MOBILE HEALTH SERVICES FOR RURAL AREAS IN TURKEY: A CASE STUDY FOR BURDUR

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MASTER OF SCIENCE

By

Damla Kurugöl

March, 2013

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Bahar Yetiş Kara (Supervisor)

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Dr. Hünkar Toyoğlu (Co-Supervisor)

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Oya Ekin Karaşan

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Asst. Prof. Haluk Aygüneş

Approved for the Institute of Engineering Sciences:

Prof. Dr. Levent Onural

Director of the Graduate School of Engineering and Science

ABSTRACT

Mobile Health Services for Rural Areas in Turkey: A Case Study for Burdur

Damla Kurugöl

M.S. in Industrial Engineering

Supervisor: Assoc. Prof. Bahar Y. Kara,

Co-Supervisor: Dr. Hunkar Toyoğlu

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Currently, healthcare services in urban areas are provided by family health centers coordinated by community health centers. By the application of family physician based system, it is planned to provide mobile healthcare services (MHS) for the people living in the rural areas which have difficulties to reach those health centers in urban areas. In the scope of these ongoing studies, family physicians procure primary health services to the determined villages in between defined time periods. The aim of this project is to schedule a working plan by using family physicians' mobile healthcare service times effectively. In this context, when the problem was examined, we realized that it has similarities with the periodic vehicle routing problem (PVRP). We proposed several different solution approaches to the PVRP in the context of the mobile healthcare services application that we are interested in. We tested the implementation of our proposed solution approaches using both simulated data and extended data obtained from the villages of Burdur city.

Key words: Periodic vehicle routing, healthcare logistics, family healthcare system, heuristics.

ÖZET

Türkiyede Kırsal Kesim Mobil Sağlık Hizmetleri: Burdur Uygulaması

Damla Kurugöl

Endüstri Mühendisliği, Yüksek Lisans

Tez Yöneticisi: Doç. Dr. Bahar Y. Kara,

Eş-Tez Yöneticisi: Dr. Hunkar Toyoğlu

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Günümüzde, kırsal kesimde sağlık hizmetleri toplum sağlığı merkezleri tarafından koordine edilen aile sağlığı merkezleri tarafından verilmektedir. Aile hekimi tabanlı sistemin uygulamaya başlanmasından beri, kırsal kesimde yaşayan ve kent merkezlerine ulaşımı zor olan insanlar için mobil sağlık hizmetlerinin sağlanması planlanmıştır. Bu çalışmalar ışığında, aile hekimleri belirlenen köylere belirli zamanlarda temel sağlık hizmetleri sağlamakla yükümlüdür. Bu çalışmanın temel amacı, aile hekimlerinin mobil sağlık hizmeti servis zamanını efektiv kullanabilmelerini sağlayacak bir çalışma takvimi oluşturmaktır. Bu amaçla, problem incelendiğinde periyodik araç rotalama problemiyle benzerlik gösterdiği tespit edilmiştir. Bu çalışmada periyodik araç rotalama problemine mobil sağlık hizmetleri uygulaması açısından birçok değişik çözüm yaklaşımı geliştirilmiştir. Önerilen yaklaşımların uygulaması Burdur şehrinin köylerinden elde edilen genişletilmiş ve simüle edilmiş veri setleri aracılığıyla test edilmiş ve kıyaslamaya tabi tutulmuştur.

Anahtar kelimeler: Periyodik araç rotalama, sağlık lojistiği, aile sağlığı sistemi, sezgiseller

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To My Family and My Dear Sister Sıla…

Chapter 1

Introduction

In today's world, health services provided to the people living in rural areas gained real importance. The main reason of this significance is the increase of mortality rate especially mortality rate of children [1]. In Turkey, thousands of people died in rural areas due to lack of care [2]. When the historical data is reviewed, the mortality rate in rural areas is greater than urban areas in Turkey [3], [4], [5]. For instance, 57,7% of women living in rural areas can take healthcare service during their pregnancies whereas the rest cannot reach directly to the health services provided and have to give birth to their children at home [6]. Since the rate of direct accessibility to health services in rural areas is low, it is obligatory to extend and activate mother and children health, preventive health and mobile health services in rural areas. Therefore, Ministry of Health in Turkey has decided to make a plan to provide mobile health services to these people.

For this purpose, they employed family physicians to provide mobile healthcare services to the people in rural areas during predefined time intervals. Therefore, there is a need to schedule the visit slots of a doctor to provide healthcare service to the people living in the rural parts.

The aim of our study is to generate a cost efficient service plan for family physicians to give healthcare service to these people. Our problem is defined as the determination of monthly mobile healthcare service routes that provide healthcare services by using the village to doctor assignments. The problem includes weekly visits of the villages in the rural areas by the family physician that is assigned to that village.

The rest of the thesis is organized as follows. In Chapter 2, public healthcare system in urban and rural areas of the world is explained in general. In Chapter 3, healthcare system in Turkey is evaluated in detail and then the problem definition is given in Chapter 4 with the details about the specific features of this study. In Chapter 5, we present an overview of the vehicle routing problem (VRP), PVRP and their extensions proposed in the literature.

Then, the solution methodology which includes heuristics proposed is presented in detail in Chapter 6. In this chapter, the integer programming model and the approximation algorithm that are suggested to solve the assignment problem of villages to doctors are presented. Moreover, a heuristic is constructed to find the schedule which determines the weekly routes of the doctors by using the assignment gathered from the result of the IP model and approximation algorithm. Then, two different improvement algorithms are presented that are used to find the minimum distanced route by making interchanges in the weekly visit sequence of the villages that will be followed by a family physician during his/her monthly service schedule. In Chapter 7, the case study implementation to the Burdur city is presented. In this chapter, a cost effective service schedule is constructed for family physicians that give healthcare service and the results are compared for two improvement algorithm. In Chapter 8, an optional schedule selection methodology is explained and the solution algorithm is given. In Chapter 9, the computational results are given for the extended and simulated data sets. The final chapter is devoted to the conclusions and future work directions.

Chapter 2

Public Healthcare Systems in the World

The level of healthcare services depends on the population of the area. There are several definitions for rural area which shows differences between countries. While rural means a place in which population density is demographically low in Turkey, in USA there is a limit to be defined as rural area, which is having 2500 or less population. However, in Canada this limit is relatively lower [7]. According to the Canadian federal government, rural is the population outside settlements with 1000 or less population with population density of 400 or less inhabitants per square kilometer [8]. These definitions of rural are most frequently used by the federal government of these countries. On the contrary, for USA urban area is defined as the districts which have more than 2500 population and for Canada it is restricted to having more than 1000 population.

The health care services are provided by hospitals in metropolitans (urban areas) like cities and provinces whereas in rural areas it is provided by health centers or polyclinics.

i) Primary healthcare, concentrates on the people and their basic needs and it aims to support them. Hospitals and primary health centers are one side of the system in which health care is provided.

Primary healthcare needs to be delivered at sites that are close to the people. Thus, it should rely on maximum usage of both equipment and professional health care practitioners. Primary health care can be categorized in the following eight components [9], [10]:

- Appropriate treatment of common diseases using appropriate technology,
- Prevention and control of local diseases,
- Maternal and child care, including family planning,
- Immunization against the infectious diseases,
- Provision of essential drugs,
- Education for the identification and prevention,
- Promotion of mental, emotional and spiritual health,
- Proper food supplies and nutrition; adequate supply of safe water and basic sanitation,

ii) Preventive healthcare, which includes some activities of the primary healthcare services, refers to measures taken to prevent diseases or injuries rather than curing the patients or treating their symptoms.

Preventive healthcare strategies help to avoid the development of disease. Most population-based health activities are primary preventive healthcare services.

The health services are provided by special organizations that are available and responsible for the health care services in countries. For instance, "Health Protection Agency" is the responsible organization in UK; "Public Health Agency of Canada", in Canada and "Centers for Disease Control and Prevention", in USA.

The healthcare services provided in different countries of the world show variations. For instance, healthcare service providers, the locations of healthcare services and the funding of those healthcare services change from country to country. For the summary of rural and urban healthcare services in different countries see Table-1.

According to our researches, for instance, in Germany 90% of the population have the health insurance provided by government whereas 9% have private health insurance. Patients are required to remain connected to family physicians for at least 3 months from the beginning of the delivery of their files to them. Family doctors may refer patients to other specialists or hospital if they deem it necessary. Family physicians are obliged to care for emergency cases outside their working hours [11].

In UK, the family physicians are called as general practitioners [12]. Most of the health services in the UK are funded by taxes. Healthcare system is funded by 8.4 % of the United Kingdom's gross domestic product (GDP). The healthcare services are provided by the National Health Service (NHS). The health care services are delivered in a primary and secondary health care setting. Practitioners serve the patients in their offices, in clinics which have a group of practitioners, like seen in USA, or in healthcare centers and NHS hospitals. People must apply firstly to the practitioner that they are registered. They cannot apply to the second step in case they don't have referral from the practitioner except emergencies conditions [13].

In Canada, national health insurance covers all people living there. Family physicians work in private offices in major cities and they also take care of their patients' treatment which they refer to the secondary healthcare facilities. However, healthcare centers and small hospitals are used for services in rural areas. In health centers; family physicians, nurses, midwives, dentists work as the staff which have signed a contract with local governments. They give preventive and medicinal health services at the same time [14].

COUNTRIES		GERMANY	UK	CANADA	USA	ISRAEL	PORTUGAL	CUBA	HOLLAND	TURKEY
URBAN	Fund	90% of the population have government funded , 9% have private funded health insurance.	Taxes , 8.4 % of the United Kingdom's gross domestic product (GDP).	National Health Insurance covers all the people	Private health insurances, 14% have no insurance	General health insurance covers 96% of population	National Health Service (NHS) funded by general taxation,special social health insurance and voluntary private health insurance.	Healthcare system covers everyone, free, accessible, 6.8%of GNP allocated to the health services	Private health insurances	Private insurances, government funded insurances
	HC Service Provider	Family physicians	General Practitioners (GP)	Physicians	Physicians	Team of physicians	Team of family physicians	family physicians	GPs work alone or in small practices	Family physicians and doctors
	HC Service location	Heathcare centers, hospitals	National Health Service (NHS) hospitals, offices, clinics, healtcare centers.	Private offices	Offices, clinics with a group of healthcare physicians	Healthcare centers with x-ray and labaratory services, family and primary medicine facilities	Healthcare centers	Family physician's office, center of dentistry, polyclinics, hospitals, preventative and specialized treatment centers	Office, another physican's office with a group of physicians together	Hospitals, family health centers, healthcare facilities
	Procedure	1. Application to healthcare practitioner 2. Referral if necessary	1. Application to healthcare practitioner 2. Referral if necessary (other than emergency conditions)	1. Application to healthcare practitioner 2. Referral if necessary			Each person must register to a family physician		1. Application to the healthcare practitioner 2. Referral of patient if necessary Also, people can apply to hospitals research institutes, polyclinics directly	1. Application to healthcare practitioner 2. Referral of patient if necessary Also, people can apply to hospitals directly
	Services	primary healthcare services, secondary healthcare services	primary healthcare services, secondary healthcare services				Primary care, preventive care and health education services	Preventive health services, immunization, rehabilitation services, dietetics	Preventive care	Primary and preventive healthcare services
RURAL	Rural area Service Locations	Family physicians ' office		Healthcare centers, small hospitals		Healthcare units,family practice clinics	Healthcare centers	Polyclinics (each has a service region)	Physicians' office, health centers	Healtcare facilities
	Rural area Service Provider	Family physicians		family physician, nurses, midwives and dentists	Primary care physicians	Family physicians and nurses		Family physicians	GPs	GPs, Nurses, healthcare workers
	Rural area Services	primary healthcare services	Primary healthcare services	Preventive healthcare services, medicinal health services	primary healthcare services	primary healthcare services	primary healthcare services	Primary healthcare services	Primary healthcare services	Primary healthcare services

Table-1: Healthcare in Countries

In USA, most of the people have private health insurances whereas 14% have no insurance. Family physicians serve the patients in their offices or clinics which have a group of family physicians which is applied in recent years [15].

In Israel, general health insurance comprehends 96% of the population. Primary health care services provided by a family physician and nurses in health units in rural areas, whereas in urban areas the health centers providing healthcare services by a team which is more crowded in healthcare centers to 2000-3000 people. The services given in urban areas also include x-ray and laboratory [16].

In Portugal, the healthcare system is characterized by three systems; the National Health Service (NHS) funded by general taxation, special social health insurance and voluntary private health insurance. The primary healthcare services are provided by healthcare centers. Family physicians are working as a team in these health centers. Each patient must register to a family physician [17].

In Cuba, health care system covers everyone, free of charge and accessible. 6.8% of Gross National Product (GNP) allocated to the health services. The healthcare services are given in polyclinic, family physician's office, hospital or in the center of dentistry. The duties of family physician are similar with the ones applied in Turkey. For instance, the family physicians in Cuba have to provide preventive health, immunization, rehabilitation services and dietetics. People can apply to hospitals; research institutes (RIs) or polyclinics directly. Each polyclinic has a service region. Family physicians in the regions are in close contact with the people living in those places. Thus, despite using the chance to apply other healthcare service facilities (hospitals, RIs), the residents choose to apply to the polyclinics since they are having good relationships with the family physicians [18].

In Holland, there is a referral system which refers the patient to a specialist, if the family physician deem that is necessary like the one will be seen in Turkey’s healthcare system part. There are two ways of providing service; in office or in some other physician’s office with a group of physicians giving service together [19].

When it comes to Turkey, the healthcare services are covered by private insurances or government funded insurances. Family physicians and doctors give healthcare services in urban areas located in hospitals and family health centers. The patients can take service by application to the family physician or by directly reaching to the hospitals. When the patient goes to the family physician if the physician deems that it is necessary he/she refers the patient to a hospital for detailed examinations. In rural parts there are some healthcare facilities in which a few nurses, healthcare workers and family physicians/general practitioners (GPs) are available to give primary healthcare services to the residents.

From all of this information, it can be realized that all of the healthcare systems in rural areas of different countries show similarities with each other and with Turkey's health care system. The details about Turkey's healthcare system are presented in the following chapter. However, there exist some differences in urban healthcare service facilities of different countries.

As it is mentioned, the health care services are provided in urban areas by hospitals and health centers in general. However, providing basic services to the people live in rural parts is an important problem in developing countries. For this reason, the mortality rate of people who live in those areas is remarkably higher than urban areas. Therefore, there is a major need of mobile healthcare services to reach the people who live in rural areas and to reduce the number of deaths. However, according to our researches there is not an ***effective healthcare service system*** in any country in the world. The need of an effective healthcare service system was our motivation to concentrate on this problem in this study.

Chapter 3

Healthcare System in Turkey

As mentioned previously, according to our researches special healthcare services are needed in rural areas of countries in the world. To satisfy those needs, major changes in healthcare system in rural and urban areas have taken place in Turkey [20]. After the application of new healthcare system in all cities of Turkey (2010), the system is reconsidered and reorganized to satisfy deficiencies in its structure.

Once the available system is investigated, it can be seen that all the managerial decisions which are related to health care are made by the Ministry of Health in Turkey. The organizational structure, which is hierarchical in this public organization, is shown in Figure-1.

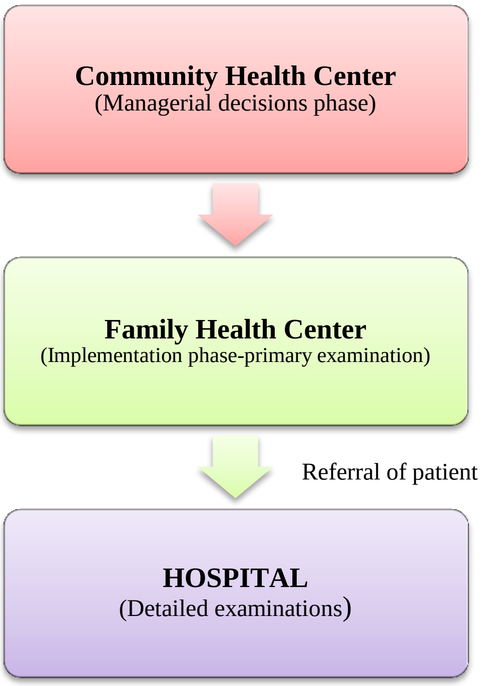


Figure-1: Organizational structure

3.1 Community Health Center

Community Health Centers aim to protect and improve community health by identifying risks and problems and making plans to solve these problems. It also manages primary preventive and rehabilitative health services by following, evaluating and supporting the services that are given. In addition to these, it coordinates the relations among organizations.

3.2 Family Health Center

Family Health Centers are healthcare organizations in which one or more family doctor/s and social workers provide both stable and mobile health services to people who are in need.

The primary health services are given in the family health centers whereas secondary health services are given in the hospitals. Stable services in urban areas include primary examination of patient in those family health centers and referral of hospital if it is necessary according to the decision of the family physician.

