 1950    |                 |            | 0.00  | 0.00               | 0.00 | 0.00               |      |                    |       |                            |      |                            |      |  |  |  |
| 10  | 6   | 1      | 1956 | 1956 | 1920        | 1956    | 39908.59        | 1.88       | 1.88  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 1846 | 1846 | 1488        | 1728(*) |                 | 24.06      | 24.06 | ---                | ---  |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 1600 | 1600 | 1344        | 1600    | 88992.59        | 19.05      | 19.05 | 0.00               | 0.00 | 9.81               | 9.81 | 24.06              | 24.06 |                            |      |                            |      |  |  |  |
|     |     | 4      | 1848 | 1848 | 1776        | 1848    | 88297.99        | 4.05       | 4.05  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 1872 | 1872 | 1872        | 1872    |                 |            | 0.00  | 0.00               | 0.00 | 0.00               |      |                    |       |                            |      |                            |      |  |  |  |
| 10  | 8   | 1      | 1956 | 1956 | 1920        | 1956    | 39908.59        | 1.88       | 1.88  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 1846 | 1846 | 1488        | 1728(*) |                 | 24.06      | 24.06 | ---                | ---  |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 3      | 1600 | 1600 | 1344        | 1600    | 88992.59        | 19.05      | 19.05 | 0.00               | 0.00 | 9.81               | 9.81 | 24.06              | 24.06 |                            |      |                            |      |  |  |  |
|     |     | 4      | 1848 | 1848 | 1776        | 1848    | 88297.99        | 4.05       | 4.05  | 0.00               | 0.00 |                    |      |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 1872 | 1872 | 1872        | 1872    |                 |            | 0.00  | 0.00               | 0.00 | 0.00               |      |                    |       |                            |      |                            |      |  |  |  |

**Table E.9:** Computational results for *No Wait Problem* where  $p_j \in [25,35]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 |
| 25  | 2   | 1         | 14480 | 14480 | 14480          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 11234 | 11234 | 11222          |         |                       | 0.11       | 0.11  |                       |      | 0.12                  | 0.12  | 0.47                  | 0.47  |                                  |      |                                  |      |
|     |     | 3         | 10184 | 10184 | 10136          |         |                       | 0.47       | 0.47  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 13394 | 13394 | 13394          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 14118 | 14118 | 14118          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
| 25  | 4   | 1         | 8864  | 8864  | 8720           |         |                       | 1.65       | 1.65  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 7430  | 7430  | 6758           |         |                       | 9.94       | 9.94  |                       |      | 5.52                  | 5.60  | 12.06                 | 12.06 |                                  |      |                                  |      |
|     |     | 3         | 6840  | 6840  | 6104           |         |                       | 12.06      | 12.06 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 8386  | 8418  | 8066           |         |                       | 3.97       | 4.36  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 8502  | 8502  | 8502           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
| 25  | 6   | 1         | 7806  | 7640  | 7120           |         |                       | 9.63       | 7.30  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 6842  | 6842  | 5766           |         |                       | 18.66      | 18.66 |                       |      | 12.67                 | 12.33 | 24.69                 | 24.69 |                                  |      |                                  |      |
|     |     | 3         | 6494  | 6494  | 5208           |         |                       | 24.69      | 24.69 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 7406  | 7406  | 6882           |         |                       | 7.61       | 7.61  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 7454  | 7500  | 7254           |         |                       | 2.76       | 3.39  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
| 25  | 8   | 1         | 7196  | 7032  | 6560           |         |                       | 9.70       | 7.20  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 6712  | 6712  | 5394           |         |                       | 24.43      | 24.43 |                       |      | 15.26                 | 14.30 | 30.83                 | 30.83 |                                  |      |                                  |      |
|     |     | 3         | 6374  | 6374  | 4872           |         |                       | 30.83      | 30.83 |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 4         | 6830  | 6830  | 6438           |         |                       | 6.09       | 6.09  |                       |      |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 7142  | 6986  | 6786           |         |                       | 5.25       | 2.95  |                       |      |                       |       |                       |       |                                  |      |                                  |      |

**Table E.9 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$



| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|--|--|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2  | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |  |
| 40  | 2   | 1      | 35200 | 35200 | 35200       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 27280 | 27280 | 27280       |         |                 | 0.00       | 0.00  |                    |      | 0.12               | 0.12  | 0.58               | 0.58  |                            |      |                            |      |  |  |  |
|     |     | 3      | 24784 | 24784 | 24640       |         |                 | 0.58       | 0.58  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 32560 | 32560 | 32560       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 34320 | 34320 | 34320       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
| 40  | 4   | 1      | 20292 | 20324 | 20000       |         |                 | 1.46       | 1.62  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 16772 | 16772 | 15500       |         |                 | 8.21       | 8.21  |                    |      | 5.01               | 4.96  | 11.60              | 10.80 |                            |      |                            |      |  |  |  |
|     |     | 3      | 15624 | 15512 | 14000       |         |                 | 11.60      | 10.80 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 19204 | 19268 | 18500       |         |                 | 3.81       | 4.15  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 19500 | 19500 | 19500       |         |                 | 0.00       | 0.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
| 40  | 6   | 1      | 16492 | 16492 | 15440       |         |                 | 6.81       | 6.81  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 14744 | 14744 | 12338       |         |                 | 19.50      | 19.50 |                    |      | 13.49              | 13.57 | 29.90              | 30.31 |                            |      |                            |      |  |  |  |
|     |     | 3      | 14040 | 14084 | 10808       |         |                 | 29.90      | 30.31 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 15854 | 15854 | 14726       |         |                 | 7.66       | 7.66  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 16074 | 16074 | 15522       |         |                 | 3.56       | 3.56  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
| 40  | 8   | 1      | 14758 | 14428 | 13520       |         |                 | 9.16       | 6.72  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 2      | 13942 | 13708 | 11036       |         |                 | 26.33      | 24.21 |                    |      | 17.35              | 15.86 | 40.30              | 37.43 |                            |      |                            |      |  |  |  |
|     |     | 3      | 13592 | 13314 | 9688        |         |                 | 40.30      | 37.43 |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 4      | 14094 | 14094 | 13172       |         |                 | 7.00       | 7.00  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |
|     |     | 5      | 14432 | 14432 | 13884       |         |                 | 3.95       | 3.95  |                    |      |                    |       |                    |       |                            |      |                            |      |  |  |  |

**Table E.9 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |
| 55  | 2   | 1         | 64880 | 64880 | 64880          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 50282 | 50282 | 50282          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 45608 | 45608 | 45416          |         |                       | 0.42       | 0.42  |                       |      | 0.08                  | 0.08  | 0.42                  | 0.42  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 60014 | 60014 | 60014          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 63258 | 63258 | 63258          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
| 55  | 4   | 1         | 36312 | 36360 | 35760          |         |                       | 1.54       | 1.68  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 29744 | 29816 | 27714          |         |                       | 7.32       | 7.58  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 27488 | 27488 | 25032          |         |                       | 9.81       | 9.81  |                       |      | 4.48                  | 4.62  | 9.81                  | 9.81  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 34310 | 34406 | 33078          |         |                       | 3.72       | 4.01  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 34866 | 34866 | 34866          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
| 55  | 6   | 1         | 28172 | 28172 | 26720          |         |                       | 5.43       | 5.43  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 24758 | 25082 | 21266          |         |                       | 16.42      | 17.94 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 23806 | 23888 | 18704          |         |                       | 27.28      | 27.72 |                       |      | 11.88                 | 12.60 | 27.28                 | 27.72 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 26854 | 27356 | 25382          |         |                       | 5.80       | 7.78  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 27214 | 27134 | 26052          |         |                       | 4.46       | 4.15  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
| 55  | 8   | 1         | 24622 | 24128 | 22720          |         |                       | 8.37       | 6.20  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 23368 | 22992 | 18414          |         |                       | 26.90      | 24.86 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 22578 | 22150 | 16240          |         |                       | 39.03      | 36.39 |                       |      | 18.14                 | 16.46 | 39.03                 | 36.39 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 23738 | 23468 | 21978          |         |                       | 8.01       | 6.78  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 24014 | 23936 | 22152          |         |                       | 8.41       | 8.05  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |

**Table E.9 (continued):** Computational results for *No Wait Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2  | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 10  | 2   | 1      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00  | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1440 | 1440 | 1440        | 1440    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 1380 | 1380 | 1380        | 1380    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1560 | 1560 | 1560        | 1560    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
| 10  | 4   | 1      | 994  | 994  | 936         | 960     | 2796.81         | 6.20       | 6.20  | 3.54               | 3.54 | 5.93               | 5.93  | 10.83              | 10.83 | 1.65                       | 1.65 | 4.72                       | 4.72 |
|     |     | 2      | 1064 | 1064 | 960         | 1016    | 9737.77         | 10.83      | 10.83 | 4.72               | 4.72 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 880  | 880  | 828         | 880     | 2819.89         | 6.28       | 6.28  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1054 | 1054 | 1040        | 1054    | 3000.27         | 1.35       | 1.35  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1092 | 1092 | 1040        | 1092    | 6470.92         | 5.00       | 5.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
| 10  | 6   | 1      | 994  | 994  | 832         | 960     | 2796.81         | 19.47      | 19.47 | 3.54               | 3.54 | 17.06              | 17.06 | 23.15              | 23.15 | 1.65                       | 1.65 | 4.72                       | 4.72 |
|     |     | 2      | 1064 | 1064 | 864         | 1016    | 6583.86         | 23.15      | 23.15 | 4.72               | 4.72 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 880  | 880  | 736         | 880     | 2235.39         | 19.57      | 19.57 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1054 | 1054 | 936         | 1054    | 3000.27         | 12.61      | 12.61 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1092 | 1092 | 988         | 1092    | 6470.92         | 10.53      | 10.53 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
| 10  | 8   | 1      | 994  | 994  | 832         | 960     | 2796.81         | 19.47      | 19.47 | 3.54               | 3.54 | 17.06              | 17.06 | 23.15              | 23.15 | 1.65                       | 1.65 | 4.72                       | 4.72 |
|     |     | 2      | 1064 | 1064 | 864         | 1016    | 11335.24        | 23.15      | 23.15 | 4.72               | 4.72 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 880  | 880  | 736         | 880     | 2357.05         | 19.57      | 19.57 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1054 | 1054 | 936         | 1054    | 3000.27         | 12.61      | 12.61 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1092 | 1092 | 988         | 1092    | 6470.92         | 10.53      | 10.53 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |

**Table E.10:** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | NWH1 | NWH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|
|     |     |           |      |      |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |
| 25  | 2   | 1         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 8112 | 8112 | 8112           |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |
|     |     | 3         | 7774 | 7774 | 7774           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 8788 | 8788 | 8788           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
| 25  | 4   | 1         | 4760 | 4760 | 4732           |         |                       | 0.59       | 0.59  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 4760 | 4716 | 4656           |         |                       | 2.23       | 1.29  |                       |      | 0.85                  | 0.57  | 2.23                  | 1.29  |                                  |      |                                  |      |      |      |
|     |     | 3         | 4214 | 4204 | 4186           |         |                       | 0.67       | 0.43  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 4768 | 4758 | 4732           |         |                       | 0.76       | 0.55  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 4732 | 4732 | 4732           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
| 25  | 6   | 1         | 3606 | 3500 | 3380           |         |                       | 6.69       | 3.55  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 4176 | 4128 | 3696           |         |                       | 12.99      | 11.69 |                       |      | 7.62                  | 6.13  | 12.99                 | 11.69 |                                  |      |                                  |      |      |      |
|     |     | 3         | 3256 | 3208 | 2990           |         |                       | 8.90       | 7.29  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 3970 | 3916 | 3796           |         |                       | 4.58       | 3.16  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 3984 | 3984 | 3796           |         |                       | 4.95       | 4.95  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
| 25  | 8   | 1         | 3606 | 3500 | 3016           |         |                       | 19.56      | 16.05 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 4176 | 4128 | 3216           |         |                       | 29.85      | 28.36 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 3         | 3256 | 3208 | 2668           |         |                       | 22.04      | 20.24 |                       |      | 21.13                 | 19.19 | 29.85                 | 28.36 |                                  |      |                                  |      |      |      |
|     |     | 4         | 3810 | 3714 | 3328           |         |                       | 14.48      | 11.60 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 3984 | 3984 | 3328           |         |                       | 19.71      | 19.71 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |

**Table E.10 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |
| 40  | 2   | 1         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 20160 | 20160 | 20160          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 19320 | 19320 | 19320          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
| 40  | 4   | 1         | 11488 | 11488 | 11440          |         |                       | 0.42       | 0.42  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 10680 | 10632 | 10560          |         |                       | 1.14       | 0.68  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 10200 | 10192 | 10120          |         |                       | 0.79       | 0.71  |                       |      | 0.57                  | 0.45  | 1.14                  | 0.71  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 11496 | 11488 | 11440          |         |                       | 0.49       | 0.42  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 11440 | 11440 | 11440          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
| 40  | 6   | 1         | 8116  | 8116  | 8008           |         |                       | 1.35       | 1.35  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 8290  | 7942  | 7680           |         |                       | 7.94       | 3.41  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 7458  | 7412  | 7084           |         |                       | 5.28       | 4.63  |                       |      | 3.90                  | 2.62  | 7.94                  | 4.63  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 8804  | 8752  | 8632           |         |                       | 1.99       | 1.39  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 8564  | 8512  | 8320           |         |                       | 2.93       | 2.31  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
| 40  | 8   | 1         | 7040  | 6986  | 6240           |         |                       | 12.82      | 11.96 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 7642  | 7594  | 6480           |         |                       | 17.93      | 17.19 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 7116  | 7116  | 5750           |         |                       | 23.76      | 23.76 |                       |      | 15.48                 | 14.70 | 23.76                 | 23.76 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 7842  | 7786  | 7280           |         |                       | 7.72       | 6.95  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 8084  | 7978  | 7020           |         |                       | 15.16      | 13.65 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |  |