According to governmental regulations, the places which have more than 2500 population can be considered as a rural area that needs family health center in Turkey. If those places satisfy that requirement, ***potential stable health services*** that are provided in those areas can be categorized as follows [21]:

- Primary care
- Child care
- Emergency preparedness and response
- Preventive health care
- Dental care
- Behavioral health services
- Immunization
- Infectious and chronic disease control and prevention

When there is no family health center, in case in which the requirements are not satisfied to open one, government can provide mobile health service to the people who live in those places.

Mobile health service is a kind of health service that is given by a doctor and a social worker in places like neighborhood and countryside. The details of the service are determined by the Community Health Center and Family Health Center.

As an example to the ***basic mobile services*** given in a mobile unit, the following four titles can be given;

- Practice
- Pregnant and baby monitoring
- Injection/Immunization
- Tension measuring

All family doctors that give mobile healthcare service have a general schedule which indicates the period of service and the sequence of visits to the places where that service is needed. These schedules should be made according to the geographical, transportation and climate conditions of those places. It is also affected from the number of connected locations to it. According to the Ministry of Health, for a village with 100 or less people, the family doctor should provide this service more than three hours in a month. For population between 100 and 750, this service should be provided more than once a week. For a village with a population over 750 people, the service should be provided more than twice a week. It is also chosen to satisfy the required healthcare services by providing service at the same day of each week. See Table-2 for summary of the general required service times according to population size determined by Ministry of Health. If there exists any nearby healthcare service facility that belongs to the Ministry of Health, that facility will be used to provide those services, otherwise the schools' gardens will be used according to the regulations [22].

POPULATION	SERVICE REQUIREMENT
Population ≤ 100	> 3hours / month
100 < Population < 750	> Once / week
Population > 750	> Twice / week

Table-2: Service Requirements of Villages

There also exists an ***on-site health service*** which is a kind of mobile health service that is given by a doctor and a social worker in places like prisons, nursing homes and orphanages. The service procedures are determined by the management. In those determined places there are some limitations that should be satisfied while services are given by family doctors. In nursing homes, for 100 people these services must be more than three hours in a month, up to 750 people they must be provided more than once in a week and for more than 750 people they must be provided more than twice in a week. For prisons and orphanages these numbers are multiplied by two according to the regulations.

In Turkey, there are also some other health care services like dental care and psychological treatments which are sponsored by private companies. These activities might be considered as a part of their marketing strategy under the name of civic involvement projects [23] like the one implemented in Turkey in 2010 by one of the companies which sells oral and dental care products (Colgate-Palmolive). The company aimed to reach out from children to their family and enlighten them about oral and dental health. They reached 1million 250 thousand children in Turkey with the school visits they have done by using mobile healthcare service vehicles [24].

In our research, we realized that despite the differences between countries' urban health services, there are similarities in the need for mobile health care services in rural areas of these countries [7]. Thus, we consider a general structure of mobile systems used in rural areas in different countries by gathering all those information together.

Chapter 4

Problem Definition

In most of the countries healthcare centers and hospitals are established in the urban areas to provide healthcare service to the people living in those cities. There are also some healthcare facilities like healthcare units, family practice clinics, polyclinics and offices of the family physicians in which healthcare services are provided to the patients. Since the population is high in urban areas, the capacity in hospitals may be insufficient. Therefore, the people living in rural parts can have difficulties in reaching the healthcare services provided in those healthcare facilities even when they travel to urban areas to receive healthcare services. Obligation to travel long distances and occurrence of adverse weather conditions makes these services even more difficult to reach for the people in rural areas. In order to provide healthcare services to the people living in rural, mobile healthcare services (MHS) are designed.

In this study, we aim to generate a service schedule for family physicians which provide MHS in rural areas. The mobile service vehicles travel with a family physician to the villages every week and give healthcare service according to the schedule generated for a physician. The family physicians/doctors start their route from the depot hospital and complete their route at the end of the week by returning to the hospital. They provide service from Monday to Friday each week. Every day they work 8 hours in total. One day service time is restricted with 2 service slots and each service slot includes 4-hour service time. The visit frequency of each village is determined by its population. The required visit frequencies according to the population size of the villages are determined from the specific requirements settled by Ministry of Health in Turkey.

The number of weekly service slots is determined by dividing visit frequency of the villages to the number of weeks in a month which is 4. For instance, if the frequency of a village is 12 by dividing to 4 we get the number of visit slots necessary per week for that village, which are 3 slots for this case. The possible frequency values according to population sizes of the villages are 12,8,4,2 and 1.

Another requirement is that the intervals between each visit should be fixed to provide periodic visits to the villages every week. For the villages with low visit frequency requirements (with low population size), the visit intervals can be more than a week. For the villages with frequencies larger than or equal to four the service needs to be provided at the same day (or service slot) every week. This constraint is very important in practice since this requirement makes it easy for patients to easily follow when the healthcare service is provided.

The service of each doctor to a village is dedicated. The doctor who gives service to a village once is the one responsible for continuously monitoring that village by making periodic visits. The service regions of a doctor, the villages that he/she is responsible, is determined by considering the monthly service capacity of each doctor which is 40 slots and following the dedicated doctor assignment for each village.

Since the service is given with a vehicle by following a visit schedule in each month, the problem is evaluated as a vehicle routing problem (VRP) in the literature. Since visits of these MHS vehicles have a repetitive structure for each week, the service that they are providing to the people living in rural areas is periodic. The problem we analyzed is evaluated as a special case of the periodic vehicle routing problem (PVRP) in the operations research (OR) literature.

Our study aims to find an effective service plan for the family physicians that use mobile healthcare service vehicles in their daily service slots to provide service to people in rural areas by minimizing the distance traveled by the doctors monthly.

Mobile healthcare vehicle routing problem has similarities with the previous studies in the PVRP literature. However, there are some features specific to our problem that is addressed in the next section.

4.1 Problem Specific Features

The features of this problem can be summarized as follows;

(i) Each route starts and ends at the hospital in which the doctors are located,

(ii) Each village's visit frequency should be aligned with the required demand of that village,

(iii) The total demand of each route should not exceed the vehicle capacity which represents the family physician's monthly service time limit,

(iv) Each town should be visited by the same doctor throughout the planning horizon: dedicated doctors are required to make doctor-patient relationship easier and to help doctors identify the illnesses quicker by continuous monitoring.

(v) Feasible visit schedules are not fixed; they are selected according to the requirements. However, in the previous studies in the literature the feasible visit days are fixed by the sets which include possible visit days.

(vi) The total travel cost of each vehicle/doctor is minimized.

We are designing an efficient mobile healthcare system by considering the problem specific features listed above. We believe that mobile health services can provide more accessible service that satisfies the demands to patients in rural areas, by using our model as a decision support tool.

Chapter 5

Literature Review

5.1 Vehicle Routing Problem and Extensions

Vehicle routing problem is the problem of providing service to the customers by using the vehicles which are starting their route from a depot and ending their route at the same depot while minimizing the total cost of traveling. Since in our problem, the mobile healthcare service vehicles travel on routes in each week of their monthly service period with the aim of minimizing that route cost, the base of our problem is the vehicle routing problem.

Literature on vehicle routing problem is wide. There exists huge range of studies that has been carried out since 1959 [25]. There are several variations of vehicle routing problem in the recent literature which is classified as; multi-depot VRP (MDVRP), capacitated VRP (CVRP), tactical planning VRP (TPVRP), VRP with time window (VRPTW) and periodic VRP (PVRP). See figure-2 for details of this classification.

Some examples which are evaluated under VRP classification literature is given below. For instance, in 1997 Cordeau et al. [26] studied multi-depot vehicle routing problem (MDVRP). Their study assigns vehicles to depots then it finds routes for each vehicle. In 2001, Cordeau et al. [27] find a solution to the multi-depot VRP with time window addition (MDVRPTW). In 2011, Baldacci et al. [28] developed an exact algorithm to solve the capacitated vehicle routing problem (CVRP) which includes an additional capacity constraint for each vehicle as a variation from classical VRP. Moreover, they evaluate multi-depot VRP (MD-VRP) and also tactical planning VRP (TP-VRP). In TP-VRP, they updated the plan by changing the number of working days and customers according to the new customer requests. In 2011, Vidal et al. [29] focused on multi-depot VRP (MDVRP) and PVRP which include periodicity of vehicle schedules.

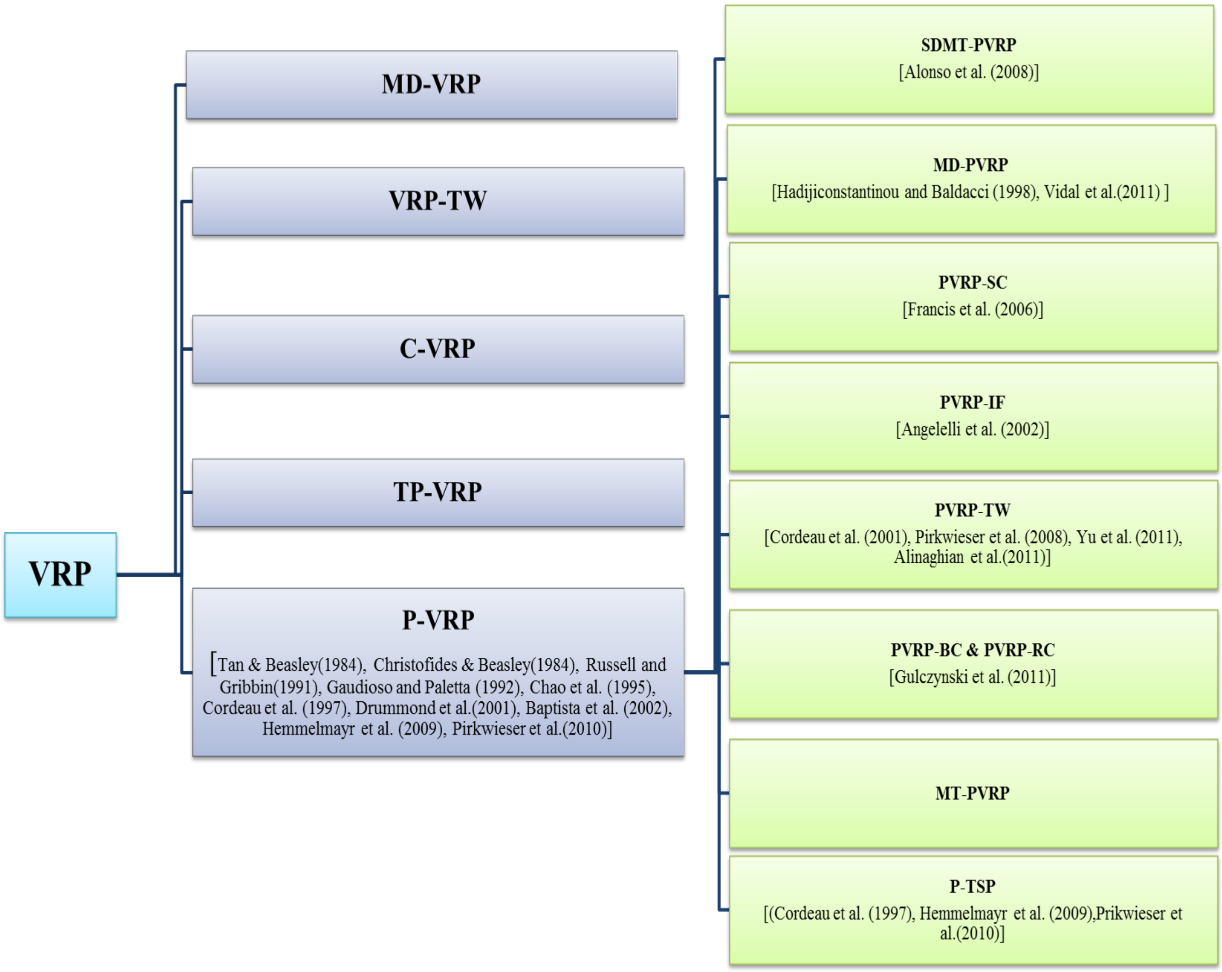


Figure-2: VRP, P-VRP and their extensions with examples

5.2 Periodic Vehicle Routing Problem and Extensions

The periodic vehicle routing problem is the general form of the vehicle routing problem. In the periodic vehicle routing problem a set of routes for each day of a given time period is found. The time period can be a month, a year etc. In this problem, each customer can be visited once or more than once during the planning horizon according to different service combinations. As an example, a customer can require two visits per month which means that it should be visited two times in a month within different service time combinations.

Literature on periodic vehicle routing problem is not wide when compared with VRP literature. PVRP studies have been carried out since 1974. The pioneering work is an application of PVRP to waste collecting problem in New York City by Beltrami and Bodin [30].

Our study is considered as a PVRP since it includes determination of MHS vehicle routes and monthly reputation of those services which makes the service periodic. The PVRP is applicable to different kinds of areas in real life such as; grocery and soft drink distribution, refuse collection problems, resource planning problem in utilities company [30], school bus routing, oil and petroleum delivery, armored arc routing and repairmen scheduling problems, waste and recycled goods collection [30], [3], [31], [32], reverse logistic problems, automobile parts distribution [33], maintenance operations [34] and vending machine replenishment.

The PVRP in the literature is also classified into subclasses which are site dependent multi-trip PVRP (SDMT-PVRP), multi-depot PVRP (MD-PVRP), PVRP with service choice (PVRP-SC), PVRP with intermediate facilities (PVRP-IF), PVRP with time windows (PVRP-TW), PVRP with balanced and reassignment constraints (PVRP-BC& PVRP-RC) and multi-trip PVRP (MT-PVRP). See figure-2 for details of PVRP classification and literature.

There also exists a special case of PVRP that is called as periodic traveling salesman problem (PTSP). The difference is that there is only one vehicle to travel. Moreover, there is no capacity restriction for this vehicle which travels periodically. Thus, it is the periodic version of classical traveling salesman problem.

The first work on PVRP is by Beltrami and Bodin [30] which includes a simple heuristic developed by modification of Clarke and Wright's saving algorithm and its application to waste collecting problem in New York City. In1979, Russell and Igo [35] defined PVRP as an assignment routing problem. In 1984, Tan and Beasley [36] enhanced a heuristic algorithm to solve PVRP based on Fisher & Jaikumar's algorithm from literature. Same year, Christofides and Beasley [37] developed an integer programming model for PVRP and suggested a two stage heuristic which includes initial allocation of customers to delivery days and interchange of customer combinations to minimize total distance traveled. In 1991, Russell and Gribbin [38] examined PVRP from a different perspective by making an initial network design using an approximation technique for the network including three improvement phases. In 1992, Gaudioso and Paletta [39] worked on PVRP by using a delivery combination improvement heuristic. In 1995, PVRP is solved by 2 phase record to record travel algorithm by Chao et al. [40]. In 1997, Cordeau et al. [26] used integer programming to find visit combinations for each customer and a tabu search heuristic to solve VRP for each day which outperforms all heuristics written before 1997. In 2001, Drummond et al. [41] examined PVRP using a parallel hybrid evolutionary metaheuristic which is also a metaheuristic like Chao et al's work [40]. In 2002, Angelelli and Speranza [42] obtained a solution for an extension of PVRP by using Tabu Search algorithm. In this work they considered that homogenous vehicles can renew their capacity by using some intermediate facilities. Same year, Baptista et al [31] found a solution to the problem classified as PVRP with service choice (PVRP-SC). It is related to collection of recycling paper containers in Almada Municipality, Portugal. In their study, the visit frequencies are considered as decision variables to provide different service choices for the different customers. In 2007, another solution is presented using a LP based rounding heuristic by Mourgaya and Vanderbeck [43]. Besides, Alegre et al [33] enhanced a two phase approach for solving the periodic pickup of raw materials problem in manufacturing auto parts industry. The first phase is assigning orders to days while the second is the construction of the routes. In 2008, Alonso et al [44] developed a solution by using Tabu Search algorithm for an extension of PVRP. In this work, an accessibility constraint is considered which prevents visit of every vehicle to every customer. The authors also allowed the service of each vehicle more than one route per day as long as it doesn't exceed maximum delay operation time. In 2009, Hemmelmayr et al. [45] also used a metaheuristic to solve the PVRP which includes Clark& Wrights saving algorithm and variable neighborhood search algorithm. In 2010, Pirkwieser and Raidl [50] used a variable neighborhood search algorithm to find a solution to PVRP. Moreover, Gulczynski et al [46] developed a new heuristic for PVRP in 2011. The heuristic that is enhanced is a combination of integer programming problem and a record to record travel algorithm. See figure-2 for details of general classification of VRP and PVRP.

There are also different approaches for different subclasses of PVRP. The solution methodologies show variations between different problem classes which are classical heuristic, metaheuristic and mathematical programming based solution methodologies. For instance, Hadjiconstantinou and Baldacci [47] studied multi-depot PVRP (MD-PVRP) in which PVRP is solved for each depot by presenting a new heuristic procedure in 1998. In 2001, Cordeau et al. [26] examined PVRP with time window (PVRP-TW), differ from classical PVRP with a time interval defined for each tour, using a tabu search heuristic based on a local search metaheuristic. In 2006, Francis and Smilowitz [48] present a study about

PVRP with service choice (PVRP-SC), is a variant of PVRP in which visit frequency to nodes is a decision of the model, using a continuous approximation formulation of integer programming presented from Francis et al [49]. In 2008, Alonso et al. [44] worked on a study about site dependent multi-trip PVRP (SDMTPVRP) using a tabu search (TS) heuristic which is a generalization of tabu search algorithm of Cordeau et al.[26] to solve PVRP. In this study site dependent multi-trip means existence of heterogeneous fleet for customers with only multiple vehicle trips. In 2009, Pirkwieser et al. [50] studied PVRP and its special case called PTSP which includes only one vehicle to find a route. In 2011, Gulczynski et al. [46] examined PVRP with reassignment constraints (PVRP-RC) which consider reassignment of customers to new service patterns and also PVRP with balanced constraints (PVRP-BC) which takes into account the balanced workload among drivers. They used integer programming based heuristic technique to solve these problem types**.** In 2011, Alinaghian et al. [51] find a solution to the multi-objective PVRP with competitive time windows (PVRP-CTW) by proposing two algorithms based on multi-objective particle swarm optimization (MOPSO) and NSGAII algorithms. In 2011, Vidal et al. [29] used a hybrid genetic search algorithm to solve multi-depot PVRP (MDPVRP) which is evaluated as a meta-heuristic technique. Recently, Yu et al. [52] presented a solution to the PVRP with time window (PVRP-TW) by using an improved ant colony optimization (IACO) technique. See Figure-3 for the classification.

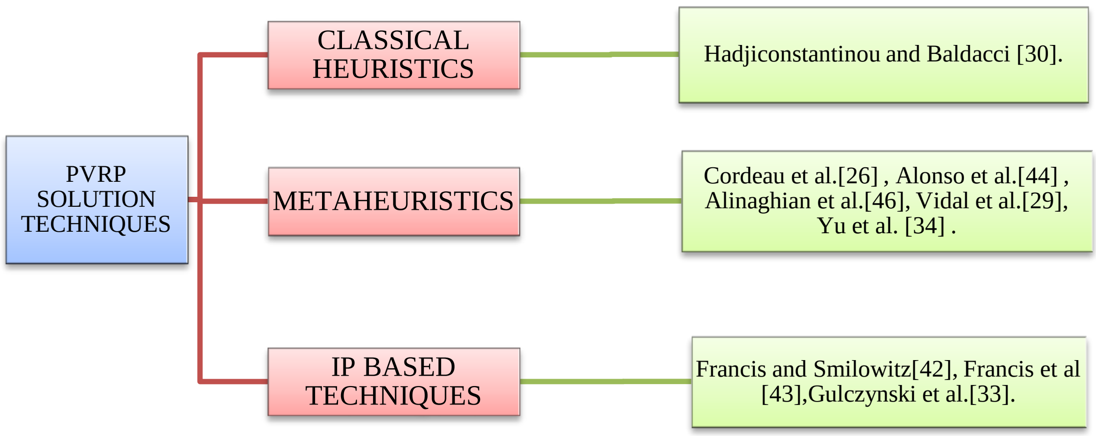


Figure- 3: PVRP Solution Techniques

In general as can be seen from details of the solution techniques given above tabu search algorithm (TSA) is used most frequently to solve the PVRPs and their extensions. For instance, Cordeau et al. [26] used TSA to solve PVRP and PTSP. In 2001, Cordeau et al. [27]

extended their work by the same solution technique to solve PVRP with time window addition. After this work, Angelelli et al. [42] solved intermediate facility extension of PVRP with TSA. Then, Alonso et al. [44] made another extended work to solve site dependent multi-trip PVRP by using TSA. There exist also another technique called variable neighborhood search algorithm (VNS) that is used in some of the papers in the PVRP literature like Pirkwieser et al. [53,50] and Hemmelmayr et al.'s [45] works. See figure-4 for classification of meta-heuristic solution techniques of PVRP.

In those works that are mentioned, some of the authors used extended data gathered from literature like Christofides & Beasley [35]. However, in general the authors used randomly generated data to analyze effectiveness of their solution technique.

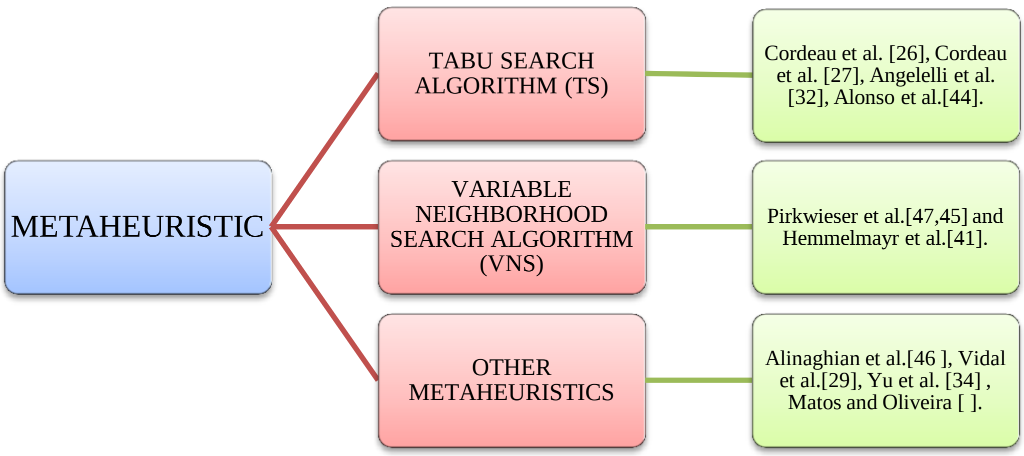


Figure-4: Metaheuristic Solution Techniques to Solve PVRP

PVRPs that are mentioned above have both similarities and differences with our problem definition according to two basic criteria, namely schedule presetting and dedicated doctor availability. In all of the previous studies in the PVRP literature, the visit schedules are preset right from the start. See Table-3 for all the papers in the PVRP literature that include visit schedule presetting.

Generally, the papers in which feasible visit schedules are preset have a method which includes generation of a group of feasible alternative visit days (combination of days) for each customer and selection from one of the visit combinations. However, they are not defining all possible visit combination sets. Therefore, their results may be suboptimal.

In addition to this, the other criterion which is addressed in our problem is the dedicated doctor assignment to customers which is considered by Francis, and Smilowitz [48] and Francis et al. [49]. To satisfy dedicated doctor assignment, Francis and Smilowitz [48] created a constraint that forces the choice of one vehicle for each customer in their Binary Integer Programming (BIP) formulation which they used to find routes of each vehicle. Also, Francis et al. [49] used BIP model which forces one vehicle assignment for each demand node (customer). Only those studies force dedicated doctor assignment in their models. See Table-3 for details.

In our model, we consider availability of dedicated doctors and we do not fix visit schedules. We used a special method to determine visit days of the doctors/vehicles for each node/village. We consider visit for each village in between fixed time intervals by satisfying the healthcare service regulations of the government. To the best of our knowledge, in the current literature there is no work that covers both of those criteria mentioned in our study. For those reasons, we decided to concentrate on finding a solution to this problem by using a different perspective. See Table-3 for detailed classification of PVRP literature.

No	Authors	Published year	PROBLEM ADRESSED	SOLUTION METHODOLOGY		Schedules are defined/not (FIXED)	Dedicated visit
				EXACT	HEURISTIC		
1	Beltrami and Bodin	1974	PVRP	-	+	+	-
2	R. Russell, W. Igo	1979	PVRP	+	-	+	-
3	Tan & Beasley	1984	PVRP	+	+	+	-
4	Christofides and Beasley	1984	PRP	+	+	+	-
5	Russell and Gribbin	1991	PRP	+	+	+	-
6	Gaudioso & Paletta	1992	PVRP	+	+	+	-
7	I. M. Chao, B. L. Golden, E. Wasil	1995	PVRP	+	+	+	-
8	Cordeau, Gendreau and Laporte	1997	MDPVRP,PVRP,PTSP	+	TS	+	-
9	Hadjiconstantinou and Baldacci	1998	MDPVRP	+	-	+	-
10	L.M.A. Drummond, L. S.Ochi, D.S. Vianna	2001	PVRP	-	+	+	-
11	J-F Cordeau, G. Laporte and A. Mercier	2001	MDPVRP,PVRPTW	-	TS	+	-
12	Enrico Angelelli,Maria Grazia Speranza	2002	PVRP-IF	-	TS	+	-
13	Baptista, Oliveria, Zuquete	2002	PVRP	+	+	+	-
14	A. C. Matos, R.C. Oliveira	2004	PVRP	-	ACO	+	-
15	Peter Francis, Karen Smilowitz	2006	PVRP-SC	+	+	+	+
16	Francis, Smilotwitz,Tzur	2006	PVRP-SC	+	-	+	+
17	J, Alegre, M. Laguna, J. Pacheco	2007	PVRP	-	+	+	-
18	Mourgaya & Vanderbeck	2007	MPVRP	-	+	+	-
19	Alonso, Alvarez and Beasley	2008	SDMTPVRP	-	TS	+	-
20	Hemmelmayr et al.	2009	PVRP-PTSP	-	VNS	+	-

(TS: Tabu Search Algorithm, VNS: Variable Neighborhood Search Algorithm, ACO: Ant Colony Optimization)

Table-3: PVRP Classification

No	Authors	Published year	PROBLEM ADRESSED	SOLUTION METHODOLOGY		Schedules are defined/not (FIXED)	Dedicated visit
				EXACT	HEURISTIC		
21	PM Francis, KR Smilowitz, M Tzur	2009	MDPVRP,CVRP,PVRPTW, PVRP-SC,PVRP	+	+	+	-
22	Sandro Pirkwieser Günther R. Raidl	2009	PVRPTW	-	+	+	-
23	Wen, M., Cordeau, J-F, Laporte, G., Larsen, J.	2009	MPVRP	+	+	+	-
24	Coene,Arnout,Spieksma	2010	PVRP	+	-	+	-
25	Sandro Pirkwieser and Gunther R. Raidl	2010	PVRP-PTSP	-	VNS	+	-
26	Pirkwieser and Raidl	2010	PVRPTW	-	VNS	+	-
27	Gulczynski et al.	2011	PVRP-BC, PVRP-RC	+	+	+	-
28	Vidal, Crainic, Gendreau,Lahrichi, Rei	2011	MD-PVRP, PVRP	-	+	+	-
29	Baldacci, Bartolini, Mingozzi, Valletta	2011	MDPVRP,CVRP,TP-VRP	+	-	+	-
30	Bin Yu, Zhong Zhen Yang	2011	PVRPTW	-	ACO	+	-
31	THEODORE ATHANASOPOULOS	2011	PVRPTW,MPVRPTW	+	-	+	-
32	J.G. Kim, J.S. Kim, D.H. Lee	2011	PVRP	-	+	+	-
33	M. Alinaghian, M. Ghazanfari, A. Salamatbakhsh, N. Norouzi	2012	Multi objective-PVRP, PVRPCTW	-	+	+	-

(TS: Tabu Search Algorithm, VNS: Variable Neighborhood Search Algorithm, ACO: Ant Colony Optimization)

Table-3 Cont'd: PVRP Classification Cont'd

Chapter 6

Solution Methodology

6.1 Summary of Methodology

We design an efficient solution methodology to the scheduling problem of family physicians in rural parts of Turkey that satisfy the demands under the problem specific constraints. To do this, we suggested a three stage solution method; first stage is the assignment phase, the second one is the routing phase and the last one is the improvement of the routing phase.

In the first step, we solve the problem of assigning each village to a doctor. The goal is to solve this problem such that the maximum service capacity of each doctor will be filled. This problem definition triggers the well-known C-VRP where the vehicles denote the doctors and the doctor capacities being the 40 slots per month. We first used optimization software with a classical formulation given in the literature with Miller Tucker Zemlin subtour elimination constraints. However, during our preliminary analyses the CPU requirement of this model was high and so we decided to develop different methodologies for the doctor to village assignment.

We offered two solutions to the assignment problem. In the first method, we generated a binary integer programming (BIP) model to determine minimum cost assignments of nodes/villages to the vehicles/family physicians adhering to the working hour limit for each doctor. This BIP model which is called as assignment model (AM) was coded in GAMS (General Algebraic Modeling System) and solved using CPLEX 10.2.2 optimization program. In the second solution method, we constructed an approximation algorithm (AA) to find an assignment which satisfies the total workload of the family physicians. The AA in the second method provides a shorter CPU run time when compared to BIP model of the first method. Eventually, each village is assigned to a doctor using one of these methods.

The next step is finding an optimal weekly route to generate a monthly schedule for each doctor. However, the periodic vehicle routing problem is NP-complete since it is a generalization of the traveling salesman problem. Thus, a heuristic algorithm is developed to solve the routing problem for each doctor. The heuristic algorithms are coded in Matlab programming language.

After development of the initial routes for each doctor, two different improvement algorithms are implemented to obtain cost saving in terms of total traveling cost for each doctor. See figure-5 for the scheme showing the steps of the proposed solution methodology.

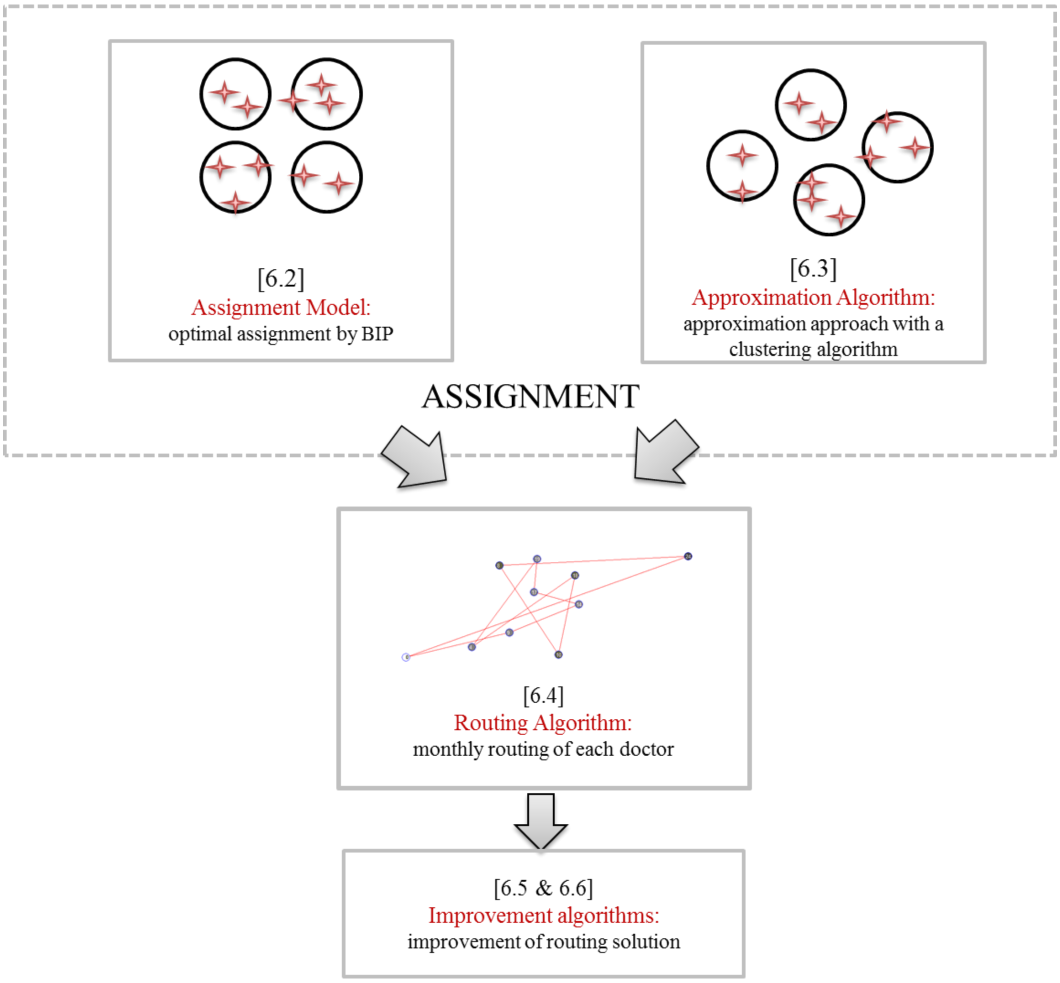


Figure-5: Solution Methodology

In all of these methods that are developed to find a monthly schedule for a doctor, the general goal is to minimize the monthly total travel distance for a doctor such that demands of the villages are served while satisfying the constraints. The demands of the villages are the required visit frequencies for each village. For instance, if the village needs to be visited 2 times in a month, the demand of that village is two. As we mentioned before, the demands of the villages are determined by the population sizes of the villages.

To summarize, the solution methodology includes three stages:

1. Assigning each village to a doctor such that frequency requirements are satisfied.
2. Designing the weekly routes in such a way that the total travel cost of doctors is minimized. Thus, for each week in the planning horizon cost minimizing routes must be configured. The routing solution also needs to satisfy the problem constraints.
3. Enhancing the monthly routes of each doctor to reduce monthly travel cost. See Figure-6 for the general structure of the solution methodology.