**Table E.10 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|--|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |  |
| 55  | 2   | 1         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 37632 | 37632 | 37632          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 36064 | 36064 | 36064          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 40768 | 40768 | 40768          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
| 55  | 4   | 1         | 21216 | 21202 | 21112          |         |                       | 0.49       | 0.43  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 19654 | 19640 | 19488          |         |                       | 0.85       | 0.78  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 18758 | 18758 | 18676          |         |                       | 0.44       | 0.44  |                       |      | 0.44                  | 0.41 | 0.85                  | 0.78  |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 21202 | 21202 | 21112          |         |                       | 0.43       | 0.43  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 21112 | 21112 | 21112          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
| 55  | 6   | 1         | 15094 | 14736 | 14560          |         |                       | 3.67       | 1.21  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 14420 | 14372 | 13872          |         |                       | 3.95       | 3.60  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 13324 | 13406 | 12880          |         |                       | 3.45       | 4.08  |                       |      | 2.62                  | 2.54 | 3.95                  | 4.08  |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 15264 | 15248 | 15028          |         |                       | 1.57       | 1.46  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 14624 | 14902 | 14560          |         |                       | 0.44       | 2.35  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
| 55  | 8   | 1         | 12490 | 12276 | 11284          |         |                       | 10.69      | 8.79  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 2         | 13088 | 12876 | 11376          |         |                       | 15.05      | 13.19 |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 3         | 11282 | 11158 | 9982           |         |                       | 13.02      | 11.78 |                       |      | 10.38                 | 8.95 | 15.05                 | 13.19 |                                  |      |                                  |      |      |      |  |  |
|     |     | 4         | 13212 | 12890 | 12324          |         |                       | 7.21       | 4.59  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |
|     |     | 5         | 12282 | 12336 | 11596          |         |                       | 5.92       | 6.38  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |  |

**Table E.10 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins.<br># | NWH1 | NWH2 | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |
|-----|-----|-----------|------|------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|     |     |           |      |      |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 |
| 10  | 2   | 1         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 2040 | 2040 | 2040           | 2040    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 1980 | 1980 | 1980           | 1980    |                       | 0.00       | 0.00  | 0.00                  | 0.00 | 0.00                  | 0.00  | 0.00                  | 0.00  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 4         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 2160 | 2160 | 2160           | 2160    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
| 10  | 4   | 1         | 1296 | 1296 | 1296           | 1296    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 1236 | 1236 | 1224           | 1236    | 5167.71               | 0.98       | 0.98  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 1200 | 1200 | 1188           | 1200    | 2626.64               | 1.01       | 1.01  | 0.00                  | 0.00 | 0.58                  | 0.58  | 1.01                  | 1.01  | 0.00                             | 0.00 | 0.00                             | 0.00 |
|     |     | 4         | 1308 | 1308 | 1296           | 1308    | 1499.70               | 0.93       | 0.93  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 1440 | 1440 | 1440           | 1440    |                       | 0.00       | 0.00  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
| 10  | 6   | 1         | 1296 | 1236 | 1152           | 1236    | 1316.86               | 12.50      | 7.29  | 4.85                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 1236 | 1236 | 1088           | 1236    | 5167.71               | 13.60      | 13.60 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 1132 | 1132 | 990            | 1076    | 1270.04               | 14.34      | 14.34 | 5.20                  | 5.20 | 11.77                 | 10.73 | 14.34                 | 14.34 | 3.06                             | 2.09 | 5.26                             | 5.26 |
|     |     | 4         | 1236 | 1236 | 1152           | 1236    | 926.56                | 7.29       | 7.29  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 1440 | 1440 | 1296           | 1368    | 2934.76               | 11.11      | 11.11 | 5.26                  | 5.26 |                       |       |                       |       |                                  |      |                                  |      |
| 10  | 8   | 1         | 1296 | 1236 | 1152           | 1236    | 1316.86               | 12.50      | 7.29  | 4.85                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 2         | 1236 | 1236 | 1088           | 1236    | 5167.71               | 13.60      | 13.60 | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 3         | 1132 | 1132 | 990            | 1076    | 1270.04               | 14.34      | 14.34 | 5.20                  | 5.20 | 13.08                 | 12.04 | 17.65                 | 17.65 | 3.06                             | 2.09 | 5.26                             | 5.26 |
|     |     | 4         | 1236 | 1236 | 1152           | 1236    | 926.56                | 7.29       | 7.29  | 0.00                  | 0.00 |                       |       |                       |       |                                  |      |                                  |      |
|     |     | 5         | 1440 | 1440 | 1224           | 1368    | 2934.76               | 17.65      | 17.65 | 5.26                  | 5.26 |                       |       |                       |       |                                  |      |                                  |      |

**Table E.11:** Computational results for *No Wait Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |  |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|--|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |  |
| 25  | 2   | 1         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 11492 | 11492 | 11492          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 11154 | 11154 | 11154          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 12168 | 12168 | 12168          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
| 25  | 4   | 1         | 6562  | 6562  | 6552           |         |                       | 0.15       | 0.15  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 6224  | 6224  | 6188           |         |                       | 0.58       | 0.58  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 6016  | 6016  | 6006           |         |                       | 0.17       | 0.17  |                       |      | 0.21                  | 0.21 | 0.58                  | 0.58  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 6562  | 6562  | 6552           |         |                       | 0.15       | 0.15  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 6552  | 6552  | 6552           |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
| 25  | 6   | 1         | 4720  | 4706  | 4680           |         |                       | 0.85       | 0.56  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 5092  | 5092  | 4964           |         |                       | 2.58       | 2.58  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 4386  | 4386  | 4290           |         |                       | 2.24       | 2.24  |                       |      | 1.60                  | 1.19 | 2.58                  | 2.58  |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 5012  | 4996  | 4968           |         |                       | 0.89       | 0.56  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 5040  | 4968  | 4968           |         |                       | 1.45       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
| 25  | 8   | 1         | 4306  | 4306  | 3960           |         |                       | 8.74       | 8.74  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 2         | 4990  | 4922  | 4352           |         |                       | 14.66      | 13.10 |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 3         | 3974  | 3974  | 3630           |         |                       | 9.48       | 9.48  |                       |      | 8.63                  | 7.99 | 14.66                 | 13.10 |                                  |      |                                  |      |      |      |  |
|     |     | 4         | 4456  | 4456  | 4392           |         |                       | 1.46       | 1.46  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |
|     |     | 5         | 4780  | 4708  | 4392           |         |                       | 8.83       | 7.19  |                       |      |                       |      |                       |       |                                  |      |                                  |      |      |      |  |

**Table E.11 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$



| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |  |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|--|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |  |  |
| 40  | 2   | 1      | 30240 | 30240 | 30240       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 28560 | 28560 | 28560       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |  |  |
|     |     | 3      | 27720 | 27720 | 27720       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 4      | 30240 | 30240 | 30240       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 30240 | 30240 | 30240       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
| 40  | 4   | 1      | 15848 | 15848 | 15840       |         |                 | 0.05       | 0.05 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 14992 | 14992 | 14960       |         |                 | 0.21       | 0.21 |                    |      | 0.09               | 0.09 | 0.21               | 0.21 |                            |      |                            |      |  |  |
|     |     | 3      | 14536 | 14536 | 14520       |         |                 | 0.11       | 0.11 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 4      | 15848 | 15848 | 15840       |         |                 | 0.05       | 0.05 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 15840 | 15840 | 15840       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
| 40  | 6   | 1      | 11140 | 11140 | 11088       |         |                 | 0.47       | 0.47 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 10640 | 10568 | 10472       |         |                 | 1.60       | 0.92 |                    |      | 0.73               | 0.52 | 1.60               | 0.92 |                            |      |                            |      |  |  |
|     |     | 3      | 10248 | 10228 | 10164       |         |                 | 0.83       | 0.63 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 4      | 11152 | 11152 | 11088       |         |                 | 0.58       | 0.58 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 11108 | 11088 | 11088       |         |                 | 0.18       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
| 40  | 8   | 1      | 8864  | 8720  | 8640        |         |                 | 2.59       | 0.93 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 2      | 9312  | 9312  | 8840        |         |                 | 5.34       | 5.34 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 3      | 8522  | 8522  | 7920        |         |                 | 7.60       | 7.60 |                    |      | 3.64               | 3.15 | 7.60               | 7.60 |                            |      |                            |      |  |  |
|     |     | 4      | 9484  | 9484  | 9360        |         |                 | 1.32       | 1.32 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |
|     |     | 5      | 9484  | 9412  | 9360        |         |                 | 1.32       | 0.56 |                    |      |                    |      |                    |      |                            |      |                            |      |  |  |

**Table E.11 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |      | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |      | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|------|--------------------|------|--------------------|------|--------------------|------|----------------------------|------|----------------------------|------|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2 | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 55  | 2   | 1      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      | 0.00               | 0.00 | 0.00               | 0.00 |                            |      |                            |      |
|     |     | 2      | 53312 | 53312 | 53312       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 51744 | 51744 | 51744       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 56448 | 56448 | 56448       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 4   | 1      | 29254 | 29254 | 29232       |         |                 | 0.08       | 0.08 |                    |      | 0.07               | 0.07 | 0.16               | 0.16 |                            |      |                            |      |
|     |     | 2      | 27652 | 27652 | 27608       |         |                 | 0.16       | 0.16 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 26810 | 26810 | 26796       |         |                 | 0.05       | 0.05 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 29246 | 29246 | 29232       |         |                 | 0.05       | 0.05 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 29232 | 29232 | 29232       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 6   | 1      | 20286 | 20274 | 20160       |         |                 | 0.63       | 0.57 |                    |      | 0.58               | 0.47 | 1.22               | 0.79 |                            |      |                            |      |
|     |     | 2      | 19272 | 19190 | 19040       |         |                 | 1.22       | 0.79 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 18570 | 18556 | 18480       |         |                 | 0.49       | 0.41 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 20274 | 20274 | 20160       |         |                 | 0.57       | 0.57 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 20160 | 20160 | 20160       |         |                 | 0.00       | 0.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
| 55  | 8   | 1      | 15808 | 15996 | 15624       |         |                 | 1.18       | 2.38 |                    |      | 1.69               | 1.77 | 3.31               | 2.44 |                            |      |                            |      |
|     |     | 2      | 16158 | 16022 | 15640       |         |                 | 3.31       | 2.44 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 3      | 14662 | 14596 | 14322       |         |                 | 2.37       | 1.91 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 4      | 16744 | 16726 | 16560       |         |                 | 1.11       | 1.00 |                    |      |                    |      |                    |      |                            |      |                            |      |
|     |     | 5      | 15700 | 15800 | 15624       |         |                 | 0.49       | 1.13 |                    |      |                    |      |                    |      |                            |      |                            |      |

**Table E.11 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | NWH1 | NWH2 | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |       | Maximum LB Gap (%) |       | Average Optimality Gap (%) |      | Maximum Optimality Gap (%) |      |
|-----|-----|--------|------|------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|-------|--------------------|-------|----------------------------|------|----------------------------|------|
|     |     |        |      |      |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2  | NWH1               | NWH2  | NWH1                       | NWH2 | NWH1                       | NWH2 |
| 10  | 2   | 1      | 2400 | 2400 | 2400        | 2400    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 0.00               | 0.00  | 0.00               | 0.00  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1860 | 1860 | 1860        | 1860    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 1680 | 1680 | 1680        | 1680    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 2220 | 2220 | 2220        | 2220    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 2340 | 2340 | 2340        | 2340    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
| 10  | 4   | 1      | 1440 | 1440 | 1440        | 1440    |                 | 0.00       | 0.00  | 0.00               | 0.00 | 2.71               | 2.71  | 8.78               | 8.78  | 0.00                       | 0.00 | 0.00                       | 0.00 |
|     |     | 2      | 1214 | 1214 | 1116        | 1214    | 5615.35         | 8.78       | 8.78  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 1056 | 1056 | 1008        | 1056    | 1776.71         | 4.76       | 4.76  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1332 | 1332 | 1332        | 1332    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1404 | 1404 | 1404        | 1404    |                 | 0.00       | 0.00  | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
| 10  | 6   | 1      | 1300 | 1300 | 1200        | 1240    | 709.58          | 8.33       | 8.33  | 4.84               | 4.84 | 17.03              | 17.03 | 31.63              | 31.63 | 1.23                       | 1.23 | 4.84                       | 4.84 |
|     |     | 2      | 1214 | 1214 | 992         | 1214    | 6216.62         | 22.38      | 22.38 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 1032 | 1032 | 784         | 1032    | 1707.36         | 31.63      | 31.63 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1306 | 1306 | 1184        | 1306    | 1246.28         | 10.30      | 10.30 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1404 | 1404 | 1248        | 1386    | 3096.17         | 12.50      | 12.50 | 1.30               | 1.30 |                    |       |                    |       |                            |      |                            |      |
| 10  | 8   | 1      | 1300 | 1300 | 1200        | 1240    | 709.58          | 8.33       | 8.33  | 4.84               | 4.84 | 17.03              | 17.03 | 31.63              | 31.63 | 1.23                       | 1.23 | 4.84                       | 4.84 |
|     |     | 2      | 1214 | 1214 | 992         | 1214    | 2875.94         | 22.38      | 22.38 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 3      | 1032 | 1032 | 784         | 1032    | 863.08          | 31.63      | 31.63 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 4      | 1306 | 1306 | 1184        | 1306    | 1246.28         | 10.30      | 10.30 | 0.00               | 0.00 |                    |       |                    |       |                            |      |                            |      |
|     |     | 5      | 1404 | 1404 | 1248        | 1386    | 3096.17         | 12.50      | 12.50 | 1.30               | 1.30 |                    |       |                    |       |                            |      |                            |      |

**Table E.12:** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |       | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |      |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|-------|-----------------------|-------|----------------------------------|------|----------------------------------|------|------|------|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 | NWH1 | NWH2 |
| 25  | 2   | 1         | 13520 | 13520 | 13520          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 10478 | 10478 | 10478          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00  | 0.00                  | 0.00  |                                  |      |                                  |      |      |      |
|     |     | 3         | 9464  | 9464  | 9464           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 12506 | 12506 | 12506          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 13182 | 13182 | 13182          |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
| 25  | 4   | 1         | 7280  | 7280  | 7280           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 5798  | 5774  | 5642           |         |                       | 2.76       | 2.34  |                       |      | 0.71                  | 0.62  | 2.76                  | 2.34  |                                  |      |                                  |      |      |      |
|     |     | 3         | 5136  | 5136  | 5096           |         |                       | 0.78       | 0.78  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 6734  | 6734  | 6734           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 7098  | 7098  | 7098           |         |                       | 0.00       | 0.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
| 25  | 6   | 1         | 5252  | 5252  | 5200           |         |                       | 1.00       | 1.00  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 5140  | 5048  | 4278           |         |                       | 20.15      | 18.00 |                       |      | 8.04                  | 7.61  | 20.15                 | 18.00 |                                  |      |                                  |      |      |      |
|     |     | 3         | 3960  | 3960  | 3640           |         |                       | 8.79       | 8.79  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 4         | 5066  | 5066  | 4810           |         |                       | 5.32       | 5.32  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 5320  | 5320  | 5070           |         |                       | 4.93       | 4.93  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
| 25  | 8   | 1         | 4700  | 4700  | 4160           |         |                       | 12.98      | 12.98 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 2         | 4978  | 4978  | 3782           |         |                       | 31.62      | 31.62 |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 3         | 3876  | 3776  | 2912           |         |                       | 33.10      | 29.67 |                       |      | 19.37                 | 18.34 | 33.10                 | 31.62 |                                  |      |                                  |      |      |      |
|     |     | 4         | 4728  | 4654  | 4292           |         |                       | 10.16      | 8.43  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |
|     |     | 5         | 4930  | 4930  | 4524           |         |                       | 8.97       | 8.97  |                       |      |                       |       |                       |       |                                  |      |                                  |      |      |      |

**Table E.12 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | NWH1  | NWH2  | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) |       | Optimality Gap (%) |      | Average LB Gap (%) |      | Maximum LB Gap (%) |       | Average Optimality Gap (%) |       | Maximum Optimality Gap (%) |      |      |      |  |
|-----|-----|--------|-------|-------|-------------|---------|-----------------|------------|-------|--------------------|------|--------------------|------|--------------------|-------|----------------------------|-------|----------------------------|------|------|------|--|
|     |     |        |       |       |             |         |                 | NWH1       | NWH2  | NWH1               | NWH2 | NWH1               | NWH2 | NWH1               | NWH2  | NWH1                       | NWH2  | NWH1                       | NWH2 | NWH1 | NWH2 |  |
| 40  | 2   | 1      | 33600 | 33600 | 33600       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 2      | 26040 | 26040 | 26040       |         |                 | 0.00       | 0.00  |                    |      | 0.00               | 0.00 | 0.00               | 0.00  |                            |       |                            |      |      |      |  |
|     |     | 3      | 23520 | 23520 | 23520       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 4      | 31080 | 31080 | 31080       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 5      | 32760 | 32760 | 32760       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
| 40  | 4   | 1      | 17600 | 17600 | 17600       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 2      | 13784 | 13784 | 13640       |         |                 | 1.06       | 1.06  |                    |      |                    |      | 0.51               | 0.51  | 1.30                       | 1.30  |                            |      |      |      |  |
|     |     | 3      | 12480 | 12480 | 12320       |         |                 | 1.30       | 1.30  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 4      | 16312 | 16312 | 16280       |         |                 | 0.20       | 0.20  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 5      | 17160 | 17160 | 17160       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
| 40  | 6   | 1      | 12400 | 12384 | 12320       |         |                 | 0.65       | 0.52  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 2      | 10112 | 10112 | 9548        |         |                 | 5.91       | 5.91  |                    |      |                    |      | 3.46               | 3.43  | 8.49                       | 8.49  |                            |      |      |      |  |
|     |     | 3      | 9356  | 9356  | 8624        |         |                 | 8.49       | 8.49  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 4      | 11652 | 11652 | 11396       |         |                 | 2.25       | 2.25  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 5      | 12012 | 12012 | 12012       |         |                 | 0.00       | 0.00  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
| 40  | 8   | 1      | 9792  | 9968  | 9600        |         |                 | 2.00       | 3.83  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 2      | 9356  | 9134  | 7750        |         |                 | 20.72      | 17.86 |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 3      | 8460  | 8396  | 6720        |         |                 | 25.89      | 24.94 |                    |      |                    |      | 11.27              | 10.87 | 25.89                      | 24.94 |                            |      |      |      |  |
|     |     | 4      | 10116 | 10116 | 9620        |         |                 | 5.16       | 5.16  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |
|     |     | 5      | 10000 | 10000 | 9750        |         |                 | 2.56       | 2.56  |                    |      |                    |      |                    |       |                            |       |                            |      |      |      |  |

**Table E.12 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins.<br># | NWH1  | NWH2  | Lower<br>Bound | Optimal | CPU<br>Times<br>(sec) | LB Gap (%) |       | Optimality<br>Gap (%) |      | Average<br>LB Gap (%) |      | Maximum<br>LB Gap (%) |       | Average<br>Optimality Gap<br>(%) |      | Maximum<br>Optimality Gap<br>(%) |      |
|-----|-----|-----------|-------|-------|----------------|---------|-----------------------|------------|-------|-----------------------|------|-----------------------|------|-----------------------|-------|----------------------------------|------|----------------------------------|------|
|     |     |           |       |       |                |         |                       | NWH1       | NWH2  | NWH1                  | NWH2 | NWH1                  | NWH2 | NWH1                  | NWH2  | NWH1                             | NWH2 | NWH1                             | NWH2 |
| 55  | 2   | 1         | 62720 | 62720 | 62720          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 2         | 48608 | 48608 | 48608          |         |                       | 0.00       | 0.00  |                       |      | 0.00                  | 0.00 | 0.00                  | 0.00  |                                  |      |                                  |      |
|     |     | 3         | 43904 | 43904 | 43904          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 4         | 58016 | 58016 | 58016          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 5         | 61152 | 61152 | 61152          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
| 55  | 4   | 1         | 32480 | 32480 | 32480          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 2         | 25370 | 25352 | 25172          |         |                       | 0.79       | 0.72  |                       |      | 0.33                  | 0.31 | 0.79                  | 0.77  |                                  |      |                                  |      |
|     |     | 3         | 22912 | 22912 | 22736          |         |                       | 0.77       | 0.77  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 4         | 30068 | 30068 | 30044          |         |                       | 0.08       | 0.08  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 5         | 31668 | 31668 | 31668          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
| 55  | 6   | 1         | 22580 | 22552 | 22400          |         |                       | 0.80       | 0.68  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 2         | 18152 | 18092 | 17360          |         |                       | 4.56       | 4.22  |                       |      | 2.23                  | 2.02 | 4.56                  | 4.22  |                                  |      |                                  |      |
|     |     | 3         | 16240 | 16192 | 15680          |         |                       | 3.57       | 3.27  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 4         | 21176 | 21120 | 20720          |         |                       | 2.20       | 1.93  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 5         | 21840 | 21840 | 21840          |         |                       | 0.00       | 0.00  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
| 55  | 8   | 1         | 17698 | 17698 | 17360          |         |                       | 1.95       | 1.95  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 2         | 15680 | 15556 | 13826          |         |                       | 13.41      | 12.51 |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 3         | 13774 | 13424 | 12152          |         |                       | 13.35      | 10.47 |                       |      | 6.99                  | 6.24 | 13.41                 | 12.51 |                                  |      |                                  |      |
|     |     | 4         | 17390 | 17390 | 16502          |         |                       | 5.38       | 5.38  |                       |      |                       |      |                       |       |                                  |      |                                  |      |
|     |     | 5         | 17076 | 17076 | 16926          |         |                       | 0.89       | 0.89  |                       |      |                       |      |                       |       |                                  |      |                                  |      |

**Table E.12 (continued):** Computational results for *No Wait Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

# **Appendix F**

## Numerical Results for the General Problem

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1440 | 1440        | 1440    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1380 | 1380        | 1380    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 936  | 936         | 936     |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 864  | 864         | 864     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 828  | 828         | 828     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 936  | 936         | 936     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 936  | 936         | 936     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 728  | 728         | 728     |                 | 0.00       | 0.00               | 0.55               | 2.75               | 0.00                       | 0.00                       |
|     |     | 2      | 672  | 672         | 672     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 644  | 644         | 644     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 728  | 728         | 728     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 748  | 728         | 748     | 443.07          | 2.75       | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 686  | 624         | 686     | 124.91          | 9.94       | 0.00               | 14.27              | 19.87              | 0.00                       | 0.00                       |
|     |     | 2      | 672  | 576         | 672     | 460.94          | 16.67      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 608  | 552         | 608     | 248.54          | 10.14      | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 716  | 624         | 716     | 271.69          | 14.74      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 748  | 624         | 748     | 443.07          | 19.87      | 0.00               |                    |                    |                            |                            |

**Table F.1:** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$



| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 8788 | 8788        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 8112 | 8112        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 7774 | 7774        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 8788 | 8788        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 8788 | 8788        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 4732 | 4732        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 4368 | 4368        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 4186 | 4186        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 4732 | 4732        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 4732 | 4732        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 3380 | 3380        |         |                 | 0.00       |                    | 0.09               | 0.45               |                            |                            |
|     |     | 2      | 3134 | 3120        |         |                 | 0.45       |                    |                    |                    |                            |                            |
|     |     | 3      | 2990 | 2990        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 3380 | 3380        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 3380 | 3380        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 2722 | 2704        |         |                 | 0.67       |                    | 1.49               | 5.37               |                            |                            |
|     |     | 2      | 2630 | 2496        |         |                 | 5.37       |                    |                    |                    |                            |                            |
|     |     | 3      | 2410 | 2392        |         |                 | 0.75       |                    |                    |                    |                            |                            |
|     |     | 4      | 2722 | 2704        |         |                 | 0.67       |                    |                    |                    |                            |                            |
|     |     | 5      | 2704 | 2704        |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.1 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 21840 | 21840       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 19320 | 19320       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 11440 | 11440       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 10560 | 10560       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 10120 | 10120       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 11440 | 11440       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 11440 | 11440       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 8008  | 8008        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 7392  | 7392        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 7084  | 7084        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 8008  | 8008        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 8008  | 8008        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 6256  | 6240        |         |                 | 0.26       |                    | 0.33               | 0.58               |                            |                            |
|     |     | 2      | 5792  | 5760        |         |                 | 0.56       |                    |                    |                    |                            |                            |
|     |     | 3      | 5552  | 5520        |         |                 | 0.58       |                    |                    |                    |                            |                            |
|     |     | 4      | 6256  | 6240        |         |                 | 0.26       |                    |                    |                    |                            |                            |
|     |     | 5      | 6240  | 6240        |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.1 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 40768 | 40768       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 37632 | 37632       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 36064 | 36064       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 40768 | 40768       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 40768 | 40768       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 21112 | 21112       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 19488 | 19488       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 18676 | 18676       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 21112 | 21112       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 21112 | 21112       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 14560 | 14560       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 13440 | 13440       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 12880 | 12880       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 14560 | 14560       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 14560 | 14560       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 11298 | 11284       |         |                 | 0.12       |                    | 0.14               | 0.29               |                            |                            |
|     |     | 2      | 10446 | 10416       |         |                 | 0.29       |                    |                    |                    |                            |                            |
|     |     | 3      | 9996  | 9982        |         |                 | 0.14       |                    |                    |                    |                            |                            |
|     |     | 4      | 11298 | 11284       |         |                 | 0.12       |                    |                    |                    |                            |                            |
|     |     | 5      | 11284 | 11284       |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.1 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 2040 | 2040        | 2040    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1980 | 1980        | 1980    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1296 | 1296        | 1296    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1224 | 1224        | 1224    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1188 | 1188        | 1188    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1296 | 1296        | 1296    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1296 | 1296        | 1296    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1008 | 1008        | 1008    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 952  | 952         | 952     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 924  | 924         | 924     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1008 | 1008        | 1008    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1008 | 1008        | 1008    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 864  | 864         | 864     |                 | 0.00       | 0.00               | 4.30               | 8.33               | 0.00                       | 0.00                       |
|     |     | 2      | 884  | 816         | 884     | 223.77          | 8.33       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 812  | 792         | 812     | 256.36          | 2.53       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 884  | 864         | 884     | 464.63          | 2.31       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 936  | 864         | 936     | 127.09          | 8.33       | 0.00               |                    |                    |                            |                            |