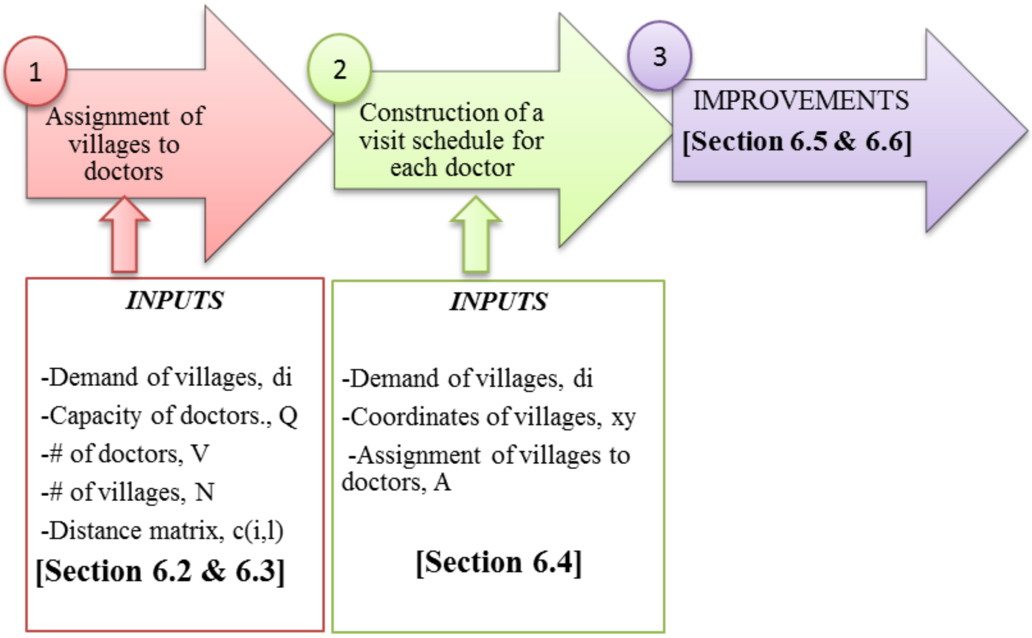


Figure-6: General Structure of the Solution Methodology

In the first stage of the problem, we suggest two methods to solve the assignment problem;

1. AM: Run the integer programming formulation for an hour and get the incumbent which may not be the optimal solution to the assignment problem. The reason we do this is that it takes a long time to compute the optimal BIP solution.
2. AA: Use a clustering based algorithm to find near optimal solution to the assignment problem.

6.2 Assignment Model (AM)

This model aims to find an optimal assignment of villages to the doctors with the purpose of minimizing the travel distance between the villages for each doctor. The model generates an assignment by considering the requirement of dedicated doctor assignment to each village. This means assigning the same doctor to a village for each visit. The advantage of this requirement is that the patients can be followed and examined in each visit by the same doctor. This helps the patients be familiar with the family physician dedicated to their village.

The doctors' service slots are equal to 2 slots per day, 10 slots per week and 40 slots per month in total. Thus, the monthly capacity of each doctor is 40 slots. The model also provides the work balance between doctors since every doctor works with full capacity in a month which is equal to 40 slot service time for each of them. In addition to those, the model does not allow any unassigned villages. Thus, there is no village deprived of mobile healthcare service.

The inputs of this model are the number of available doctors, number of villages that should be visited, total available monthly service time of a doctor which is 40 slots for each doctor, total demand of each village which represents the frequency of visits required for each village and the village to village distances. The output is the assignment of doctors to villages under those constraints. The resulting assignment matrix represents the villages that a doctor should visit in his/her monthly schedule.

The details about the assignment model (AM) including definitions, parameters and variables will be defined next.

In our model, the nodes represent villages; paths represent shortest distances between villages.

Indices

$i \text{ is index for villages}, \quad i = 1, .. N$

$l \text{ is index for villages}, \quad l = 1, .. N$

$v \text{ is index for doctors}, \quad v = 1, .. V$

Parameters

N: $total\ number\ of\ villages$

d_i: $demand\ of\ village\ i$

V: $number\ of\ doctors$

$c(i,l)$: $distance\ between\ i\ th\ and\ l\ th\ villages$

$Q_v\ =\ Q$: $capacity\ of\ each\ doctor\ =$

$number\ of\ available\ work\ slot\ for\ a\ doctor\quad = 40$

$1\ slot =\ 4\ hours$

$1\ day = 2\ slots = 8\ hours$

$1\ week = 10\ slots = 40\ hours$

$1\ month = 40\ slots = 160\ hours$

Decision Variables

A: $assignment\ matrix\ of\ size\ \ V\ x\ N$

z: $total\ cost$

$$x(v,i)\ = \begin{cases} 1, if\ doctor\ v\ visits\ node\ i \\ 0, ow. \end{cases}$$

$$y(i,l)\ = \begin{cases} 1, if\ node\ i\ and\ l\ are\ visited\ by\ the\ same\ doctor \\ 0, ow. \end{cases}$$

The integer programming (IP) model formulation is given below.

$$Min\ z = \sum_{i,l} c_{il}\ y_{il} \qquad (1)$$

$st.$

$$\sum_{i} x_{vi} d_i \leq Q,\ \ for\ all\ v = 1, ..V \qquad (2)$$

$$\sum_{v} x_{vi} = 1, for\ all\ i = 1, ..N \qquad (3)$$

$$x_{vi} + x_{vl} \leq\ y_{il} + 1, \qquad for\ all\ i, l, v, (i \neq l) \qquad (4)$$

$$x_{vi}, y_{il} \in \{0,1\}\ , for\ all\ v, i\ and\ l \qquad (5)$$

Objective (1) is the cost minimization.

Constraint (2): Capacity restriction. Total capacity of a doctor is maximum Q = 40 work slots per a month.

Constraint (3): Dedicated doctor assignment. All nodes assigned to only one doctor.

Constraint (4): Ensures that y_{il} becomes 1 if both i & l are served by the same doctor.

Constraint (5): Binary conditions on the variable set.

The number of binary variables $= \ |N|^2 + |V| * |N|$.
The number of constraints = $|V| * |N|^2 + |V| + |N|$

The IP model (AM) we developed has a long worst case running time. Thus, we suggest an approximation algorithm (AA) to find an assignment in a shorter CPU time.

6.3 Approximation algorithm (AA)

An approximation algorithm is constructed to assign a cluster of villages to each doctor within a shorter CPU time. In clustering literature, K-means is a widely used algorithm to divide the data points into K-clusters in data mining [54]. To do so, first the initial cluster centers are picked randomly. In this case, the number of cluster centers is equal to the number of doctors. Then, each node is assigned to the nearest cluster center. After the assignment, cluster centers are updated. The new cluster centers are calculated as the mean position (in both x and y coordinates) of the nodes assigned to each cluster. This constitutes the first iteration of the K-means clustering algorithm. In the next iteration, the assignment and cluster center update steps are repeated. The algorithm terminates when the cost function does not change any more or when the maximum number of iterations are reached.

This clustering approach cannot be directly applied to our assignment problem because we cannot just assign nodes to the nearest cluster center. The reason is that in our assignment problem each cluster (or doctor) has a limited capacity. Therefore, we can only assign a node to a doctor if that doctor’s capacity, i.e. the number of time slots within a month (which is equal to 40 in our case) is not full. Therefore, we modified the k-means clustering algorithm and adapted it to solve our problem. In our algorithm each cluster is the set of villages assigned to a doctor and each observation node is a village.

In the modified K-means clustering algorithm, instead of assigning the nodes/villages to cluster centers with a random order, we first start from the villages with highest frequencies. The nodes with K highest frequencies are initialized as K cluster centers. We then order the villages with decreasing frequency values and assign them to these cluster centers in that order. This helps us in assigning the highest frequency villages first and the nodes with low frequencies are easier to assign later to the remaining slots in the clusters. We continue to assign the villages in this order until the capacity of that doctor do not allow for assignment of the next node. If that is the case, then we assign that node to the second nearest cluster center (or doctor). After assigning all nodes, we update the cluster centers using the same approach as we explained for K-means algorithm. This is the first iteration; we then continue this assignment and update steps at each iteration as long as the total cost function is decreasing at each iteration. We stop otherwise. We run this algorithm several times with different cluster center initializations and choose the one with the smallest cost as the final assignment. The total cost function is sum of distances of all nodes to their cluster centers. See figure-7 for the flow chart of the modified K-means algorithm.

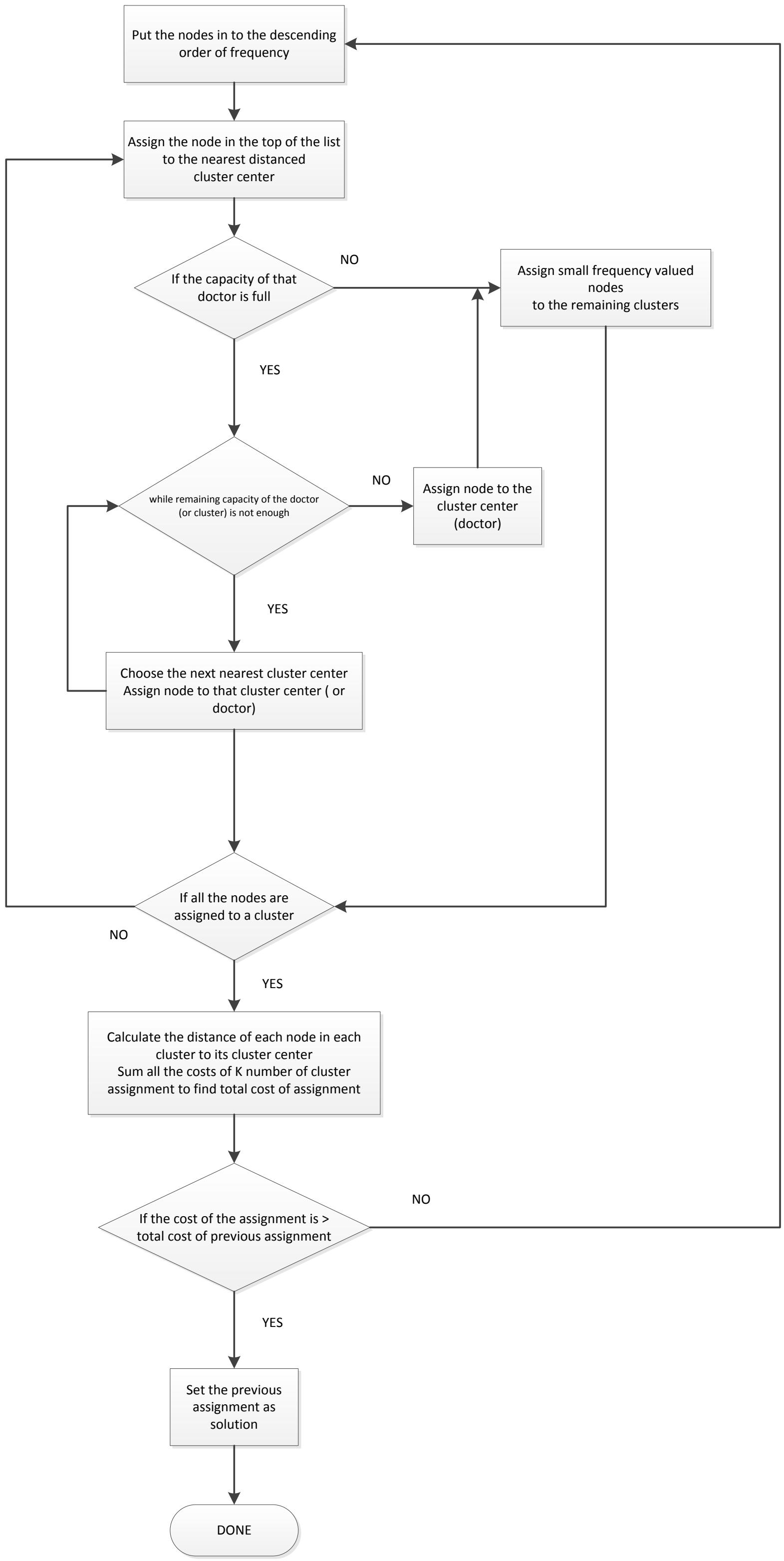


Figure-7: Flowchart of the Modified K-means Algorithm

For an example of the steps of the modified k-means clustering algorithm see figure-8. For this example, Burdur data which will be detailed in Chapter 7 is used. In the figure, the small circles with the same color represent the villages in the same cluster (or assigned to the same doctor) whereas the stars represent the centers of the clusters. As can be seen from figure-8 the algorithm terminates after 3 updates. The cluster centers and village cluster assignment change can be followed on the figures starting with the initial solution. Then, by checking the assignment result of modified K-means clustering algorithm, it can be realized that the last iteration clustering cost (step-3) is more than the one before (step-2). Therefore, the algorithm preserves the last best result (in step-2) as the solution for that run.

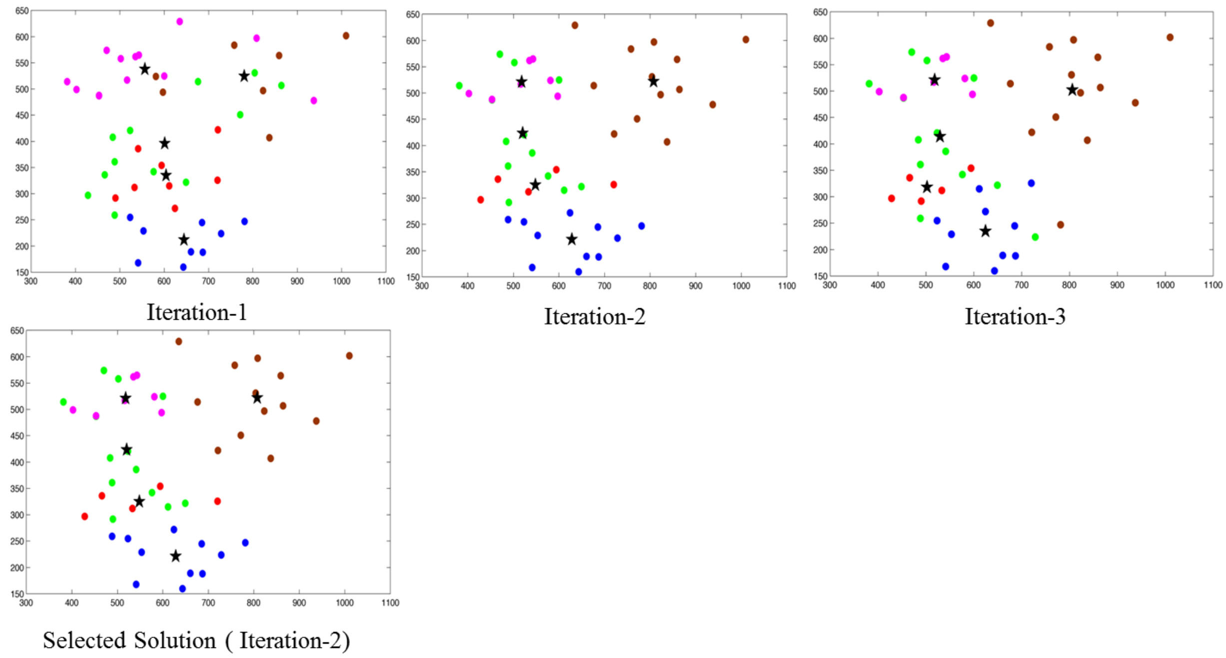


Figure-8: Modified K-means Clustering Algorithm Steps

The complexity of the modified k-means clustering algorithm is calculated and we get $O(n^2 + 3 * n + 14 * d)$, where d represents the number of doctors and n represents the number of villages.

6.4 Routing Algorithm (RA)

The goal of this algorithm is to find a route for each doctor that minimizes total travel distance for each doctor in a month. The inputs of the algorithm are the village to doctor assignments, obtained from the assignment model (AM) or the approximation algorithm (AA) as mentioned before, the coordinates of each village and the frequency value of each village that represents number of visits required. The outputs are the weekly routes for each doctor. Due to all the constraints in our problem, the shortest path routing could not be directly implemented to solve this problem to find the weekly routes of each doctor. Here we will explain our proposed method to solve this problem.

In the schedule, each doctor has 2 work slots per day, 10 slots per week and 40 slots per month in total. The routing algorithm finds a monthly route for each doctor. For the villages the possible monthly frequencies according to the population of villages are 12, 8, 4, 2 and 1. The algorithm locates villages starting from the village with the highest frequency. First, the villages with 12, 8 and 4 frequency values are grouped and placed by following a sequence. The ones with the highest frequency value have priority in the initial placement of the villages into the schedule of the doctors. Therefore, placement starts with the villages with frequency value 12. The frequency value of a village is divided into the number of weeks in a month (4) to find the number of visit slots necessary to be provided for that village in a week of the monthly schedule. For instance, for a village with 12 frequency value, 12/4=3 is the number of consecutive visit slots in a week which is equal to 1 ½ day service time since a doctor has maximum 2 visit slots per day. For the villages with frequency 4, 4/4=1 is the number of consecutive visit slots per week which is equal to a half day service time for that village in a week. For the nodes with frequency larger than 4, there will be visits every week. During the placement of the villages into the schedule, the same schedule is preserved for the same slots of each week in a month for the villages. This helps the patients in those villages to easily remember the visit day of the doctor. The nodes with frequency larger than 4 are placed into the schedule of the doctor following the descending frequency order of nodes. In order to see the example routing of instance-1 for nodes with frequency larger than or equal to 4, check the step 1 of the illustration-1 shown below. The villages with visit frequency 12 are visited 3 slots, with 8 visited 2 slots and with 4 visited 1 sequential slot per week. If there are villages with frequency less than 4, they are scheduled differently because they will not be visited every week. If the frequency is 2, there will be only 2 visits in a month, with duration of 1 slot. This visit also needs to be placed in nonconsecutive weeks within a month, i.e. every other week. This is another problem specific constraint and the reason to have it is to make the intervals between each visit time regular, which is important for patients that need follow-up visits. Therefore, the visits are scheduled for the first and third week or the second and fourth week. The decision between these two options is made based on the nearest neighbor methodology. If the cost of placement of the new village with frequency 2 to the first and third weeks is less than the placement into second and fourth weeks, then it is placed into the first and third weeks otherwise it is placed into the second and fourth weeks. Finally, the villages with frequency one are placed to the visit schedule. For the nodes with frequency one, there will be only one visit within a month. These villages are placed into the schedule based on the distance to the previous village in the schedule. From the remaining villages with frequency one, the one with the smallest distance is selected. See Appendix- 6 for the detailed flow chart of the routing algorithm.

The following illustration shows the steps of an example routing of Instance-1 according to the assignment result obtained from the assignment model (AM) and approximation algorithm (AA) consecutively. In the figures of the illustrations, the weeks are represented with “W-1,-2,-3,-4” and the 5 days of a week are represented by “M, T, W, Th, F” whereas the service slots that is determined as 2 for each day are represented with “M-1, M-2” for the first 4-hour morning slot and second 4-hour evening slot of Monday and similarly for the other days.

Illustration-1: Initial Schedule of Instance-1

Data:

N=25

V=3

Village Set = {1 to 25}

Doctor Set = {V1, V2, V3}

Villages	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Frequencies of villages	12	8	8	8	8	8	8	8	8	8	4	4	4	4	4	4	2	2	2	1	1	1	1	1	1

Table-4: Frequency values of each village, Instance-1

Assignment model (AM) resulting cluster of villages for each doctor:

Nodes assigned to V1 = {3, 8, 9, 10, 15, 19, 23, 24}

Nodes assigned to V2 = {4, 5, 6, 7, 11, 20, 21, 22, 25}

Nodes assigned to V3 = {1, 2, 12, 13, 14, 16, 17, 18}

Visit schedule of the doctors constructed using the assignment of AM:

Resulting schedule for V1;

Place villages with frequency >= 4										
Step-1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	8	8	9	9	10	10	15	
W-2	3	3	8	8	9	9	10	10	15	
W-3	3	3	8	8	9	9	10	10	15	
W-4	3	3	8	8	9	9	10	10	15	
Place villages with frequency = 2										
Step-2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	8	8	9	9	10	10	15	**19**
W-2	3	3	8	8	9	9	10	10	15	
W-3	3	3	8	8	9	9	10	10	15	**19**
W-4	3	3	8	8	9	9	10	10	15	
Place villages with frequency = 1										
Step-3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	8	8	9	9	10	10	15	19
W-2	3	3	8	8	9	9	10	10	15	**23**
W-3	3	3	8	8	9	9	10	10	15	19
W-4	3	3	8	8	9	9	10	10	15	**24**

Resulting schedule for V2, V3;

V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	4	4	5	5	6	6	7	7	11	21
W-2	4	4	5	5	6	6	7	7	11	20
W-3	4	4	5	5	6	6	7	7	11	22
W-4	4	4	5	5	6	6	7	7	11	25
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	2	2	12	13	14	16	17
W-2	1	1	1	2	2	12	13	14	16	18
W-3	1	1	1	2	2	12	13	14	16	17
W-4	1	1	1	2	2	12	13	14	16	18

Approximation algorithm (AA) resulting cluster of villages for each doctor:

Nodes assigned to V1 = {1, 3, 4, 7, 19, 23, 24}

Nodes assigned to V2 = {2, 5, 11, 12, 13, 15, 16, 20, 21, 22, 25}

Nodes assigned to V3 = {6, 8, 9, 10, 14, 17, 18}

Visit schedule of the doctors constructed using the assignment of AA:

For V1;

V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	3	3	4	4	7	7	19
W-2	1	1	1	3	3	4	4	7	7	23
W-3	1	1	1	3	3	4	4	7	7	19
W-4	1	1	1	3	3	4	4	7	7	24

For V2 and V3;

V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	11	12	13	15	16	22
W-2	2	2	5	5	11	12	13	15	16	21
W-3	2	2	5	5	11	12	13	15	16	20
W-4	2	2	5	5	11	12	13	15	16	25
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	6	6	8	8	9	9	10	10	14	17
W-2	6	6	8	8	9	9	10	10	14	18
W-3	6	6	8	8	9	9	10	10	14	17
W-4	6	6	8	8	9	9	10	10	14	18

The complexity of the routing algorithm is calculated and we get $O(d * n)$, where n represents the number of villages and d represents the number of doctors.

6.5 Routing Algorithm Improvement-1 (RAI-1)

This improvement algorithm enhances the initial routing constructed by the routing algorithm. In the previous algorithm, we placed the same village to the same day of each week in the schedule to satisfy the constraint. In this improvement phase, we keep the columns in the schedule, which represent the same day of each week fixed. However, we change the order of the columns to find a routing with smaller cost. The methodology is similar with traveling salesman problem since the algorithm generates a route between columns and each column will be visited once. The first and the last villages are the hospital (or depot) location where all the doctors start their weekly shifts. Therefore the routing starts from that hospital and ends there. In this algorithm the columns are thought as nodes and the distance is calculated in between those nodes, or the columns. We find a visit sequence for those columns by minimizing the travel route distance from column to column. The column to column distance is calculated as the sum of distance between each row of column i to the same row of column j. Since there are four rows in a column corresponding to the four weeks of a month, we then sum the distance between each row to obtain the column to column distance. Using these distances, we find a route with minimum total distance.

In this algorithm, the placement of the villages into the same day of the schedule of the doctor in each week is preserved. For instance, if the village is visited in the morning slot of Monday then it is visited the next week at the morning slot of Monday. The traveling salesman problem (TSP) methodology is used to find out the best routing for the doctors.

Genetic Algorithm (GA) is used to find an approximate solution to the TSP. In TSP, the salesman travels a path with smallest distance such that each village is visited exactly once and he returns to the starting village [55] at the end. The GA used to solve TSP creates possible routes, determines best route and mutates the best route to get new possible routes and keeps them if they are better and repeats the process [56] .The stopping criteria may be either reaching a point where the cost does not change any more or stopping when the maximum number of iterations are reached. We used a genetic algorithm that is developed by Joseph Kirk [57] and adapted it to our problem. The GA developed by the author is used in many studies in the literature to solve TSP, see for example [58], [59], [60].

The inputs of the TSP adapted to our problem are the column to column distance matrix and the number of columns. The outputs are the placement of the villages with different frequency values into the monthly schedule of the doctors and the minimum total cost of the routing. See flow chart of the improvement algorithm-1 in Appendix-7. See the illustration-2 for the improved routing-1 result gathered by using the same data used in illustration-1. That routing solution gathered as a result of illustration-1 is used as an initial solution for this algorithm.

Illustration-2: Improved Schedule-1 of Instance-1

Results of improvement algorithm with Assignment model (AM):

Assignment Model Result	Schedule of initial placement										Schedule of Improved Placement-1										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V1**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	8	8	9	9	10	10	15	19	W-1	15	8	8	19	10	10	9	9	3	3
W-2	3	3	8	8	9	9	10	10	15	23	W-2	15	8	8	23	10	10	9	9	3	3
W-3	3	3	8	8	9	9	10	10	15	19	W-3	15	8	8	19	10	10	9	9	3	3
W-4	3	3	8	8	9	9	10	10	15	24	W-4	15	8	8	24	10	10	9	9	3	3
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V2**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	4	4	5	5	6	6	7	7	11	21	W-1	7	7	21	11	5	5	6	6	4	4
W-2	4	4	5	5	6	6	7	7	11	20	W-2	7	7	20	11	5	5	6	6	4	4
W-3	4	4	5	5	6	6	7	7	11	22	W-3	7	7	22	11	5	5	6	6	4	4
W-4	4	4	5	5	6	6	7	7	11	25	W-4	7	7	25	11	5	5	6	6	4	4
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V3**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	2	2	12	13	14	16	17	W-1	1	1	1	12	13	16	2	2	17	14
W-2	1	1	1	2	2	12	13	14	16	18	W-2	1	1	1	12	13	16	2	2	18	14
W-3	1	1	1	2	2	12	13	14	16	17	W-3	1	1	1	12	13	16	2	2	17	14
W-4	1	1	1	2	2	12	13	14	16	18	W-4	1	1	1	12	13	16	2	2	18	14

Results of improvement algorithm with Approximation algorithm (AA):

Approximation algorithm result	Schedule of initial placement										Schedule of Improved Placement-1										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V1**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	3	3	4	4	7	7	19	W-1	7	7	1	1	1	3	3	4	4	19
W-2	1	1	1	3	3	4	4	7	7	23	W-2	7	7	1	1	1	3	3	4	4	23
W-3	1	1	1	3	3	4	4	7	7	19	W-3	7	7	1	1	1	3	3	4	4	19
W-4	1	1	1	3	3	4	4	7	7	24	W-4	7	7	1	1	1	3	3	4	4	24
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V2**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	11	12	13	15	16	22	W-1	12	22	11	13	5	5	15	2	2	16
W-2	2	2	5	5	11	12	13	15	16	21	W-2	12	21	11	13	5	5	15	2	2	16
W-3	2	2	5	5	11	12	13	15	16	20	W-3	12	20	11	13	5	5	15	2	2	16
W-4	2	2	5	5	11	12	13	15	16	25	W-4	12	25	11	13	5	5	15	2	2	16
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V3**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	6	6	8	8	9	9	10	10	14	17	W-1	9	9	10	10	6	6	14	17	8	8
W-2	6	6	8	8	9	9	10	10	14	18	W-2	9	9	10	10	6	6	14	18	8	8
W-3	6	6	8	8	9	9	10	10	14	17	W-3	9	9	10	10	6	6	14	17	8	8
W-4	6	6	8	8	9	9	10	10	14	18	W-4	9	9	10	10	6	6	14	18	8	8

The complexity of the GA of the TSP is calculated and we get $O\ (d * n * 10^6)$ since the complexity of the TSP is $O(n * 10^6)$, where n represents the number of villages, d represents the number of doctors, population size is 100 and the number of iterations is 1000.

6.6 Routing Algorithm Improvement-2 (RAI-2)

In the previous method for placement of the villages in to the schedule, the routing algorithm started the placement from the village with highest frequency. However, the distances between the villages were not considered while the placement was made. To improve this algorithm, we can place into the next empty slot, the nearest village to the currently placed one. This method can provide a better solution in terms of total cost of the route. The algorithm starts with the initial solution obtained by the routing algorithm. In this improvement, for each weekly schedule of a doctor we placed the nearest neighboring village as the next village to visit for a doctor. We also conserved the periodic placement of the same villages to the consecutive service slots in a week depending on the frequency values. The algorithm starts with the placement of the villages with frequency greater than 2. According to the descending sequence of frequencies the first node is selected as the first village in the sequence. Then the nearest village to this village is determined by considering the nearest neighboring methodology. The algorithm continues with the update of remaining node set. The nearest neighboring villages are placed without looking at the descending frequency order of villages. After placement of the villages with frequency greater than 2, the rest of the villages with frequency less than or equal to 2 are placed. The placement method is the same with initial routing placement for these nodes because they were already placed using the nearest neighbor strategy. The villages with frequency 2 are firstly placed then the ones with frequency 1 are placed into the remaining slots by considering the nearest neighboring village methodology. See Appendix-8 for the flow chart of the nearest neighborhood methodology based improvement algorithm.

This improvement continues with the second improvement phase. In that phase, the traveling salesman approach that was explained in the previous improvement section is applied to the resulting improved routing obtained by nearest neighboring methodology. The TSP methodology is applied for all the villages. Then, the final placement of the villages into the schedule is gathered. The final route that is constructed is the route with better cost saving compared to the routing gathered as a result of the nearest neighboring phase of the algorithm. See the illustration-3 for the example routing result for instance-1.

Illustration-3: Improved Schedule-2 of Instance-1

Results of improvement algorithm with Assignment model (AM):

Assignment Model Result	Schedule of initial placement										Schedule of Improved Placement-2										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	9	9	10	10	19	8	8	15	W-1	3	3	8	8	9	9	10	10	15	19
W-2	3	3	9	9	10	10	23	8	8	15	W-2	3	3	8	8	9	9	10	10	15	23
W-3	3	3	9	9	10	10	19	8	8	15	W-3	3	3	8	8	9	9	10	10	15	19
W-4	3	3	9	9	10	10	24	8	8	15	W-4	3	3	8	8	9	9	10	10	15	24
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	7	7	21	11	5	5	6	6	4	4	W-1	4	4	5	5	6	6	7	7	11	21
W-2	7	7	20	11	5	5	6	6	4	4	W-2	4	4	5	5	6	6	7	7	11	20
W-3	7	7	22	11	5	5	6	6	4	4	W-3	4	4	5	5	6	6	7	7	11	22
W-4	7	7	25	11	5	5	6	6	4	4	W-4	4	4	5	5	6	6	7	7	11	25
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	12	13	16	2	2	17	14	W-1	1	1	1	2	2	12	13	14	16	17
W-2	1	1	1	12	13	16	2	2	18	14	W-2	1	1	1	2	2	12	13	14	16	18
W-3	1	1	1	12	13	16	2	2	17	14	W-3	1	1	1	2	2	12	13	14	16	17
W-4	1	1	1	12	13	16	2	2	18	14	W-4	1	1	1	2	2	12	13	14	16	18

Results of improvement algorithm with Approximation algorithm (AA):

Assignment algorithm Result	Schedule of initial placement										Schedule of Improved Placement-2										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	3	3	4	4	7	7	19	W-1	19	4	4	3	3	1	1	1	7	7
W-2	1	1	1	3	3	4	4	7	7	23	W-2	23	4	4	3	3	1	1	1	7	7
W-3	1	1	1	3	3	4	4	7	7	19	W-3	19	4	4	3	3	1	1	1	7	7
W-4	1	1	1	3	3	4	4	7	7	24	W-4	24	4	4	3	3	1	1	1	7	7
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	11	12	13	15	16	22	W-1	12	22	11	13	5	5	15	2	2	16
W-2	2	2	5	5	11	12	13	15	16	21	W-2	12	21	11	13	5	5	15	2	2	16
W-3	2	2	5	5	11	12	13	15	16	20	W-3	12	20	11	13	5	5	15	2	2	16
W-4	2	2	5	5	11	12	13	15	16	25	W-4	12	25	11	13	5	5	15	2	2	16
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	6	6	8	8	9	9	10	10	14	17	W-1	8	8	17	14	6	6	10	10	9	9
W-2	6	6	8	8	9	9	10	10	14	18	W-2	8	8	18	14	6	6	10	10	9	9
W-3	6	6	8	8	9	9	10	10	14	17	W-3	8	8	17	14	6	6	10	10	9	9
W-4	6	6	8	8	9	9	10	10	14	18	W-4	8	8	18	14	6	6	10	10	9	9

The complexity of the routing algorithm improvement 1(RAI-1) is calculated and we get $O((k^2 + n * 10^6) * d)$ since the complexity of the TSP is $O(n * 10^6)$, where n represents the number of villages, d represents the number of doctors, k represents the number of villages with frequency more than 1, population size is 100, number of iterations is 1000.

Chapter 7

Case Study: Burdur Case

7.1 Current Healthcare System of City of Burdur

The family physician system has been applied to Burdur city since 14 July 2008 starting with the pilot applications. In this new system, the mobile healthcare services (MHS) are provided for the people living in rural areas of Burdur city. In Burdur city there are 71 family health units. From those units 47 of them have mobile healthcare services. 71 family physician give service in 32 health centers which are transformed into family health centers from health clinics. In mobile units, 47 family doctors are providing regular service to 182 villages and 11 districts with a total population of 235191 every month. See figure-9 for the districts of Burdur city. The rural to urban population rate is 72.85 %. Due to the large ratio of the rural population size, there is a need for mobile healthcare services for the people living in rural areas.