**Table F.2:** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 12168 | 12168       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 11492 | 11492       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 11154 | 11154       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 12168 | 12168       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 12168 | 12168       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 6552  | 6552        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 6188  | 6188        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 6006  | 6006        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 6552  | 6552        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 6552  | 6552        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 4680  | 4680        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 4420  | 4420        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 4290  | 4290        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 4680  | 4680        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 4680  | 4680        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 3744  | 3744        |         |                 | 0.00       |                    | 0.05               | 0.25               |                            |                            |
|     |     | 2      | 3545  | 3536        |         |                 | 0.25       |                    |                    |                    |                            |                            |
|     |     | 3      | 3432  | 3432        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 3744  | 3744        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 3744  | 3744        |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.2 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 30240 | 30240       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 28560 | 28560       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 27720 | 27720       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 30240 | 30240       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 30240 | 30240       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 15840 | 15840       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 14960 | 14960       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 14520 | 14520       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 15840 | 15840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 15840 | 15840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 11088 | 11088       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 10472 | 10472       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 10164 | 10164       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 11088 | 11088       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 11088 | 11088       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 8640  | 8640        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 8160  | 8160        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 7920  | 7920        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 8640  | 8640        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 8640  | 8640        |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.2 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 56448 | 56448       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 53312 | 53312       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 51744 | 51744       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 56448 | 56448       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 56448 | 56448       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 29232 | 29232       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 27608 | 27608       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 26796 | 26796       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 29232 | 29232       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 29232 | 29232       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 20160 | 20160       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 19040 | 19040       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 18480 | 18480       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 15624 | 15624       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 14756 | 14756       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 14322 | 14322       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 15624 | 15624       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 15624 | 15624       |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.2 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2400 | 2400        | 2400    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1860 | 1860        | 1860    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1680 | 1680        | 1680    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2220 | 2220        | 2220    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2340 | 2340        | 2340    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1440 | 1440        | 1440    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1116 | 1116        | 1116    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1008 | 1008        | 1008    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1332 | 1332        | 1332    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1404 | 1404        | 1404    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1120 | 1120        | 1120    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 868  | 868         | 868     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 784  | 784         | 784     |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1036 | 1036        | 1036    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1092 | 1092        | 1092    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 960  | 960         | 960     |                 | 0.00       | 0.00               | 5.65               | 12.37              | 0.00                       | 0.00                       |
|     |     | 2      | 836  | 744         | 836     | 132.34          | 12.37      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 728  | 672         | 728     | 163.90          | 8.33       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 898  | 888         | 898     | 265.87          | 1.13       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 996  | 936         | 996     | 160.56          | 6.41       | 0.00               |                    |                    |                            |                            |

**Table F.3:** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$



| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 13520 | 13520       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 10478 | 10478       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 9464  | 9464        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 12506 | 12506       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 13182 | 13182       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 7280  | 7280        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 5642  | 5642        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 5096  | 5096        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 6734  | 6734        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 7098  | 7098        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 5200  | 5200        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 4030  | 4030        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 3640  | 3640        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 4810  | 4810        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 5070  | 5070        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 4160  | 4160        |         |                 | 0.00       |                    | 0.33               | 1.67               |                            |                            |
|     |     | 2      | 3278  | 3224        |         |                 | 1.67       |                    |                    |                    |                            |                            |
|     |     | 3      | 2912  | 2912        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 3848  | 3848        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 4056  | 4056        |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.3 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 33600 | 33600       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 26040 | 26040       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 23520 | 23520       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 31080 | 31080       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 32760 | 32760       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 17600 | 17600       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 13640 | 13640       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 12320 | 12320       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 16280 | 16280       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 17160 | 17160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 12320 | 12320       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 9548  | 9548        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 8624  | 8624        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 11396 | 11396       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 12012 | 12012       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 9600  | 9600        |         |                 | 0.00       |                    | 0.02               | 0.12               |                            |                            |
|     |     | 2      | 7440  | 7440        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 6728  | 6720        |         |                 | 0.12       |                    |                    |                    |                            |                            |
|     |     | 4      | 8880  | 8880        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 9360  | 9360        |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.3 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 62720 | 62720       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 48608 | 48608       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 43904 | 43904       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 58016 | 58016       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 61152 | 61152       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 32480 | 32480       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 25172 | 25172       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 22736 | 22736       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 30044 | 30044       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 31668 | 31668       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 22400 | 22400       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 17360 | 17360       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 15680 | 15680       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 20720 | 20720       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 17360 | 17360       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 13454 | 13454       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 12152 | 12152       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 16058 | 16058       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 16926 | 16926       |         |                 | 0.00       |                    |                    |                    |                            |                            |

**Table F.3 (continued):** Computational results for *General Problem* where  $p_j \in [1,11]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1440 | 1440        | 1440    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1380 | 1380        | 1380    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 936  | 936         | 936     |                 | 0.00       | 0.00               | 2.14               | 4.17               | 0.00                       | 0.00                       |
|     |     | 2      | 900  | 864         | 900     | 3667.16         | 4.17       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 838  | 828         | 838     | 1989.84         | 1.21       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 956  | 936         | 956     | 1977.28         | 2.14       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 966  | 936         | 966     | 3129.95         | 3.21       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 844  | 728         | 844     | 813.64          | 15.93      | 0.00               | 19.05              | 22.92              | 0.10                       | 0.52                       |
|     |     | 2      | 826  | 672         | 826     | 1161.52         | 22.92      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 770  | 644         | 766     | 637.23          | 19.57      | 0.52               |                    |                    |                            |                            |
|     |     | 4      | 862  | 728         | 862     | 615.01          | 18.41      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 862  | 728         | 862     | 965.10          | 18.41      | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 844  | 624         | 844     | 813.64          | 35.26      | 0.00               | 38.89              | 43.40              | 0.10                       | 0.52                       |
|     |     | 2      | 826  | 576         | 826     | 952.30          | 43.40      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 770  | 552         | 766     | 1929.22         | 39.49      | 0.52               |                    |                    |                            |                            |
|     |     | 4      | 862  | 624         | 862     | 615.01          | 38.14      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 862  | 624         | 862     | 965.10          | 38.14      | 0.00               |                    |                    |                            |                            |

**Table F.4:** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 8788 | 8788        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 8112 | 8112        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 7774 | 7774        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 8788 | 8788        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 8788 | 8788        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 4732 | 4732        |         |                 | 0.00       |                    | 0.34               | 1.72               |                            |                            |
|     |     | 2      | 4443 | 4368        |         |                 | 1.72       |                    |                    |                    |                            |                            |
|     |     | 3      | 4186 | 4186        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 4732 | 4732        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 4732 | 4732        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 3666 | 3380        |         |                 | 8.46       |                    | 11.59              | 16.06              |                            |                            |
|     |     | 2      | 3621 | 3120        |         |                 | 16.06      |                    |                    |                    |                            |                            |
|     |     | 3      | 3315 | 2990        |         |                 | 10.87      |                    |                    |                    |                            |                            |
|     |     | 4      | 3770 | 3380        |         |                 | 11.54      |                    |                    |                    |                            |                            |
|     |     | 5      | 3752 | 3380        |         |                 | 11.01      |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 3262 | 2704        |         |                 | 20.64      |                    | 23.90              | 30.05              |                            |                            |
|     |     | 2      | 3246 | 2496        |         |                 | 30.05      |                    |                    |                    |                            |                            |
|     |     | 3      | 2954 | 2392        |         |                 | 23.49      |                    |                    |                    |                            |                            |
|     |     | 4      | 3337 | 2704        |         |                 | 23.41      |                    |                    |                    |                            |                            |
|     |     | 5      | 3297 | 2704        |         |                 | 21.93      |                    |                    |                    |                            |                            |

**Table F.4 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 21840 | 21840       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 19320 | 19320       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 11440 | 11440       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 10560 | 10560       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 10120 | 10120       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 11440 | 11440       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 11440 | 11440       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 8308  | 8008        |         |                 | 3.75       |                    | 6.29               | 7.98               |                            |                            |
|     |     | 2      | 7914  | 7392        |         |                 | 7.06       |                    |                    |                    |                            |                            |
|     |     | 3      | 7600  | 7084        |         |                 | 7.28       |                    |                    |                    |                            |                            |
|     |     | 4      | 8647  | 8008        |         |                 | 7.98       |                    |                    |                    |                            |                            |
|     |     | 5      | 8440  | 8008        |         |                 | 5.39       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 7112  | 6240        |         |                 | 13.97      |                    | 15.88              | 17.21              |                            |                            |
|     |     | 2      | 6748  | 5760        |         |                 | 17.15      |                    |                    |                    |                            |                            |
|     |     | 3      | 6438  | 5520        |         |                 | 16.63      |                    |                    |                    |                            |                            |
|     |     | 4      | 7314  | 6240        |         |                 | 17.21      |                    |                    |                    |                            |                            |
|     |     | 5      | 7140  | 6240        |         |                 | 14.42      |                    |                    |                    |                            |                            |

**Table F.4 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 40768 | 40768       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 37632 | 37632       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 36064 | 36064       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 40768 | 40768       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 40768 | 40768       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 21112 | 21112       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 19488 | 19488       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 18676 | 18676       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 21112 | 21112       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 21112 | 21112       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 14983 | 14560       |         |                 | 2.91       |                    | 4.48               | 5.68               |                            |                            |
|     |     | 2      | 14204 | 13440       |         |                 | 5.68       |                    |                    |                    |                            |                            |
|     |     | 3      | 13484 | 12880       |         |                 | 4.69       |                    |                    |                    |                            |                            |
|     |     | 4      | 15366 | 14560       |         |                 | 5.54       |                    |                    |                    |                            |                            |
|     |     | 5      | 15083 | 14560       |         |                 | 3.59       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 12460 | 11284       |         |                 | 10.42      |                    | 11.85              | 13.32              |                            |                            |
|     |     | 2      | 11800 | 10416       |         |                 | 13.29      |                    |                    |                    |                            |                            |
|     |     | 3      | 11187 | 9982        |         |                 | 12.07      |                    |                    |                    |                            |                            |
|     |     | 4      | 12787 | 11284       |         |                 | 13.32      |                    |                    |                    |                            |                            |
|     |     | 5      | 12429 | 11284       |         |                 | 10.15      |                    |                    |                    |                            |                            |

**Table F.4 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 2040 | 2040        | 2040    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1980 | 1980        | 1980    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1296 | 1296        | 1296    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1224 | 1224        | 1224    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1188 | 1188        | 1188    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1296 | 1296        | 1296    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1296 | 1296        | 1296    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1078 | 1008        | 1078    | 960.90          | 6.94       | 0.00               | 8.70               | 11.11              | 0.00                       | 0.00                       |
|     |     | 2      | 1055 | 952         | 1055    | 717.96          | 10.82      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 984  | 924         | 984     | 731.85          | 6.49       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1090 | 1008        | 1090    | 700.67          | 8.13       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1120 | 1008        | 1120    | 675.74          | 11.11      | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 1078 | 864         | 1078    | 1402.63         | 24.77      | 0.00               | 26.82              | 29.63              | 0.00                       | 0.00                       |
|     |     | 2      | 1055 | 816         | 1055    | 519.41          | 29.29      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 984  | 792         | 984     | 312.95          | 24.24      | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1090 | 864         | 1090    | 700.67          | 26.16      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1120 | 864         | 1120    | 675.74          | 29.63      | 0.00               |                    |                    |                            |                            |

**Table F.5:** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$



| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 12168 | 12168       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 11492 | 11492       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 11154 | 11154       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 12168 | 12168       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 12168 | 12168       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 6552  | 6552        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 6188  | 6188        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 6006  | 6006        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 6552  | 6552        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 6552  | 6552        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 4680  | 4680        |         |                 | 0.00       |                    | 1.95               | 7.08               |                            |                            |
|     |     | 2      | 4733  | 4420        |         |                 | 7.08       |                    |                    |                    |                            |                            |
|     |     | 3      | 4290  | 4290        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 4730  | 4680        |         |                 | 1.07       |                    |                    |                    |                            |                            |
|     |     | 5      | 4755  | 4680        |         |                 | 1.60       |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 4085  | 3744        |         |                 | 9.11       |                    | 13.37              | 19.15              |                            |                            |
|     |     | 2      | 4213  | 3536        |         |                 | 19.15      |                    |                    |                    |                            |                            |
|     |     | 3      | 3830  | 3432        |         |                 | 11.60      |                    |                    |                    |                            |                            |
|     |     | 4      | 4248  | 3744        |         |                 | 13.46      |                    |                    |                    |                            |                            |
|     |     | 5      | 4251  | 3744        |         |                 | 13.54      |                    |                    |                    |                            |                            |

**Table F.5 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 30240 | 30240       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 28560 | 28560       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 27720 | 27720       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 30240 | 30240       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 30240 | 30240       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 15840 | 15840       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 14960 | 14960       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 14520 | 14520       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 15840 | 15840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 15840 | 15840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 11088 | 11088       |         |                 | 0.00       |                    | 0.22               | 0.72               |                            |                            |
|     |     | 2      | 10512 | 10472       |         |                 | 0.38       |                    |                    |                    |                            |                            |
|     |     | 3      | 10164 | 10164       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 11168 | 11088       |         |                 | 0.72       |                    |                    |                    |                            |                            |
|     |     | 5      | 11088 | 11088       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 9114  | 8640        |         |                 | 5.49       |                    | 8.02               | 9.68               |                            |                            |
|     |     | 2      | 8932  | 8160        |         |                 | 9.46       |                    |                    |                    |                            |                            |
|     |     | 3      | 8524  | 7920        |         |                 | 7.63       |                    |                    |                    |                            |                            |
|     |     | 4      | 9476  | 8640        |         |                 | 9.68       |                    |                    |                    |                            |                            |
|     |     | 5      | 9320  | 8640        |         |                 | 7.87       |                    |                    |                    |                            |                            |

**Table F.5 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 56448 | 56448       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 53312 | 53312       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 51744 | 51744       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 56448 | 56448       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 56448 | 56448       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 29232 | 29232       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 27608 | 27608       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 26796 | 26796       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 29232 | 29232       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 29232 | 29232       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 20160 | 20160       |         |                 | 0.00       |                    | 0.06               | 0.29               |                            |                            |
|     |     | 2      | 19095 | 19040       |         |                 | 0.29       |                    |                    |                    |                            |                            |
|     |     | 3      | 18480 | 18480       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 16214 | 15624       |         |                 | 3.78       |                    | 5.10               | 6.93               |                            |                            |
|     |     | 2      | 15779 | 14756       |         |                 | 6.93       |                    |                    |                    |                            |                            |
|     |     | 3      | 14986 | 14322       |         |                 | 4.64       |                    |                    |                    |                            |                            |
|     |     | 4      | 16610 | 15624       |         |                 | 6.31       |                    |                    |                    |                            |                            |
|     |     | 5      | 16221 | 15624       |         |                 | 3.82       |                    |                    |                    |                            |                            |

**Table F.5 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2400 | 2400        | 2400    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1860 | 1860        | 1860    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1680 | 1680        | 1680    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2220 | 2220        | 2220    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2340 | 2340        | 2340    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1440 | 1440        | 1440    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1116 | 1116        | 1116    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1008 | 1008        | 1008    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1332 | 1332        | 1332    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1404 | 1404        | 1404    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1150 | 1120        | 1150    | 344.09          | 2.68       | 0.00               | 10.29              | 17.51              | 0.18                       | 0.89                       |
|     |     | 2      | 1020 | 868         | 1020    | 861.57          | 17.51      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 910  | 784         | 902     | 664.89          | 16.07      | 0.89               |                    |                    |                            |                            |
|     |     | 4      | 1110 | 1036        | 1110    | 338.26          | 7.14       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1180 | 1092        | 1180    | 659.10          | 8.06       | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 1150 | 960         | 1150    | 344.09          | 19.79      | 0.00               | 28.67              | 37.10              | 0.18                       | 0.89                       |
|     |     | 2      | 1020 | 744         | 1020    | 839.97          | 37.10      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 910  | 672         | 902     | 852.47          | 35.42      | 0.89               |                    |                    |                            |                            |
|     |     | 4      | 1110 | 888         | 1110    | 338.26          | 25.00      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1180 | 936         | 1180    | 659.10          | 26.07      | 0.00               |                    |                    |                            |                            |

**Table F.6:** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 13520 | 13520       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 10478 | 10478       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 9464  | 9464        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 12506 | 12506       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 13182 | 13182       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 7280  | 7280        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 5642  | 5642        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 5096  | 5096        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 6734  | 6734        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 7098  | 7098        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 5200  | 5200        |         |                 | 0.00       |                    | 3.20               | 10.50              |                            |                            |
|     |     | 2      | 4453  | 4030        |         |                 | 10.50      |                    |                    |                    |                            |                            |
|     |     | 3      | 3821  | 3640        |         |                 | 4.97       |                    |                    |                    |                            |                            |
|     |     | 4      | 4835  | 4810        |         |                 | 0.52       |                    |                    |                    |                            |                            |
|     |     | 5      | 5070  | 5070        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 4385  | 4160        |         |                 | 5.41       |                    | 15.39              | 24.13              |                            |                            |
|     |     | 2      | 4002  | 3224        |         |                 | 24.13      |                    |                    |                    |                            |                            |
|     |     | 3      | 3561  | 2912        |         |                 | 22.29      |                    |                    |                    |                            |                            |
|     |     | 4      | 4370  | 3848        |         |                 | 13.57      |                    |                    |                    |                            |                            |
|     |     | 5      | 4524  | 4056        |         |                 | 11.54      |                    |                    |                    |                            |                            |

**Table F.6 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 33600 | 33600       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 26040 | 26040       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 23520 | 23520       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 31080 | 31080       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 32760 | 32760       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 17600 | 17600       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 13640 | 13640       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 12320 | 12320       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 16280 | 16280       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 17160 | 17160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 12320 | 12320       |         |                 | 0.00       |                    | 1.42               | 4.45               |                            |                            |
|     |     | 2      | 9768  | 9548        |         |                 | 2.30       |                    |                    |                    |                            |                            |
|     |     | 3      | 9008  | 8624        |         |                 | 4.45       |                    |                    |                    |                            |                            |
|     |     | 4      | 11436 | 11396       |         |                 | 0.35       |                    |                    |                    |                            |                            |
|     |     | 5      | 12012 | 12012       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 9792  | 9600        |         |                 | 2.00       |                    | 9.30               | 16.01              |                            |                            |
|     |     | 2      | 8410  | 7440        |         |                 | 13.04      |                    |                    |                    |                            |                            |
|     |     | 3      | 7796  | 6720        |         |                 | 16.01      |                    |                    |                    |                            |                            |
|     |     | 4      | 9730  | 8880        |         |                 | 9.57       |                    |                    |                    |                            |                            |
|     |     | 5      | 9910  | 9360        |         |                 | 5.88       |                    |                    |                    |                            |                            |

**Table F.6 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 62720 | 62720       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 48608 | 48608       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 43904 | 43904       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 58016 | 58016       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 61152 | 61152       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 32480 | 32480       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 25172 | 25172       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 22736 | 22736       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 30044 | 30044       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 31668 | 31668       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 22400 | 22400       |         |                 | 0.00       |                    | 0.78               | 2.18               |                            |                            |
|     |     | 2      | 17739 | 17360       |         |                 | 2.18       |                    |                    |                    |                            |                            |
|     |     | 3      | 15949 | 15680       |         |                 | 1.72       |                    |                    |                    |                            |                            |
|     |     | 4      | 20720 | 20720       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 17640 | 17360       |         |                 | 1.61       |                    | 6.33               | 11.28              |                            |                            |
|     |     | 2      | 14852 | 13454       |         |                 | 10.39      |                    |                    |                    |                            |                            |
|     |     | 3      | 13523 | 12152       |         |                 | 11.28      |                    |                    |                    |                            |                            |
|     |     | 4      | 16960 | 16058       |         |                 | 5.62       |                    |                    |                    |                            |                            |
|     |     | 5      | 17394 | 16926       |         |                 | 2.76       |                    |                    |                    |                            |                            |

**Table F.6 (continued):** Computational results for *General Problem* where  $p_j \in [5,15]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 1834 | 1560        | 1820    | 181898.53       | 17.56      | 0.77               | 17.51              | 17.82              |                            |                            |
|     |     | 2      | 1708 | 1450        | 1708(*) |                 | 17.79      | ---                |                    |                    |                            |                            |
|     |     | 3      | 1648 | 1400        | 1648(*) |                 | 17.71      | ---                |                    |                    |                            |                            |
|     |     | 4      | 1838 | 1560        | 1838    | 161391.61       | 17.82      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1820 | 1560        | 1810(*) |                 | 16.67      | ---                |                    |                    |                            |                            |
| 10  | 4   | 1      | 1434 | 936         | 1434    | 85488.61        | 53.21      | 0.00               | 58.05              | 65.22              | 1.58                       | 4.03                       |
|     |     | 2      | 1444 | 874         | 1388    | 192790.49       | 65.22      | 4.03               |                    |                    |                            |                            |
|     |     | 3      | 1354 | 848         | 1354    | 179757.190      | 59.67      | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1461 | 936         | 1445    | 74839.4         | 56.09      | 1.11               |                    |                    |                            |                            |
|     |     | 5      | 1461 | 936         | 1444    | 134805.22       | 56.09      | 1.18               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1434 | 728         | 1434    | 85488.61        | 96.98      | 0.00               | 102.80             | 111.73             | 1.58                       | 4.03                       |
|     |     | 2      | 1444 | 682         | 1388    | 192790.49       | 111.73     | 4.03               |                    |                    |                            |                            |
|     |     | 3      | 1354 | 664         | 1354    | 179757.190      | 103.92     | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1461 | 728         | 1445    | 74839.4         | 100.69     | 1.11               |                    |                    |                            |                            |
|     |     | 5      | 1461 | 728         | 1444    | 134805.22       | 100.69     | 1.18               |                    |                    |                            |                            |
| 10  | 8   | 1      | 1434 | 624         | 1434    | 85488.61        | 129.81     | 0.00               | 136.24             | 146.42             | 1.58                       | 4.03                       |
|     |     | 2      | 1444 | 586         | 1388    | 192790.49       | 146.42     | 4.03               |                    |                    |                            |                            |
|     |     | 3      | 1354 | 572         | 1354    | 179757.190      | 136.71     | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1461 | 624         | 1445    | 74839.4         | 134.13     | 1.11               |                    |                    |                            |                            |
|     |     | 5      | 1461 | 624         | 1444    | 134805.22       | 134.13     | 1.18               |                    |                    |                            |                            |

**Table F.7:** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$



| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 9464 | 8788        |         |                 | 7.69       |                    | 7.84               | 8.33               |                            |                            |
|     |     | 2      | 8809 | 8137        |         |                 | 8.26       |                    |                    |                    |                            |                            |
|     |     | 3      | 8476 | 7824        |         |                 | 8.33       |                    |                    |                    |                            |                            |
|     |     | 4      | 9476 | 8788        |         |                 | 7.83       |                    |                    |                    |                            |                            |
|     |     | 5      | 9412 | 8788        |         |                 | 7.10       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 6183 | 4732        |         |                 | 30.66      |                    | 32.20              | 38.79              |                            |                            |
|     |     | 2      | 6097 | 4393        |         |                 | 38.79      |                    |                    |                    |                            |                            |
|     |     | 3      | 5730 | 4236        |         |                 | 35.27      |                    |                    |                    |                            |                            |
|     |     | 4      | 6106 | 4732        |         |                 | 29.04      |                    |                    |                    |                            |                            |
|     |     | 5      | 6022 | 4732        |         |                 | 27.26      |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 5532 | 3380        |         |                 | 63.67      |                    | 71.38              | 81.59              |                            |                            |
|     |     | 2      | 5711 | 3145        |         |                 | 81.59      |                    |                    |                    |                            |                            |
|     |     | 3      | 5421 | 3040        |         |                 | 78.32      |                    |                    |                    |                            |                            |
|     |     | 4      | 5595 | 3380        |         |                 | 65.53      |                    |                    |                    |                            |                            |
|     |     | 5      | 5672 | 3380        |         |                 | 67.81      |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 5532 | 2704        |         |                 | 104.59     |                    | 113.96             | 126.54             |                            |                            |
|     |     | 2      | 5711 | 2521        |         |                 | 126.54     |                    |                    |                    |                            |                            |
|     |     | 3      | 5421 | 2442        |         |                 | 121.99     |                    |                    |                    |                            |                            |
|     |     | 4      | 5595 | 2704        |         |                 | 106.92     |                    |                    |                    |                            |                            |
|     |     | 5      | 5672 | 2704        |         |                 | 109.76     |                    |                    |                    |                            |                            |

**Table F.7 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 22990 | 21840       |         |                 | 5.27       |                    | 5.49               | 6.12               |                            |                            |
|     |     | 2      | 21380 | 20200       |         |                 | 5.84       |                    |                    |                    |                            |                            |
|     |     | 3      | 20588 | 19400       |         |                 | 6.12       |                    |                    |                    |                            |                            |
|     |     | 4      | 23034 | 21840       |         |                 | 5.47       |                    |                    |                    |                            |                            |
|     |     | 5      | 22880 | 21840       |         |                 | 4.76       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 13738 | 11440       |         |                 | 20.09      |                    | 21.98              | 26.48              |                            |                            |
|     |     | 2      | 13195 | 10600       |         |                 | 24.48      |                    |                    |                    |                            |                            |
|     |     | 3      | 12901 | 10200       |         |                 | 26.48      |                    |                    |                    |                            |                            |
|     |     | 4      | 13754 | 11440       |         |                 | 20.23      |                    |                    |                    |                            |                            |
|     |     | 5      | 13572 | 11440       |         |                 | 18.64      |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 11777 | 8008        |         |                 | 47.07      |                    | 53.72              | 61.61              |                            |                            |
|     |     | 2      | 11924 | 7432        |         |                 | 60.44      |                    |                    |                    |                            |                            |
|     |     | 3      | 11578 | 7164        |         |                 | 61.61      |                    |                    |                    |                            |                            |
|     |     | 4      | 11920 | 8008        |         |                 | 48.85      |                    |                    |                    |                            |                            |
|     |     | 5      | 12062 | 8008        |         |                 | 50.62      |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 11777 | 6240        |         |                 | 88.73      |                    | 97.08              | 106.75             |                            |                            |
|     |     | 2      | 11924 | 5800        |         |                 | 105.59     |                    |                    |                    |                            |                            |
|     |     | 3      | 11578 | 5600        |         |                 | 106.75     |                    |                    |                    |                            |                            |
|     |     | 4      | 11920 | 6240        |         |                 | 91.03      |                    |                    |                    |                            |                            |
|     |     | 5      | 12062 | 6240        |         |                 | 93.30      |                    |                    |                    |                            |                            |