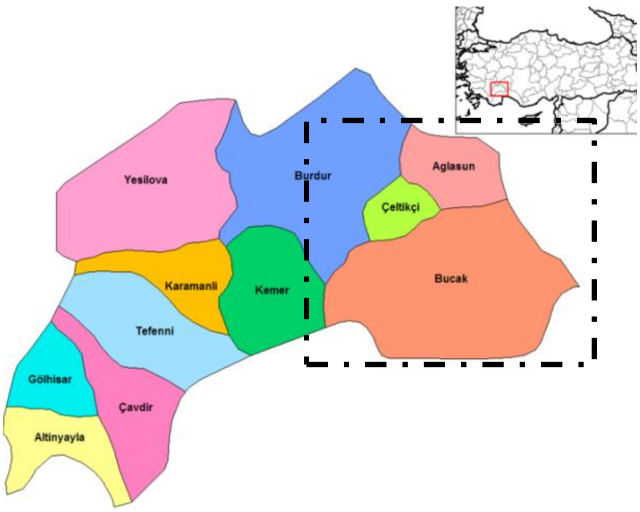


Figure-9: Districts of Burdur City

There are 6 hospitals in total in Burdur city, 32 family health centers, 1 mother and children health center, 1 dental and oral care center and 11 community health centers in total.

See figure-10. Most of these healthcare centers are located at the city center. Also, the service capacities of the hospitals in the city center are limited. Therefore, healthcare service is hard to reach for the people living in rural areas of Burdur city as well as for the people in the urban area. They have to travel to the city center to obtain healthcare services. In conditions like adverse weather conditions and low income, the residents may not have a chance to reach to the hospitals located at the city center. In order to make the healthcare services easy to reach for the people living in rural areas, mobile healthcare services are provided to rural areas.

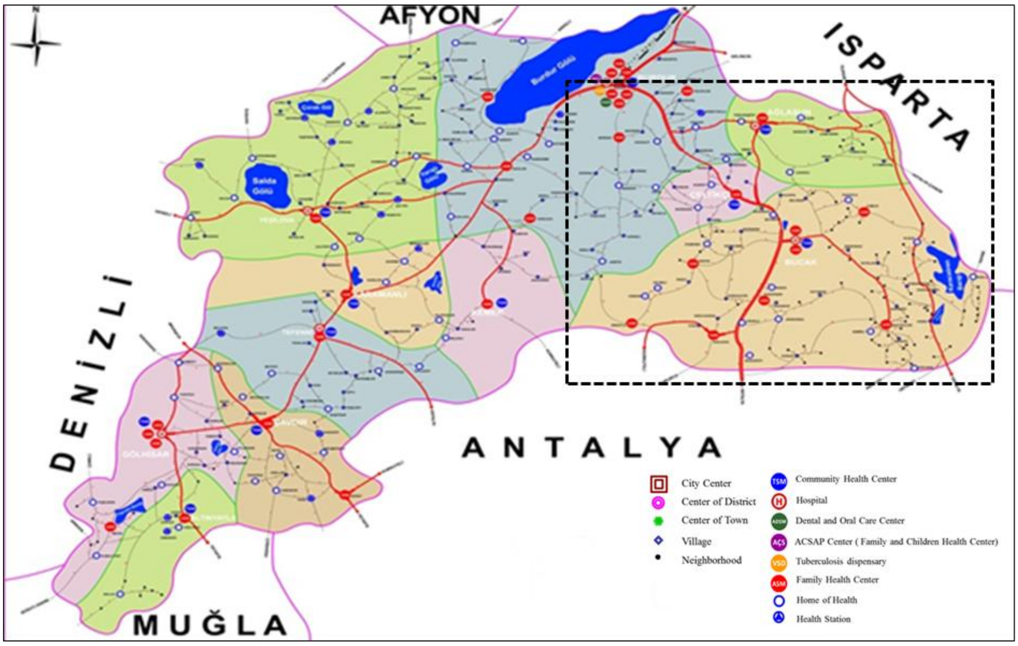


Figure-10: Healthcare Centers in Burdur city

7.2 Construction of Cost Effective Service Schedules for Family Physicians

According to the Ministry of Health's regulations the new system has certain specifications. The same doctor should provide healthcare service to the same village at same days of each week according to the regulations. Therefore, there is a need for an effective schedule for each doctor that will provide healthcare services to the villages that are assigned to him/her. Therefore, we aimed to find a schedule for family physicians that will provide an efficient use of their time while satisfying certain restrictions. This schedule will minimize the total distance traveled by a doctor in a month under certain problem specific constraints.

According to the population sizes of the villages, the equivalent minimum service time requirement is available in the legislation provisions. See table-5 for minimum service requirements according to population sizes. For instance, if the population of a village is less than 200 then the minimum service time required for that village is 4 hours per month. Another requirement of MHS schedule is that a doctor should visit the same village at the same day of a week each time. This is only true for the villages that are crowded enough to require a visit frequency of more than once per month. To satisfy this requirement, we assumed that each visit to a village occurs at a fix day for each week. The service time for each visit is equal to 4 hours (half day). Some villages may require more than 4-hour service time, in those conditions the required visit frequencies are determined from table-6 obtained from the legislation provisions [14].

Population	**Minimum time requirement for one month service**
< 200	4 hour
201 – 500	8 hour
501 – 1000	16 hour
1001 - 1500	32 hour
>1501	48 hour

Table-5: Minimum Service Requirements

As we mentioned before, every family physician has a service area in the current system. The service area of the family physician is the service region of the family health center in which the physician is located. For instance, the mobile healthcare service area of the Family Health Center (coded as 15-05-50) was determined to be Kozagac, Anbarcik and Karakoy villages. The population sizes in those villages are;

- Population of Kozagac village: 1160
- Population of Anbarcik village: 593
- Population of Karakoy village: 309

The family physician that is in charge of those districts must provide mobile health service with the following time lengths calculated from the tables:

Kozagac village: 32-hours in a month (two half days in each week or one full day in each week).

Anbarcik village: 16-hours in a month (one half day in each week or one full day every two weeks)

Karakoy village: 8-hours in a month (one half day every two weeks or one full day in a month) [14].

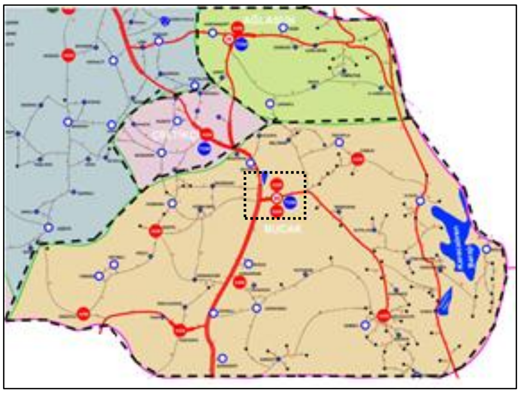
Since the family physicians have 8-hours of work duration per day, we assumed that in every visit they provide 4-hour service to a village. Under this assumption Kozagac village should be visited 8 times, Anbarcik 4 times and Karakoy 2 times in a month. See table-5 for a summary of the corresponding visit frequencies of the villages according to their population size.

Minimum time requirement for monthly service	**Visit Frequency**
4 hour (1/2 day)	1
8 hour (1/2 day biweekly or 1 full day in 1 month)	2
16 hour (1/2 day in a week or 1 full day every couple of weeks)	4
32 hour (1 day in a week)	8
48 hour(one and a half day in a week)	12

Table-6: Visit Frequencies and Service Requirements

As shown in figure-10, we restricted our study to three districts placed at the eastern part of Burdur city, which are Aglasun, Celtikci and Bucak. The real coordinates of the villages in those districts of Burdur city is gathered from Google Map and the village-to-village distances are calculated using shortest path distances.

Currently, there are 10 family health centers, two hospitals and three community health centers in Aglasun, Bucak and Celtikci districts in total. See figure-11. However, the service provided to the people in those districts is restricted. The main reason for this is the capacity restriction in terms of number of doctors and health workers that gives service to the residents of that region. To solve this problem, the Ministry of Health provides mobile healthcare services to the villages which are located far from the hospitals in the city centers. Since the doctors provide service 8 hours per day, they need an efficient schedule to help them satisfy all the required service frequencies of the people in those villages while minimizing their monthly travel distance under the restrictions that we described above.



(Hospital - depot: Red circled with "H", Villages: Black points)

Figure-11: Healthcare Centers in Aglasun, Celtikci and Bucak districts

There are 49 villages in total in the districts that are considered. See figure-12 for the locations of the 49 villages in those districts. We considered the hospital in Bucak district as the depot where the family physicians are located which is marked in figure-12. See Appendix-1 for the coordinates of the villages considered and the depot hospital. The mobile healthcare service vehicles with the physicians start their weekly tour from the hospital located in the center of Bucak district and return to this depot after completing 40-hour visit time for a week. They give service 5 days of the week and make 2 visits within their work duration of 2 slots (8 hours) per day which makes 10 visit slots in total for a week and 40 visit slots for a month.

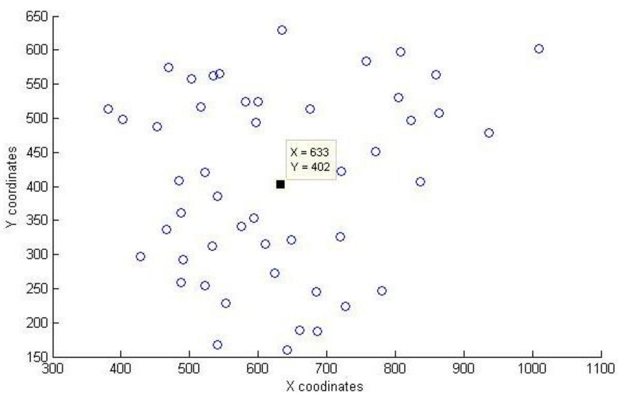


Figure-12: Location of 49 Villages in the Districts

As we mentioned in the solution methodology section, in the first step of our solution methodology we assigned the villages, which will acquire mobile healthcare service, to the family physicians, who will provide those services, using two alternative methods: assignment model (AM) and the approximation algorithm (AA). The frequencies of those villages were calculated using table-6. See Appendix-3 for the populations and frequencies of 49 villages. The frequencies and the coordinates of the villages are taken as input to the assignment model (AM) and to the approximation algorithm (AA). The assignment model and approximation algorithm provides assignments for each doctor and village as can be seen in table-6 for 5 doctors. The first model (AM) finds the optimal assignment, however it is computationally expensive to run it over 49 villages. It had a running time of 1528 minute (~ 25 hours) in Gurobi 4.5.2. The optimality gap decreased from 49.10% to 37% within the first 22.5 hours whereas the incumbent solution did not change during that time which was 41609. The second method is an approximate solution and takes a few minutes to run. As shown in table-7, the results of the assignment model and approximation algorithm are different. See figure-13 for the illustration of clusters of villages for V1.

	Assignment Model
V1	1,3,5,16,17,27,28,29,32
V2	2,4,30,42,43,44,45,46,47,48,49
V3	7,9,10,11,15,18,19,20,24,25
V4	8,13,26,35,36,37,38,39,40,41
V5	6,12,14,21,22,23,31,33,34

Approximation Algorithm	
V1	27,29,34,39,40
V2	1,2,3,7,12,20,22,25,31,32,33,35,36
V3	37,38,41,42,43,44,45,46,7,48,49
V4	5,11,13,16,21,28,30
V5	4,6,8,9,10,14,15,17,18,19,23,24,26

Table-7: Results of AA & AM

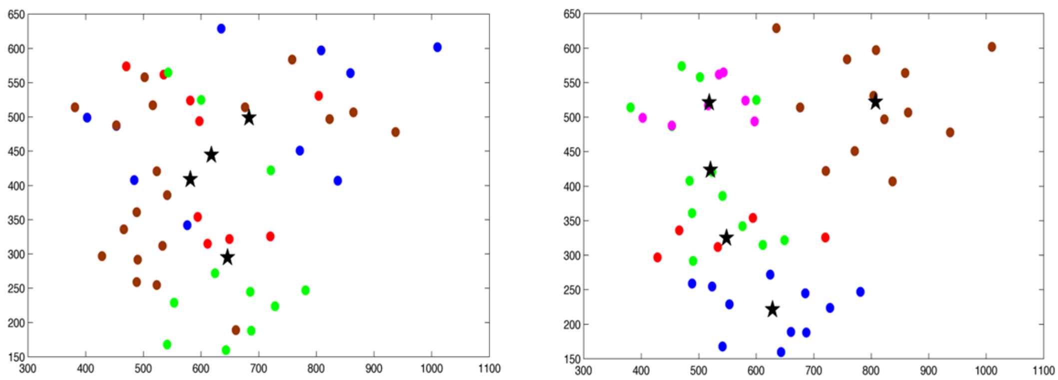


Figure-13: Cluster of Villages for AA & AM

After assigning the villages to the doctors, the schedule for each doctor was determined. To do this, the routing algorithm we designed was applied on the set of villages for each doctor. This algorithm generated the weekly schedule for each doctor. We also ran the improvement algorithm as described before. This algorithm provided a more cost efficient schedule for each doctor improving the solution of the initial routing algorithm. The initial schedule and the improved schedule results are shown in figure-14 when the improvement step was carried out with improvement-1 algorithm. It can be realized that the weekly visit sequence for the villages changed in order to find the minimum cost weekly route in the improvement algorithm. Moreover, the requirement to visit the villages at the same slot of each week is preserved.

For this problem, the minimum number of doctors that was necessary to cover all the visit requirements was determined by checking the total visit requirement of all villages that are considered. Since the total visit frequency that is required for the chosen districts are 187, the required number of doctors was calculated as $\lceil 187/40 \rceil$ =5 to satisfy all of the required visits of the villages by the algorithm. In figure-14, the weeks are represented with “W” and the days of a week are represented by “M, T, W, Th, F” whereas the service slots that is determined as 2 for each day are represented with “M-1, M-2” etc. for the first and second slots of Monday. By checking figure-14, it can be realized that there are some zero values which represent the times that the doctors spent at the places which they last visited. If the zero valued nodes are located at the last days of the week like the second slot of Friday, then the family physician returns to the depot hospital early in that week. For an instance see the routing of the first doctor (V1) with the improved schedule in figure-14. The initial placement is made by using routing algorithm (RA) and the improved algorithm-1 (RAI-1) is used as an improvement in figure-14. The zero valued nodes in between visits that mean the doctor stays at the lastly visited village to shorten the total distance traveled. For an instance, see the improved routing-1 of the third doctor (V3) in figure-14.

Assignment Model Result	Schedule of initial placement										Schedule of Improved Placement-1										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V1**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	5	5	16	16	28	28	27	29	1	3	W-1	28	28	16	16	5	5	1	27	29	3
W-2	5	5	16	16	28	28	27	29	32	17	W-2	28	28	16	16	5	5	32	27	29	17
W-3	5	5	16	16	28	28	27	29	1	0	W-3	28	28	16	16	5	5	1	27	29	0
W-4	5	5	16	16	28	28	27	29	32	0	W-4	28	28	16	16	5	5	32	27	29	0
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V2**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	42	42	42	49	49	30	46	2	44	45	W-1	49	49	44	46	42	42	42	45	2	30
W-2	42	42	42	49	49	30	46	4	43	47	W-2	49	49	43	46	42	42	42	47	4	30
W-3	42	42	42	49	49	30	46	2	44	45	W-3	49	49	44	46	42	42	42	45	2	30
W-4	42	42	42	49	49	30	46	4	43	48	W-4	49	49	43	46	42	42	42	48	4	30
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V3**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	24	24	25	25	10	11	18	15	20	7	W-1	7	25	25	11	20	15	18	24	24	10
W-2	24	24	25	25	10	11	18	19	9	0	W-2	0	25	25	11	9	19	18	24	24	10
W-3	24	24	25	25	10	11	18	15	20	0	W-3	0	25	25	11	20	15	18	24	24	10
W-4	24	24	25	25	10	11	18	19	0	0	W-4	0	25	25	11	0	19	18	24	24	10
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V4**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	40	40	40	39	39	8	13	35	36	41	W-1	8	13	40	40	40	39	39	35	36	41
W-2	40	40	40	39	39	8	13	35	37	38	W-2	8	13	40	40	40	39	39	35	37	38
W-3	40	40	40	39	39	8	13	35	36	41	W-3	8	13	40	40	40	39	39	35	36	41
W-4	40	40	40	39	39	8	13	35	37	26	W-4	8	13	40	40	40	39	39	35	37	26
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V5**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	34	34	34	6	12	21	22	33	14	0	W-1	14	6	22	21	33	12	34	34	34	0
W-2	34	34	34	6	12	21	23	31	0	0	W-2	0	6	23	21	31	12	34	34	34	0
W-3	34	34	34	6	12	21	22	33	0	0	W-3	0	6	22	21	33	12	34	34	34	0
W-4	34	34	34	6	12	21	23	31	0	0	W-4	0	6	23	21	31	12	34	34	34	0

Figure-14: Initial (RA) and Improved Schedule-1(RAI-1) obtained by AM

The improved routes of the doctors according to improvement algorithm-1 for each week of their monthly schedule are presented in the following figures. For instance as can be seen from figure-18, the route of the doctor is same in the 1st and 3rd weeks of the schedule for the second doctor (V1). Moreover, the figure – 15, 16, 17, 18 and 19 shows the weekly routes for all 5 doctor in their initial and improved monthly schedules.

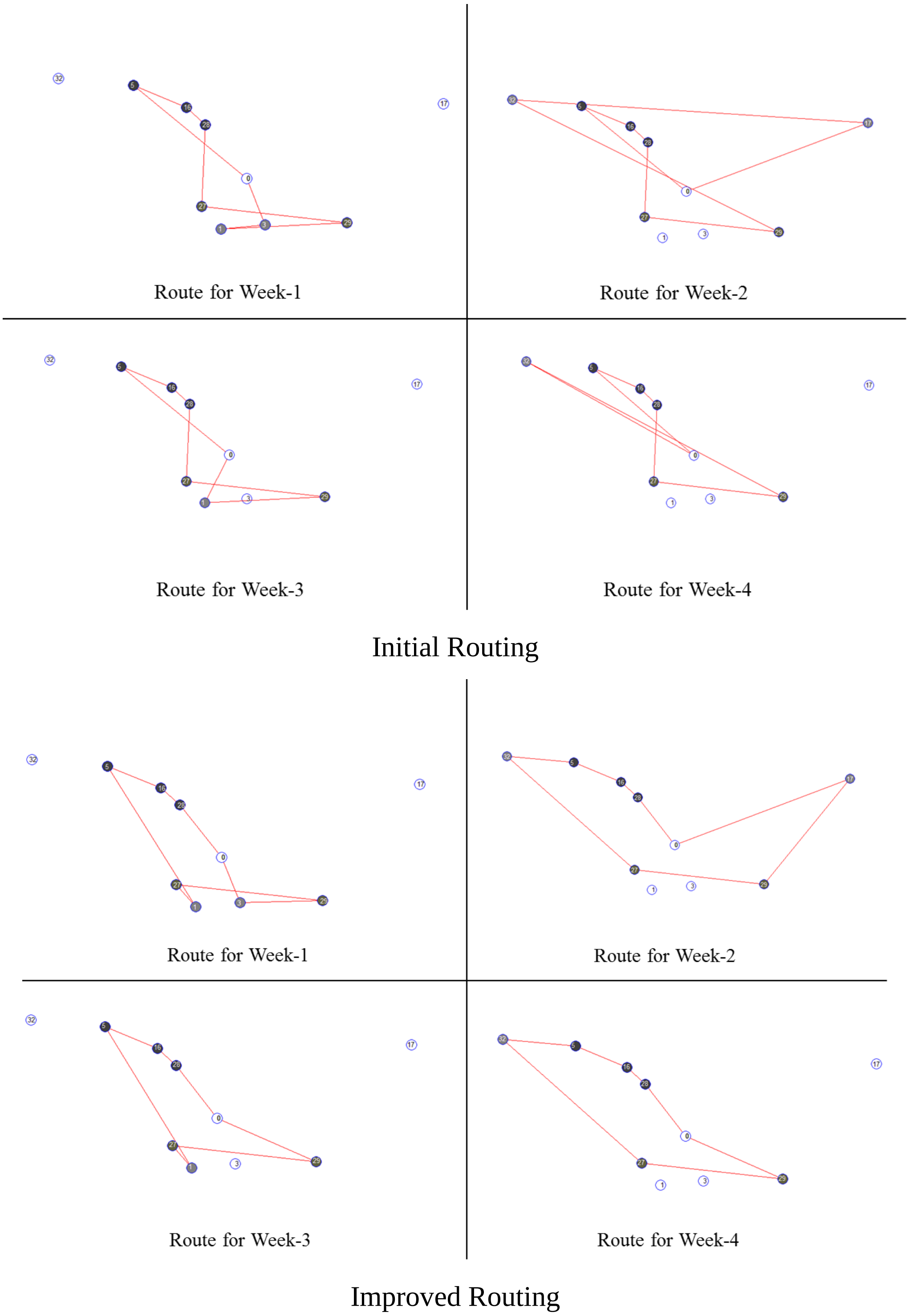
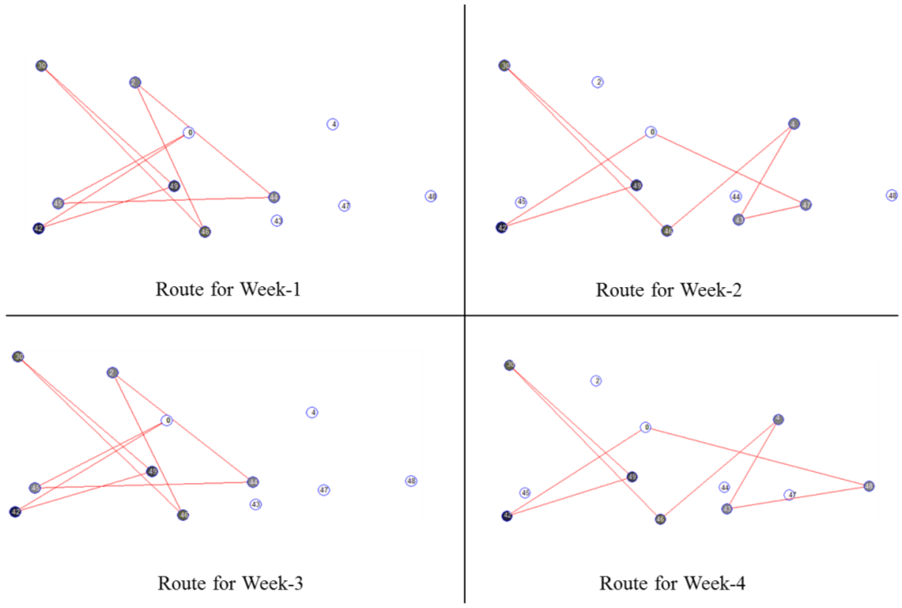
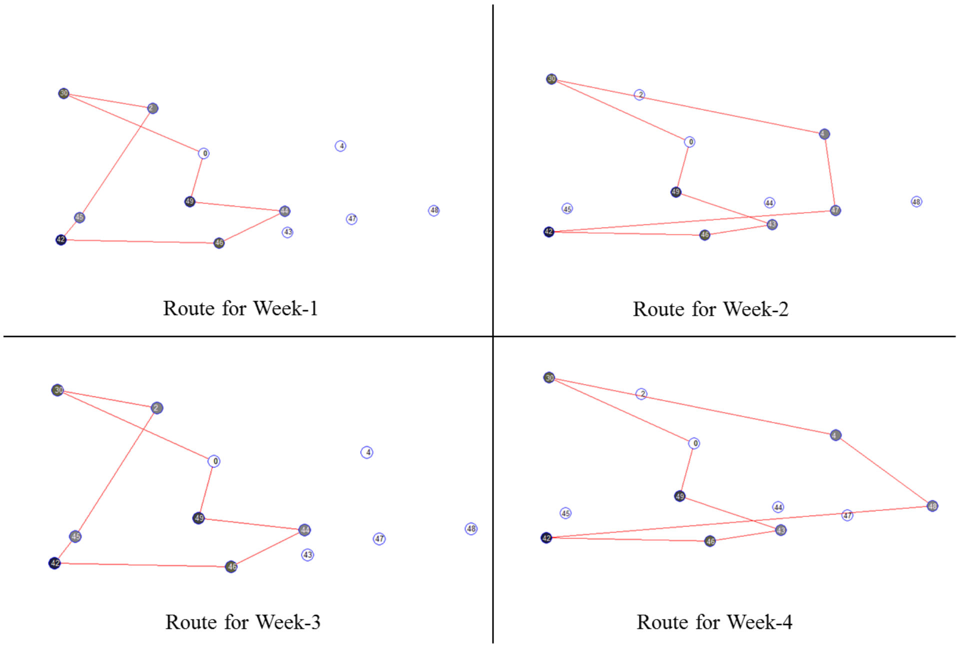


Figure-15: Initial &Improved Route-1 for doctor-1 (V1)

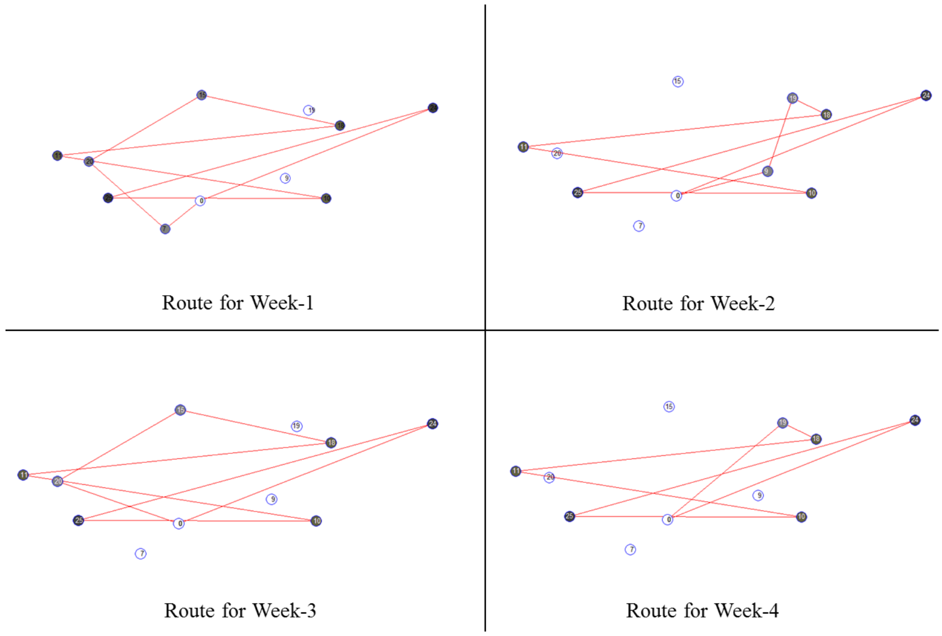


Initial Routing

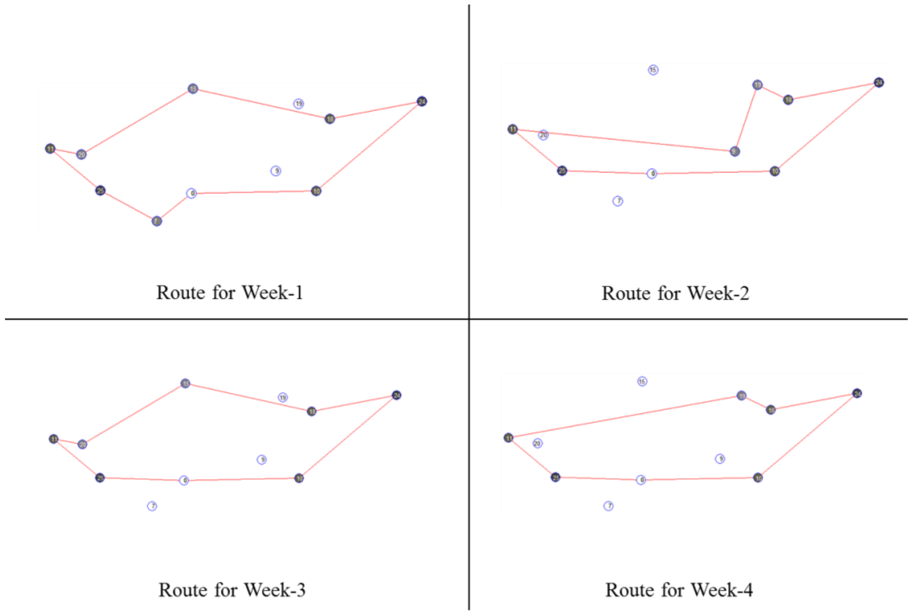


Improved Routing

Figure-16: Initial &Improved Route-1 for doctor-2 (V2)

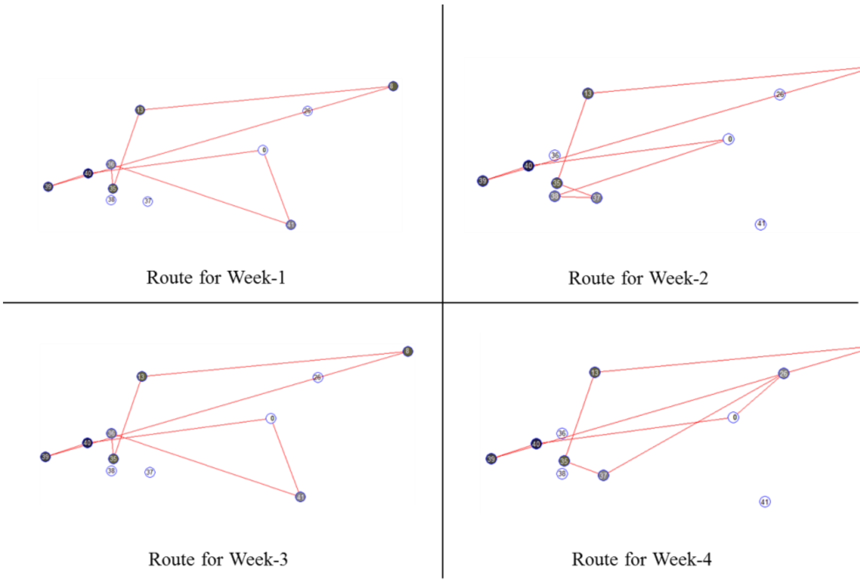


Initial Routing

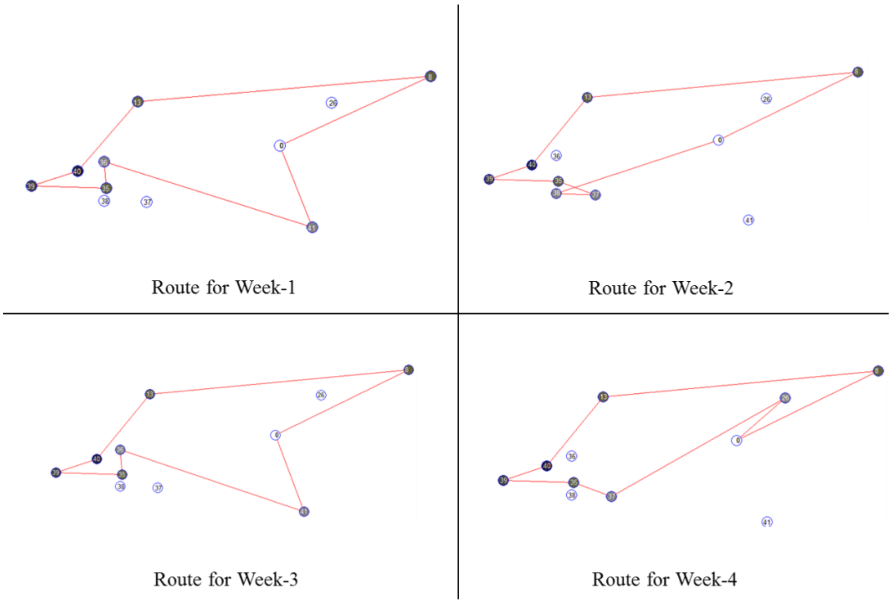


Improved Routing

Figure-17: Initial &Improved Route-1 for doctor-3 (V3)

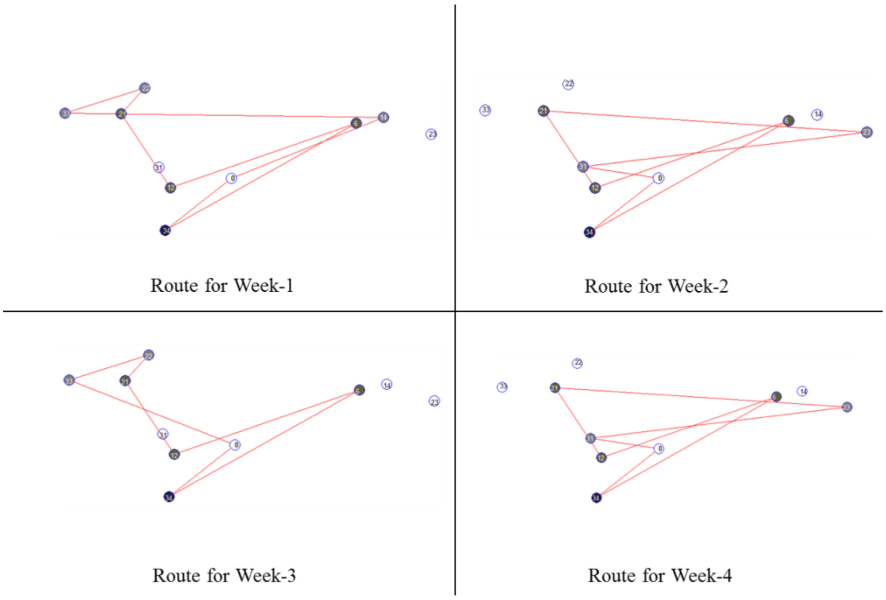


Initial Routing

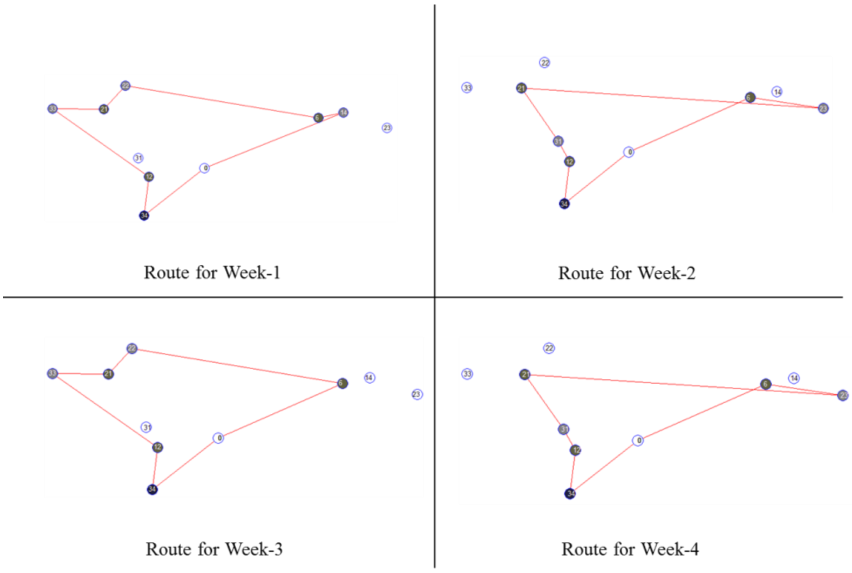


Improved Routing

Figure-18: Initial &Improved Route-1 for doctor-4 (V4)