**Table F.7 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 42396 | 40768       |         |                 | 3.99       |                    | 4.12               | 4.58               |                            |                            |
|     |     | 2      | 39371 | 37687       |         |                 | 4.47       |                    |                    |                    |                            |                            |
|     |     | 3      | 37832 | 36174       |         |                 | 4.58       |                    |                    |                    |                            |                            |
|     |     | 4      | 42436 | 40768       |         |                 | 4.09       |                    |                    |                    |                            |                            |
|     |     | 5      | 42172 | 40768       |         |                 | 3.44       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 24884 | 21112       |         |                 | 17.87      |                    | 17.72              | 20.85              |                            |                            |
|     |     | 2      | 23381 | 19543       |         |                 | 19.64      |                    |                    |                    |                            |                            |
|     |     | 3      | 22702 | 18786       |         |                 | 20.85      |                    |                    |                    |                            |                            |
|     |     | 4      | 24469 | 21112       |         |                 | 15.90      |                    |                    |                    |                            |                            |
|     |     | 5      | 24146 | 21112       |         |                 | 14.37      |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 20499 | 14560       |         |                 | 40.79      |                    | 45.35              | 52.77              |                            |                            |
|     |     | 2      | 20471 | 13495       |         |                 | 51.69      |                    |                    |                    |                            |                            |
|     |     | 3      | 19845 | 12990       |         |                 | 52.77      |                    |                    |                    |                            |                            |
|     |     | 4      | 20462 | 14560       |         |                 | 40.54      |                    |                    |                    |                            |                            |
|     |     | 5      | 20523 | 14560       |         |                 | 40.95      |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 20499 | 11284       |         |                 | 81.66      |                    | 87.40              | 96.64              |                            |                            |
|     |     | 2      | 20471 | 10471       |         |                 | 95.50      |                    |                    |                    |                            |                            |
|     |     | 3      | 19845 | 10092       |         |                 | 96.64      |                    |                    |                    |                            |                            |
|     |     | 4      | 20462 | 11284       |         |                 | 81.34      |                    |                    |                    |                            |                            |
|     |     | 5      | 20523 | 11284       |         |                 | 81.88      |                    |                    |                    |                            |                            |

**Table F.7 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2310 | 2160        | 2310    | 170999.89       | 6.94       | 0.00               | 7.84               | 9.09               | 0.00                       | 0.00                       |
|     |     | 2      | 2210 | 2040        | 2210    | 190760.79       | 8.33       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 2160 | 1980        | 2160    | 81086.12        | 9.09       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2330 | 2160        | 2330    | 129037.66       | 7.87       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2310 | 2160        | 2310    | 81365.27        | 6.94       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1750 | 1296        | 1750    | 41103.71        | 35.03      | 0.00               | 36.31              | 38.72              | 0.00                       | 0.00                       |
|     |     | 2      | 1682 | 1224        | 1682    | 39336.05        | 37.42      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1648 | 1188        | 1648    | 40989.59        | 38.72      | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1770 | 1296        | 1770    | 21453.83        | 36.57      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1734 | 1296        | 1734    | 31669.32        | 33.80      | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1750 | 1008        | 1750    | 41103.71        | 73.61      | 0.00               | 75.84              | 82.68              | 0.49                       | 2.43                       |
|     |     | 2      | 1682 | 952         | 1682    | 39336.05        | 76.68      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1688 | 924         | 1648    | 40989.59        | 82.68      | 2.43               |                    |                    |                            |                            |
|     |     | 4      | 1756 | 1008        | 1756    | 42265.24        | 74.21      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1734 | 1008        | 1734    | 31669.32        | 72.02      | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 1750 | 864         | 1750    | 41103.71        | 102.55     | 0.00               | 105.15             | 113.13             | 0.49                       | 2.43                       |
|     |     | 2      | 1682 | 816         | 1682    | 39336.05        | 106.13     | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1688 | 792         | 1648    | 40989.59        | 113.13     | 2.43               |                    |                    |                            |                            |
|     |     | 4      | 1756 | 864         | 1756    | 42265.24        | 103.24     | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1734 | 864         | 1734    | 31669.32        | 100.69     | 0.00               |                    |                    |                            |                            |

**Table F.8:** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 12518 | 12168       |         |                 | 2.88       |                    | 3.35               | 3.81               |                            |                            |
|     |     | 2      | 11917 | 11492       |         |                 | 3.70       |                    |                    |                    |                            |                            |
|     |     | 3      | 11579 | 11154       |         |                 | 3.81       |                    |                    |                    |                            |                            |
|     |     | 4      | 12568 | 12168       |         |                 | 3.29       |                    |                    |                    |                            |                            |
|     |     | 5      | 12543 | 12168       |         |                 | 3.08       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 7869  | 6552        |         |                 | 20.10      |                    | 20.78              | 21.76              |                            |                            |
|     |     | 2      | 7519  | 6188        |         |                 | 21.51      |                    |                    |                    |                            |                            |
|     |     | 3      | 7313  | 6006        |         |                 | 21.76      |                    |                    |                    |                            |                            |
|     |     | 4      | 7910  | 6552        |         |                 | 20.73      |                    |                    |                    |                            |                            |
|     |     | 5      | 7848  | 6552        |         |                 | 19.78      |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 6800  | 4680        |         |                 | 45.30      |                    | 46.82              | 49.80              |                            |                            |
|     |     | 2      | 6621  | 4420        |         |                 | 49.80      |                    |                    |                    |                            |                            |
|     |     | 3      | 6426  | 4290        |         |                 | 49.79      |                    |                    |                    |                            |                            |
|     |     | 4      | 6800  | 4680        |         |                 | 45.30      |                    |                    |                    |                            |                            |
|     |     | 5      | 6736  | 4680        |         |                 | 43.93      |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 6436  | 3744        |         |                 | 71.90      |                    | 77.64              | 84.79              |                            |                            |
|     |     | 2      | 6534  | 3536        |         |                 | 84.79      |                    |                    |                    |                            |                            |
|     |     | 3      | 6292  | 3432        |         |                 | 83.33      |                    |                    |                    |                            |                            |
|     |     | 4      | 6508  | 3744        |         |                 | 73.82      |                    |                    |                    |                            |                            |
|     |     | 5      | 6527  | 3744        |         |                 | 74.33      |                    |                    |                    |                            |                            |

**Table F.8 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 30800 | 30240       |         |                 | 1.85       |                    | 2.10               | 2.45               |                            |                            |
|     |     | 2      | 29200 | 28560       |         |                 | 2.24       |                    |                    |                    |                            |                            |
|     |     | 3      | 28400 | 27720       |         |                 | 2.45       |                    |                    |                    |                            |                            |
|     |     | 4      | 30880 | 30240       |         |                 | 2.12       |                    |                    |                    |                            |                            |
|     |     | 5      | 30800 | 30240       |         |                 | 1.85       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 18208 | 15840       |         |                 | 14.95      |                    | 14.38              | 15.22              |                            |                            |
|     |     | 2      | 17168 | 14960       |         |                 | 14.76      |                    |                    |                    |                            |                            |
|     |     | 3      | 16730 | 14520       |         |                 | 15.22      |                    |                    |                    |                            |                            |
|     |     | 4      | 18114 | 15840       |         |                 | 14.36      |                    |                    |                    |                            |                            |
|     |     | 5      | 17840 | 15840       |         |                 | 12.63      |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 14544 | 11088       |         |                 | 31.17      |                    | 32.52              | 35.66              |                            |                            |
|     |     | 2      | 14082 | 10472       |         |                 | 34.47      |                    |                    |                    |                            |                            |
|     |     | 3      | 13788 | 10164       |         |                 | 35.66      |                    |                    |                    |                            |                            |
|     |     | 4      | 14544 | 11088       |         |                 | 31.17      |                    |                    |                    |                            |                            |
|     |     | 5      | 14432 | 11088       |         |                 | 30.16      |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 13311 | 8640        |         |                 | 54.06      |                    | 59.13              | 64.72              |                            |                            |
|     |     | 2      | 13441 | 8160        |         |                 | 64.72      |                    |                    |                    |                            |                            |
|     |     | 3      | 13040 | 7920        |         |                 | 64.65      |                    |                    |                    |                            |                            |
|     |     | 4      | 13400 | 8640        |         |                 | 55.09      |                    |                    |                    |                            |                            |
|     |     | 5      | 13577 | 8640        |         |                 | 57.14      |                    |                    |                    |                            |                            |

**Table F.8 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 57218 | 56448       |         |                 | 1.36       |                    | 1.55               | 1.81               |                            |                            |
|     |     | 2      | 54192 | 53312       |         |                 | 1.65       |                    |                    |                    |                            |                            |
|     |     | 3      | 52679 | 51744       |         |                 | 1.81       |                    |                    |                    |                            |                            |
|     |     | 4      | 57328 | 56448       |         |                 | 1.56       |                    |                    |                    |                            |                            |
|     |     | 5      | 57218 | 56448       |         |                 | 1.36       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 32560 | 29232       |         |                 | 11.38      |                    | 11.21              | 11.62              |                            |                            |
|     |     | 2      | 30796 | 27608       |         |                 | 11.55      |                    |                    |                    |                            |                            |
|     |     | 3      | 29910 | 26796       |         |                 | 11.62      |                    |                    |                    |                            |                            |
|     |     | 4      | 32560 | 29232       |         |                 | 11.38      |                    |                    |                    |                            |                            |
|     |     | 5      | 32184 | 29232       |         |                 | 10.10      |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 25088 | 20160       |         |                 | 24.44      |                    | 25.51              | 28.24              |                            |                            |
|     |     | 2      | 24220 | 19040       |         |                 | 27.21      |                    |                    |                    |                            |                            |
|     |     | 3      | 23698 | 18480       |         |                 | 28.24      |                    |                    |                    |                            |                            |
|     |     | 4      | 25088 | 20160       |         |                 | 24.44      |                    |                    |                    |                            |                            |
|     |     | 5      | 24836 | 20160       |         |                 | 23.19      |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 22580 | 15624       |         |                 | 44.52      |                    | 47.78              | 53.44              |                            |                            |
|     |     | 2      | 22444 | 14756       |         |                 | 52.10      |                    |                    |                    |                            |                            |
|     |     | 3      | 21976 | 14322       |         |                 | 53.44      |                    |                    |                    |                            |                            |
|     |     | 4      | 22552 | 15624       |         |                 | 44.34      |                    |                    |                    |                            |                            |
|     |     | 5      | 22575 | 15624       |         |                 | 44.49      |                    |                    |                    |                            |                            |

**Table F.8 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [32, 38]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2510 | 2400        | 2510    | 127740.02       | 4.58       | 0.00               | 8.90               | 16.07              | 0.00                       | 0.00                       |
|     |     | 2      | 2074 | 1860        | 2072    | 124644.94       | 11.51      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1950 | 1680        | 1942    | 179867.56       | 16.07      | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2380 | 2220        | 2380    | 131910.80       | 7.21       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2460 | 2340        | 2460    | 168552.26       | 5.13       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1902 | 1440        | 1902    | 25370.04        | 32.08      | 0.00               | 41.58              | 58.33              | 0.22                       | 0.88                       |
|     |     | 2      | 1648 | 1116        | 1648    | 58345.15        | 47.67      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1596 | 1008        | 1582    | 53465.44        | 58.33      | 0.88               |                    |                    |                            |                            |
|     |     | 4      | 1852 | 1332        | 1852    | 24405.94        | 39.04      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1836 | 1404        | 1836    | 28640.59        | 30.77      | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1910 | 1120        | 1882    | 18165.78        | 70.54      | 1.49               | 82.10              | 103.57             | 0.47                       | 1.49                       |
|     |     | 2      | 1648 | 868         | 1648    | 58345.15        | 89.86      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1596 | 784         | 1582    | 53465.44        | 103.57     | 0.88               |                    |                    |                            |                            |
|     |     | 4      | 1848 | 1036        | 1848    | 20613.73        | 78.38      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1836 | 1092        | 1836    | 28640.59        | 68.13      | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 1910 | 960         | 1882    | 18165.78        | 98.96      | 1.49               | 112.45             | 137.50             | 0.47                       | 1.49                       |
|     |     | 2      | 1648 | 744         | 1648    | 58345.15        | 121.51     | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1596 | 672         | 1582    | 53465.44        | 137.50     | 0.88               |                    |                    |                            |                            |
|     |     | 4      | 1848 | 888         | 1848    | 20613.73        | 108.11     | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1836 | 936         | 1836    | 28640.59        | 96.15      | 0.00               |                    |                    |                            |                            |

**Table F.9:** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$



| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 13770 | 13520       |         |                 | 1.85       |                    | 3.86               | 6.87               |                            |                            |
|     |     | 2      | 11032 | 10478       |         |                 | 5.29       |                    |                    |                    |                            |                            |
|     |     | 3      | 10114 | 9464        |         |                 | 6.87       |                    |                    |                    |                            |                            |
|     |     | 4      | 12881 | 12506       |         |                 | 3.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 13482 | 13182       |         |                 | 2.28       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 8626  | 7280        |         |                 | 18.49      | 23.77              | 31.04              |                    |                            |                            |
|     |     | 2      | 7156  | 5642        |         |                 | 26.83      |                    |                    |                    |                            |                            |
|     |     | 3      | 6678  | 5096        |         |                 | 31.04      |                    |                    |                    |                            |                            |
|     |     | 4      | 8305  | 6734        |         |                 | 23.33      |                    |                    |                    |                            |                            |
|     |     | 5      | 8459  | 7098        |         |                 | 19.17      |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 7257  | 5200        |         |                 | 39.56      | 55.15              | 78.41              |                    |                            |                            |
|     |     | 2      | 6706  | 4030        |         |                 | 66.40      |                    |                    |                    |                            |                            |
|     |     | 3      | 6494  | 3640        |         |                 | 78.41      |                    |                    |                    |                            |                            |
|     |     | 4      | 7216  | 4810        |         |                 | 50.02      |                    |                    |                    |                            |                            |
|     |     | 5      | 7166  | 5070        |         |                 | 41.34      |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 6862  | 4160        |         |                 | 64.95      | 86.77              | 115.80             |                    |                            |                            |
|     |     | 2      | 6621  | 3224        |         |                 | 105.37     |                    |                    |                    |                            |                            |
|     |     | 3      | 6284  | 2912        |         |                 | 115.80     |                    |                    |                    |                            |                            |
|     |     | 4      | 6830  | 3848        |         |                 | 77.49      |                    |                    |                    |                            |                            |
|     |     | 5      | 6904  | 4056        |         |                 | 70.22      |                    |                    |                    |                            |                            |

**Table F.9 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 34000 | 33600       |         |                 | 1.19       |                    | 2.54               | 5.32               |                            |                            |
|     |     | 2      | 26800 | 26040       |         |                 | 2.92       |                    |                    |                    |                            |                            |
|     |     | 3      | 24772 | 23520       |         |                 | 5.32       |                    |                    |                    |                            |                            |
|     |     | 4      | 31680 | 31080       |         |                 | 1.93       |                    |                    |                    |                            |                            |
|     |     | 5      | 33200 | 32760       |         |                 | 1.34       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 19912 | 17600       |         |                 | 13.14      | 17.78              | 24.37              |                    |                            |                            |
|     |     | 2      | 16288 | 13640       |         |                 | 19.41      |                    |                    |                    |                            |                            |
|     |     | 3      | 15322 | 12320       |         |                 | 24.37      |                    |                    |                    |                            |                            |
|     |     | 4      | 19268 | 16280       |         |                 | 18.35      |                    |                    |                    |                            |                            |
|     |     | 5      | 19500 | 17160       |         |                 | 13.64      |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 15706 | 12320       |         |                 | 27.48      | 41.89              | 63.31              |                    |                            |                            |
|     |     | 2      | 14450 | 9548        |         |                 | 51.34      |                    |                    |                    |                            |                            |
|     |     | 3      | 14084 | 8624        |         |                 | 63.31      |                    |                    |                    |                            |                            |
|     |     | 4      | 15834 | 11396       |         |                 | 38.94      |                    |                    |                    |                            |                            |
|     |     | 5      | 15418 | 12012       |         |                 | 28.35      |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 13958 | 9600        |         |                 | 45.40      | 66.15              | 97.80              |                    |                            |                            |
|     |     | 2      | 13490 | 7440        |         |                 | 81.32      |                    |                    |                    |                            |                            |
|     |     | 3      | 13292 | 6720        |         |                 | 97.80      |                    |                    |                    |                            |                            |
|     |     | 4      | 13824 | 8880        |         |                 | 55.68      |                    |                    |                    |                            |                            |
|     |     | 5      | 14094 | 9360        |         |                 | 50.58      |                    |                    |                    |                            |                            |

**Table F.9 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 63270 | 62720       |         |                 | 0.88       |                    | 1.86               | 3.88               |                            |                            |
|     |     | 2      | 49653 | 48608       |         |                 | 2.15       |                    |                    |                    |                            |                            |
|     |     | 3      | 45608 | 43904       |         |                 | 3.88       |                    |                    |                    |                            |                            |
|     |     | 4      | 58841 | 58016       |         |                 | 1.42       |                    |                    |                    |                            |                            |
|     |     | 5      | 61757 | 61152       |         |                 | 0.99       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 35770 | 32480       |         |                 | 10.13      |                    | 13.94              | 19.33              |                            |                            |
|     |     | 2      | 29100 | 25172       |         |                 | 15.60      |                    |                    |                    |                            |                            |
|     |     | 3      | 27130 | 22736       |         |                 | 19.33      |                    |                    |                    |                            |                            |
|     |     | 4      | 34406 | 30044       |         |                 | 14.52      |                    |                    |                    |                            |                            |
|     |     | 5      | 34866 | 31668       |         |                 | 10.10      |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 27649 | 22400       |         |                 | 23.43      |                    | 34.40              | 52.35              |                            |                            |
|     |     | 2      | 24743 | 17360       |         |                 | 42.53      |                    |                    |                    |                            |                            |
|     |     | 3      | 23888 | 15680       |         |                 | 52.35      |                    |                    |                    |                            |                            |
|     |     | 4      | 26974 | 20720       |         |                 | 30.18      |                    |                    |                    |                            |                            |
|     |     | 5      | 26972 | 21840       |         |                 | 23.50      |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 23499 | 17360       |         |                 | 35.36      |                    | 53.27              | 81.71              |                            |                            |
|     |     | 2      | 22581 | 13454       |         |                 | 67.84      |                    |                    |                    |                            |                            |
|     |     | 3      | 22081 | 12152       |         |                 | 81.71      |                    |                    |                    |                            |                            |
|     |     | 4      | 23092 | 16058       |         |                 | 43.80      |                    |                    |                    |                            |                            |
|     |     | 5      | 23298 | 16926       |         |                 | 37.65      |                    |                    |                    |                            |                            |

**Table F.9 (continued):** Computational results for *General Problem* where  $p_j \in [25, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1440 | 1440        | 1440    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1380 | 1380        | 1380    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1560 | 1560        | 1560    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 966  | 936         | 958     | 1542.77         | 3.21       | 0.84               | 9.75               | 16.35              | 0.40                       | 0.84                       |
|     |     | 2      | 977  | 864         | 974     | 4733.44         | 13.08      | 0.31               |                    |                    |                            |                            |
|     |     | 3      | 880  | 828         | 880     | 4309.56         | 6.28       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1028 | 936         | 1028    | 3944.96         | 9.83       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1089 | 936         | 1080    | 4871.54         | 16.35      | 0.83               |                    |                    |                            |                            |
| 10  | 6   | 1      | 966  | 728         | 958     | 1542.77         | 32.69      | 0.84               | 41.82              | 49.59              | 1.32                       | 2.53                       |
|     |     | 2      | 977  | 672         | 974     | 4385.29         | 45.39      | 0.31               |                    |                    |                            |                            |
|     |     | 3      | 880  | 644         | 862     | 2002.31         | 36.65      | 2.09               |                    |                    |                            |                            |
|     |     | 4      | 1054 | 728         | 1028    | 3944.96         | 44.78      | 2.53               |                    |                    |                            |                            |
|     |     | 5      | 1089 | 728         | 1080    | 4871.54         | 49.59      | 0.83               |                    |                    |                            |                            |
| 10  | 8   | 1      | 966  | 624         | 958     | 1542.77         | 54.81      | 0.84               | 65.46              | 74.52              | 1.32                       | 2.53                       |
|     |     | 2      | 977  | 576         | 974     | 3337.92         | 69.62      | 0.31               |                    |                    |                            |                            |
|     |     | 3      | 880  | 552         | 862     | 1341.00         | 59.42      | 2.09               |                    |                    |                            |                            |
|     |     | 4      | 1054 | 624         | 1028    | 3944.96         | 68.91      | 2.53               |                    |                    |                            |                            |
|     |     | 5      | 1089 | 624         | 1080    | 4871.54         | 74.52      | 0.83               |                    |                    |                            |                            |

**Table F.10:** Computational results for *General Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,28]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 8788 | 8788        |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 8112 | 8112        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 7774 | 7774        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 8788 | 8788        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 8788 | 8788        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 4760 | 4732        |         |                 | 0.59       |                    | 1.57               | 6.30               |                            |                            |
|     |     | 2      | 4643 | 4368        |         |                 | 6.30       |                    |                    |                    |                            |                            |
|     |     | 3      | 4204 | 4186        |         |                 | 0.43       |                    |                    |                    |                            |                            |
|     |     | 4      | 4758 | 4732        |         |                 | 0.55       |                    |                    |                    |                            |                            |
|     |     | 5      | 4732 | 4732        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 3500 | 3380        |         |                 | 3.55       |                    | 12.99              | 29.84              |                            |                            |
|     |     | 2      | 4051 | 3120        |         |                 | 29.84      |                    |                    |                    |                            |                            |
|     |     | 3      | 3208 | 2990        |         |                 | 7.29       |                    |                    |                    |                            |                            |
|     |     | 4      | 3732 | 3380        |         |                 | 10.41      |                    |                    |                    |                            |                            |
|     |     | 5      | 3849 | 3380        |         |                 | 13.88      |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 3500 | 2704        |         |                 | 29.44      |                    | 40.45              | 62.30              |                            |                            |
|     |     | 2      | 4051 | 2496        |         |                 | 62.30      |                    |                    |                    |                            |                            |
|     |     | 3      | 3208 | 2392        |         |                 | 34.11      |                    |                    |                    |                            |                            |
|     |     | 4      | 3625 | 2704        |         |                 | 34.06      |                    |                    |                    |                            |                            |
|     |     | 5      | 3849 | 2704        |         |                 | 42.34      |                    |                    |                    |                            |                            |

**Table F.10 (continued):** Computational results for *General Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 21840 | 21840       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 19320 | 19320       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 11488 | 11440       |         |                 | 0.42       |                    | 0.45               | 0.71               |                            |                            |
|     |     | 2      | 10632 | 10560       |         |                 | 0.68       |                    |                    |                    |                            |                            |
|     |     | 3      | 10192 | 10120       |         |                 | 0.71       |                    |                    |                    |                            |                            |
|     |     | 4      | 11488 | 11440       |         |                 | 0.42       |                    |                    |                    |                            |                            |
|     |     | 5      | 11440 | 11440       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 8116  | 8008        |         |                 | 1.35       |                    | 5.06               | 7.44               |                            |                            |
|     |     | 2      | 7942  | 7392        |         |                 | 7.44       |                    |                    |                    |                            |                            |
|     |     | 3      | 7412  | 7084        |         |                 | 4.63       |                    |                    |                    |                            |                            |
|     |     | 4      | 8526  | 8008        |         |                 | 6.47       |                    |                    |                    |                            |                            |
|     |     | 5      | 8440  | 8008        |         |                 | 5.39       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 6902  | 6240        |         |                 | 10.61      |                    | 22.75              | 31.77              |                            |                            |
|     |     | 2      | 7590  | 5760        |         |                 | 31.77      |                    |                    |                    |                            |                            |
|     |     | 3      | 6999  | 5520        |         |                 | 26.79      |                    |                    |                    |                            |                            |
|     |     | 4      | 7381  | 6240        |         |                 | 18.29      |                    |                    |                    |                            |                            |
|     |     | 5      | 7880  | 6240        |         |                 | 26.28      |                    |                    |                    |                            |                            |

**Table F.10 (continued):** Computational results for *General Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 40768 | 40768       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 37632 | 37632       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 36064 | 36064       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 40768 | 40768       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 40768 | 40768       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 21202 | 21112       |         |                 | 0.43       |                    | 0.41               | 0.78               |                            |                            |
|     |     | 2      | 19640 | 19488       |         |                 | 0.78       |                    |                    |                    |                            |                            |
|     |     | 3      | 18758 | 18676       |         |                 | 0.44       |                    |                    |                    |                            |                            |
|     |     | 4      | 21202 | 21112       |         |                 | 0.43       |                    |                    |                    |                            |                            |
|     |     | 5      | 21112 | 21112       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 14736 | 14560       |         |                 | 1.21       |                    | 3.73               | 6.28               |                            |                            |
|     |     | 2      | 14284 | 13440       |         |                 | 6.28       |                    |                    |                    |                            |                            |
|     |     | 3      | 13406 | 12880       |         |                 | 4.08       |                    |                    |                    |                            |                            |
|     |     | 4      | 15248 | 14560       |         |                 | 4.73       |                    |                    |                    |                            |                            |
|     |     | 5      | 14902 | 14560       |         |                 | 2.35       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 12258 | 11284       |         |                 | 8.63       |                    | 12.49              | 21.95              |                            |                            |
|     |     | 2      | 12702 | 10416       |         |                 | 21.95      |                    |                    |                    |                            |                            |
|     |     | 3      | 11158 | 9982        |         |                 | 11.78      |                    |                    |                    |                            |                            |
|     |     | 4      | 12591 | 11284       |         |                 | 11.58      |                    |                    |                    |                            |                            |
|     |     | 5      | 12244 | 11284       |         |                 | 8.51       |                    |                    |                    |                            |                            |

**Table F.10 (continued):** Computational results for *General Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 28]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 2040 | 2040        | 2040    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1980 | 1980        | 1980    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2160 | 2160        | 2160    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1296 | 1296        | 1296    |                 | 0.00       | 0.00               | 1.05               | 2.31               | 0.00                       | 0.00                       |
|     |     | 2      | 1236 | 1224        | 1236    | 1478.51         | 0.98       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1200 | 1188        | 1200    | 1747.53         | 1.01       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1308 | 1296        | 1308    | 3051.37         | 0.93       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1326 | 1296        | 1326    | 2284.08         | 2.31       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1182 | 1008        | 1182    | 1280.05         | 17.26      | 0.00               | 23.52              | 30.36              | 0.28                       | 1.40                       |
|     |     | 2      | 1236 | 952         | 1236    | 1478.51         | 29.83      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1086 | 924         | 1071    | 554.78          | 17.53      | 1.40               |                    |                    |                            |                            |
|     |     | 4      | 1236 | 1008        | 1236    | 605.87          | 22.62      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1314 | 1008        | 1314    | 2086.30         | 30.36      | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 1182 | 864         | 1182    | 1280.05         | 36.81      | 0.00               | 44.11              | 52.08              | 0.28                       | 1.40                       |
|     |     | 2      | 1236 | 816         | 1236    | 1478.51         | 51.47      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1086 | 792         | 1071    | 554.78          | 37.12      | 1.40               |                    |                    |                            |                            |
|     |     | 4      | 1236 | 864         | 1236    | 605.87          | 43.06      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1314 | 864         | 1314    | 2086.30         | 52.08      | 0.00               |                    |                    |                            |                            |

**Table F.11:** Computational results for *General Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$



| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 12168 | 12168       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 11492 | 11492       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 11154 | 11154       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 12168 | 12168       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 12168 | 12168       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 6562  | 6552        |         |                 | 0.15       |                    | 0.21               | 0.58               |                            |                            |
|     |     | 2      | 6224  | 6188        |         |                 | 0.58       |                    |                    |                    |                            |                            |
|     |     | 3      | 6016  | 6006        |         |                 | 0.17       |                    |                    |                    |                            |                            |
|     |     | 4      | 6562  | 6552        |         |                 | 0.15       |                    |                    |                    |                            |                            |
|     |     | 5      | 6552  | 6552        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 4706  | 4680        |         |                 | 0.56       |                    | 4.18               | 14.03              |                            |                            |
|     |     | 2      | 5040  | 4420        |         |                 | 14.03      |                    |                    |                    |                            |                            |
|     |     | 3      | 4330  | 4290        |         |                 | 0.93       |                    |                    |                    |                            |                            |
|     |     | 4      | 4781  | 4680        |         |                 | 2.16       |                    |                    |                    |                            |                            |
|     |     | 5      | 4830  | 4680        |         |                 | 3.21       |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 4239  | 3744        |         |                 | 13.22      |                    | 20.73              | 36.03              |                            |                            |
|     |     | 2      | 4810  | 3536        |         |                 | 36.03      |                    |                    |                    |                            |                            |
|     |     | 3      | 3882  | 3432        |         |                 | 13.11      |                    |                    |                    |                            |                            |
|     |     | 4      | 4410  | 3744        |         |                 | 17.79      |                    |                    |                    |                            |                            |
|     |     | 5      | 4624  | 3744        |         |                 | 23.50      |                    |                    |                    |                            |                            |

**Table F.11 (continued):** Computational results for *General Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 30240 | 30240       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 28560 | 28560       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 27720 | 27720       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 30240 | 30240       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 30240 | 30240       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 15848 | 15840       |         |                 | 0.05       |                    | 0.09               | 0.21               |                            |                            |
|     |     | 2      | 14992 | 14960       |         |                 | 0.21       |                    |                    |                    |                            |                            |
|     |     | 3      | 14536 | 14520       |         |                 | 0.11       |                    |                    |                    |                            |                            |
|     |     | 4      | 15848 | 15840       |         |                 | 0.05       |                    |                    |                    |                            |                            |
|     |     | 5      | 15840 | 15840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 11140 | 11088       |         |                 | 0.47       |                    | 0.52               | 0.92               |                            |                            |
|     |     | 2      | 10568 | 10472       |         |                 | 0.92       |                    |                    |                    |                            |                            |
|     |     | 3      | 10228 | 10164       |         |                 | 0.63       |                    |                    |                    |                            |                            |
|     |     | 4      | 11152 | 11088       |         |                 | 0.58       |                    |                    |                    |                            |                            |
|     |     | 5      | 11088 | 11088       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 8720  | 8640        |         |                 | 0.93       |                    | 7.32               | 10.71              |                            |                            |
|     |     | 2      | 9034  | 8160        |         |                 | 10.71      |                    |                    |                    |                            |                            |
|     |     | 3      | 8522  | 7920        |         |                 | 7.60       |                    |                    |                    |                            |                            |
|     |     | 4      | 9484  | 8640        |         |                 | 9.77       |                    |                    |                    |                            |                            |
|     |     | 5      | 9295  | 8640        |         |                 | 7.58       |                    |                    |                    |                            |                            |

**Table F.11 (continued):** Computational results for *General Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 56448 | 56448       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 53312 | 53312       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 51744 | 51744       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 56448 | 56448       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 56448 | 56448       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 29254 | 29232       |         |                 | 0.08       |                    | 0.07               | 0.16               |                            |                            |
|     |     | 2      | 27652 | 27608       |         |                 | 0.16       |                    |                    |                    |                            |                            |
|     |     | 3      | 26810 | 26796       |         |                 | 0.05       |                    |                    |                    |                            |                            |
|     |     | 4      | 29246 | 29232       |         |                 | 0.05       |                    |                    |                    |                            |                            |
|     |     | 5      | 29232 | 29232       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 20274 | 20160       |         |                 | 0.57       |                    | 0.46               | 0.79               |                            |                            |
|     |     | 2      | 19190 | 19040       |         |                 | 0.79       |                    |                    |                    |                            |                            |
|     |     | 3      | 18556 | 18480       |         |                 | 0.41       |                    |                    |                    |                            |                            |
|     |     | 4      | 20267 | 20160       |         |                 | 0.53       |                    |                    |                    |                            |                            |
|     |     | 5      | 20160 | 20160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 15996 | 15624       |         |                 | 2.38       |                    | 3.64               | 8.18               |                            |                            |
|     |     | 2      | 15963 | 14756       |         |                 | 8.18       |                    |                    |                    |                            |                            |
|     |     | 3      | 14596 | 14322       |         |                 | 1.91       |                    |                    |                    |                            |                            |
|     |     | 4      | 16342 | 15624       |         |                 | 4.60       |                    |                    |                    |                            |                            |
|     |     | 5      | 15800 | 15624       |         |                 | 1.13       |                    |                    |                    |                            |                            |

**Table F.11 (continued):** Computational results for *General Problem* where  $p_j \in [1,35]$  and  $d_i \in [32,38]$

| $n$ | $K$ | Ins. # | GH   | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 10  | 2   | 1      | 2400 | 2400        | 2400    |                 | 0.00       | 0.00               | 0.00               | 0.00               | 0.00                       | 0.00                       |
|     |     | 2      | 1860 | 1860        | 1860    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1680 | 1680        | 1680    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 2220 | 2220        | 2220    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 2340 | 2340        | 2340    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 4   | 1      | 1440 | 1440        | 1440    |                 | 0.00       | 0.00               | 2.24               | 6.45               | 0.00                       | 0.00                       |
|     |     | 2      | 1188 | 1116        | 1188    | 1693.10         | 6.45       | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1056 | 1008        | 1056    | 1279.40         | 4.76       | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1332 | 1332        | 1332    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1404 | 1404        | 1404    |                 | 0.00       | 0.00               |                    |                    |                            |                            |
| 10  | 6   | 1      | 1245 | 1120        | 1240    | 621.22          | 11.16      | 0.40               | 24.57              | 49.59              | 0.08                       | 0.40                       |
|     |     | 2      | 1188 | 868         | 1188    | 2190.65         | 36.87      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1012 | 784         | 1012    | 1389.17         | 29.08      | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1265 | 1036        | 1265    | 1495.26         | 22.10      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1350 | 1092        | 1350    | 1238.59         | 23.63      | 0.00               |                    |                    |                            |                            |
| 10  | 8   | 1      | 1245 | 960         | 1240    | 621.22          | 29.69      | 0.40               | 45.33              | 59.68              | 0.08                       | 0.40                       |
|     |     | 2      | 1188 | 744         | 1188    | 2457.44         | 59.68      | 0.00               |                    |                    |                            |                            |
|     |     | 3      | 1012 | 672         | 1012    | 1326.71         | 50.60      | 0.00               |                    |                    |                            |                            |
|     |     | 4      | 1265 | 888         | 1265    | 1495.26         | 42.45      | 0.00               |                    |                    |                            |                            |
|     |     | 5      | 1350 | 936         | 1350    | 1238.59         | 44.23      | 0.00               |                    |                    |                            |                            |

**Table F.12:** Computational results for *General Problem* where  $p_j \in [1,35]$  and  $d_i \in [22,48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 25  | 2   | 1      | 13520 | 13520       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 10478 | 10478       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 9464  | 9464        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 12506 | 12506       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 13182 | 13182       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 4   | 1      | 7280  | 7280        |         |                 | 0.00       |                    | 0.60               | 2.22               |                            |                            |
|     |     | 2      | 5767  | 5642        |         |                 | 2.22       |                    |                    |                    |                            |                            |
|     |     | 3      | 5136  | 5096        |         |                 | 0.78       |                    |                    |                    |                            |                            |
|     |     | 4      | 6734  | 6734        |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 7098  | 7098        |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 25  | 6   | 1      | 5252  | 5200        |         |                 | 1.00       |                    | 7.20               | 22.13              |                            |                            |
|     |     | 2      | 4922  | 4030        |         |                 | 22.13      |                    |                    |                    |                            |                            |
|     |     | 3      | 3955  | 3640        |         |                 | 8.65       |                    |                    |                    |                            |                            |
|     |     | 4      | 4964  | 4810        |         |                 | 3.20       |                    |                    |                    |                            |                            |
|     |     | 5      | 5120  | 5070        |         |                 | 0.99       |                    |                    |                    |                            |                            |
| 25  | 8   | 1      | 4553  | 4160        |         |                 | 9.45       |                    | 26.16              | 52.45              |                            |                            |
|     |     | 2      | 4915  | 3224        |         |                 | 52.45      |                    |                    |                    |                            |                            |
|     |     | 3      | 3739  | 2912        |         |                 | 28.40      |                    |                    |                    |                            |                            |
|     |     | 4      | 4582  | 3848        |         |                 | 19.07      |                    |                    |                    |                            |                            |
|     |     | 5      | 4926  | 4056        |         |                 | 21.45      |                    |                    |                    |                            |                            |

**Table F.12 (continued):** Computational results for *General Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 40  | 2   | 1      | 33600 | 33600       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 26040 | 26040       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 23520 | 23520       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 31080 | 31080       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 32760 | 32760       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 4   | 1      | 17600 | 17600       |         |                 | 0.00       |                    | 0.51               | 1.30               |                            |                            |
|     |     | 2      | 13784 | 13640       |         |                 | 1.06       |                    |                    |                    |                            |                            |
|     |     | 3      | 12480 | 12320       |         |                 | 1.30       |                    |                    |                    |                            |                            |
|     |     | 4      | 16312 | 16280       |         |                 | 0.20       |                    |                    |                    |                            |                            |
|     |     | 5      | 17160 | 17160       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 6   | 1      | 12384 | 12320       |         |                 | 0.52       |                    | 3.03               | 6.89               |                            |                            |
|     |     | 2      | 10074 | 9548        |         |                 | 5.51       |                    |                    |                    |                            |                            |
|     |     | 3      | 9218  | 8624        |         |                 | 6.89       |                    |                    |                    |                            |                            |
|     |     | 4      | 11652 | 11396       |         |                 | 2.25       |                    |                    |                    |                            |                            |
|     |     | 5      | 12012 | 12012       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 40  | 8   | 1      | 9952  | 9600        |         |                 | 3.67       |                    | 13.67              | 23.62              |                            |                            |
|     |     | 2      | 8952  | 7440        |         |                 | 20.32      |                    |                    |                    |                            |                            |
|     |     | 3      | 8307  | 6720        |         |                 | 23.62      |                    |                    |                    |                            |                            |
|     |     | 4      | 10116 | 8880        |         |                 | 13.92      |                    |                    |                    |                            |                            |
|     |     | 5      | 10000 | 9360        |         |                 | 6.84       |                    |                    |                    |                            |                            |

**Table F.12 (continued):** Computational results for *General Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$

| $n$ | $K$ | Ins. # | GH    | Lower Bound | Optimal | CPU Times (sec) | LB Gap (%) | Optimality Gap (%) | Average LB Gap (%) | Maximum LB Gap (%) | Average Optimality Gap (%) | Maximum Optimality Gap (%) |
|-----|-----|--------|-------|-------------|---------|-----------------|------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|
| 55  | 2   | 1      | 62720 | 62720       |         |                 | 0.00       |                    | 0.00               | 0.00               |                            |                            |
|     |     | 2      | 48608 | 48608       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 3      | 43904 | 43904       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 4      | 58016 | 58016       |         |                 | 0.00       |                    |                    |                    |                            |                            |
|     |     | 5      | 61152 | 61152       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 4   | 1      | 32480 | 32480       |         |                 | 0.00       |                    | 0.31               | 0.77               |                            |                            |
|     |     | 2      | 25352 | 25172       |         |                 | 0.72       |                    |                    |                    |                            |                            |
|     |     | 3      | 22912 | 22736       |         |                 | 0.77       |                    |                    |                    |                            |                            |
|     |     | 4      | 30068 | 30044       |         |                 | 0.08       |                    |                    |                    |                            |                            |
|     |     | 5      | 31668 | 31668       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 6   | 1      | 22552 | 22400       |         |                 | 0.68       |                    | 2.00               | 4.11               |                            |                            |
|     |     | 2      | 18073 | 17360       |         |                 | 4.11       |                    |                    |                    |                            |                            |
|     |     | 3      | 16192 | 15680       |         |                 | 3.27       |                    |                    |                    |                            |                            |
|     |     | 4      | 21120 | 20720       |         |                 | 1.93       |                    |                    |                    |                            |                            |
|     |     | 5      | 21840 | 21840       |         |                 | 0.00       |                    |                    |                    |                            |                            |
| 55  | 8   | 1      | 17698 | 17360       |         |                 | 1.95       |                    | 7.24               | 15.31              |                            |                            |
|     |     | 2      | 15514 | 13454       |         |                 | 15.31      |                    |                    |                    |                            |                            |
|     |     | 3      | 13424 | 12152       |         |                 | 10.47      |                    |                    |                    |                            |                            |
|     |     | 4      | 17275 | 16058       |         |                 | 7.58       |                    |                    |                    |                            |                            |
|     |     | 5      | 17076 | 16926       |         |                 | 0.89       |                    |                    |                    |                            |                            |

**Table F.12 (continued):** Computational results for *General Problem* where  $p_j \in [1, 35]$  and  $d_i \in [22, 48]$