Initial Routing



Improved Routing

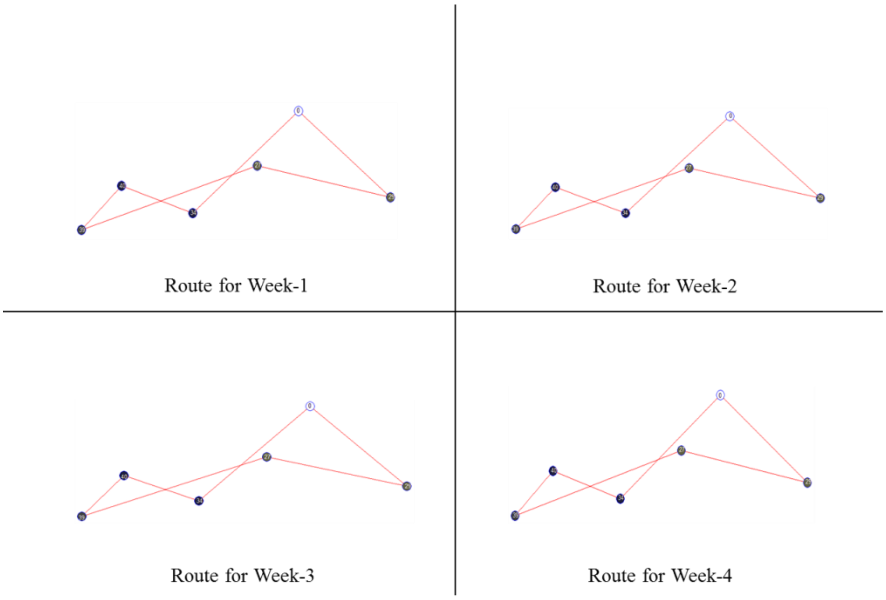
Figure-19: Initial &Improved Route-1 for doctor- 5 (V5)

As we described in the previous chapters, in order to get the solution of the assignment problem within less CPU time, an approximation algorithm was used as an alternative solution approach to the assignment problem. The output of the approximation algorithm was also the group of villages assigned to each doctor. After applying this approximate assignment algorithm, we applied the same routing algorithm as before and obtained the weekly schedules for each doctor. After this initial routing, the improvement algorithm was also used to decrease the total traveled distance of the doctors. The initial schedule and the improved schedule results obtained using the assignment solution from the approximation algorithm is shown in figure-20. Again, we preserved the requirement to visit the villages at the same slot each week.

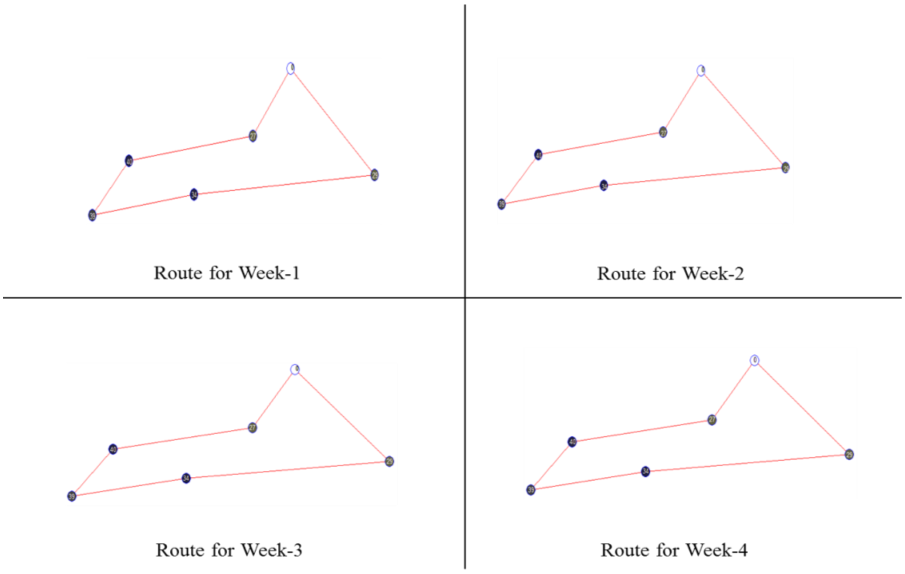
Approximation algorithm result	Schedule of initial placement										Schedule of Improved Placement-1										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	34	34	34	40	40	40	39	39	27	29	W-1	29	34	34	34	39	39	40	40	40	27
W-2	34	34	34	40	40	40	39	39	27	29	W-2	29	34	34	34	39	39	40	40	40	27
W-3	34	34	34	40	40	40	39	39	27	29	W-3	29	34	34	34	39	39	40	40	40	27
W-4	34	34	34	40	40	40	39	39	27	29	W-4	29	34	34	34	39	39	40	40	40	27
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	25	25	12	35	1	36	31	20	7	3	W-1	3	1	36	31	20	25	25	35	12	7
W-2	25	25	12	35	2	22	32	33	0	0	W-2	0	2	22	32	33	25	25	35	12	0
W-3	25	25	12	35	1	36	31	20	0	0	W-3	0	1	36	31	20	25	25	35	12	0
W-4	25	25	12	35	2	22	32	33	0	0	W-4	0	2	22	32	33	25	25	35	12	0
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	42	42	42	49	49	46	37	45	44	47	W-1	47	44	46	42	42	42	37	45	49	49
W-2	42	42	42	49	49	46	41	43	48	38	W-2	38	48	46	42	42	42	41	43	49	49
W-3	42	42	42	49	49	46	37	45	44	0	W-3	0	44	46	42	42	42	37	45	49	49
W-4	42	42	42	49	49	46	41	43	0	0	W-4	0	0	46	42	42	42	41	43	49	49
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	5	5	16	16	28	28	11	13	21	30	W-1	28	28	16	16	30	5	5	13	11	21
W-2	5	5	16	16	28	28	11	13	21	30	W-2	28	28	16	16	30	5	5	13	11	21
W-3	5	5	16	16	28	28	11	13	21	30	W-3	28	28	16	16	30	5	5	13	11	21
W-4	5	5	16	16	28	28	11	13	21	30	W-4	28	28	16	16	30	5	5	13	11	21
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	24	24	6	8	10	18	4	19	17	14	W-1	14	17	10	6	18	24	24	19	8	4
W-2	24	24	6	8	10	18	15	23	9	26	W-2	26	9	10	6	18	24	24	23	8	15
W-3	24	24	6	8	10	18	4	19	0	0	W-3	0	0	10	6	18	24	24	19	8	4
W-4	24	24	6	8	10	18	15	23	0	0	W-4	0	0	10	6	18	24	24	23	8	15

Figure-20: Initial and Improved Schedule-1 obtained by AA

The improved routes of the 5 doctors are presented consecutively in the figures – 21, 22, 23, 24 and 25 with the weekly representation of the routes in a monthly schedule.

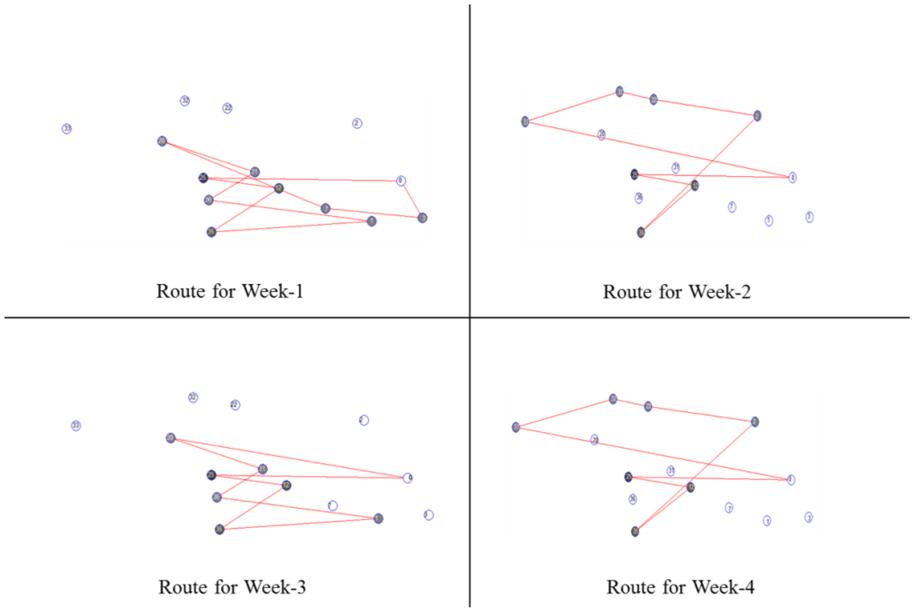


Initial Route

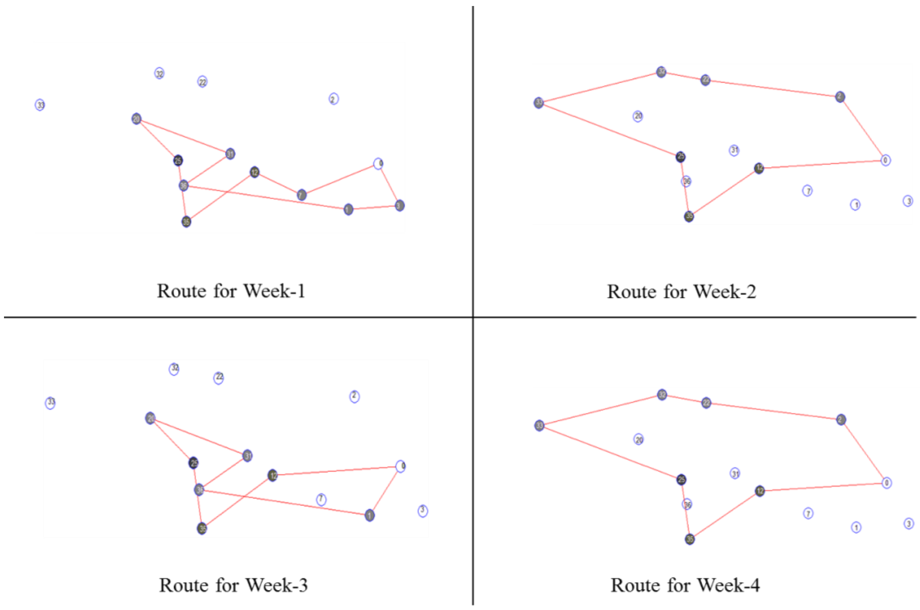


Improved Route

Figure-21: Initial & Improved Route-1 for doctor- 1 (V1)

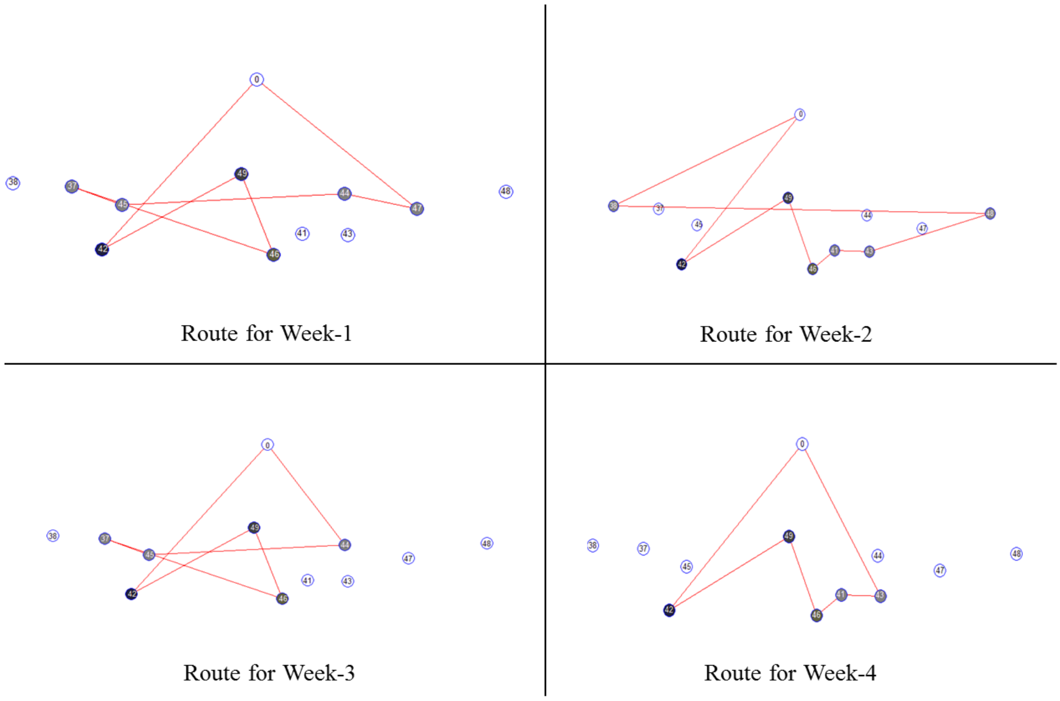


Initial Route

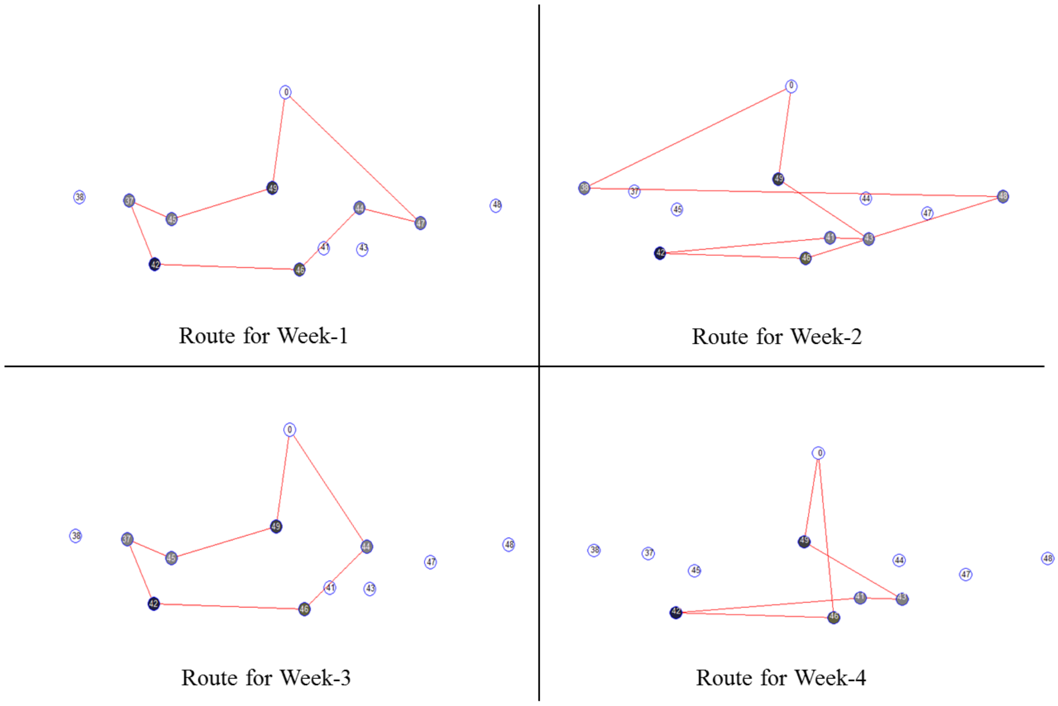


Improved Route

Figure-22: Initial & Improved Route-1 for doctor- 2 (V2)



Initial Route



Improved Route

Figure-23: Initial & Improved Route-1 for doctor- 3 (V3)

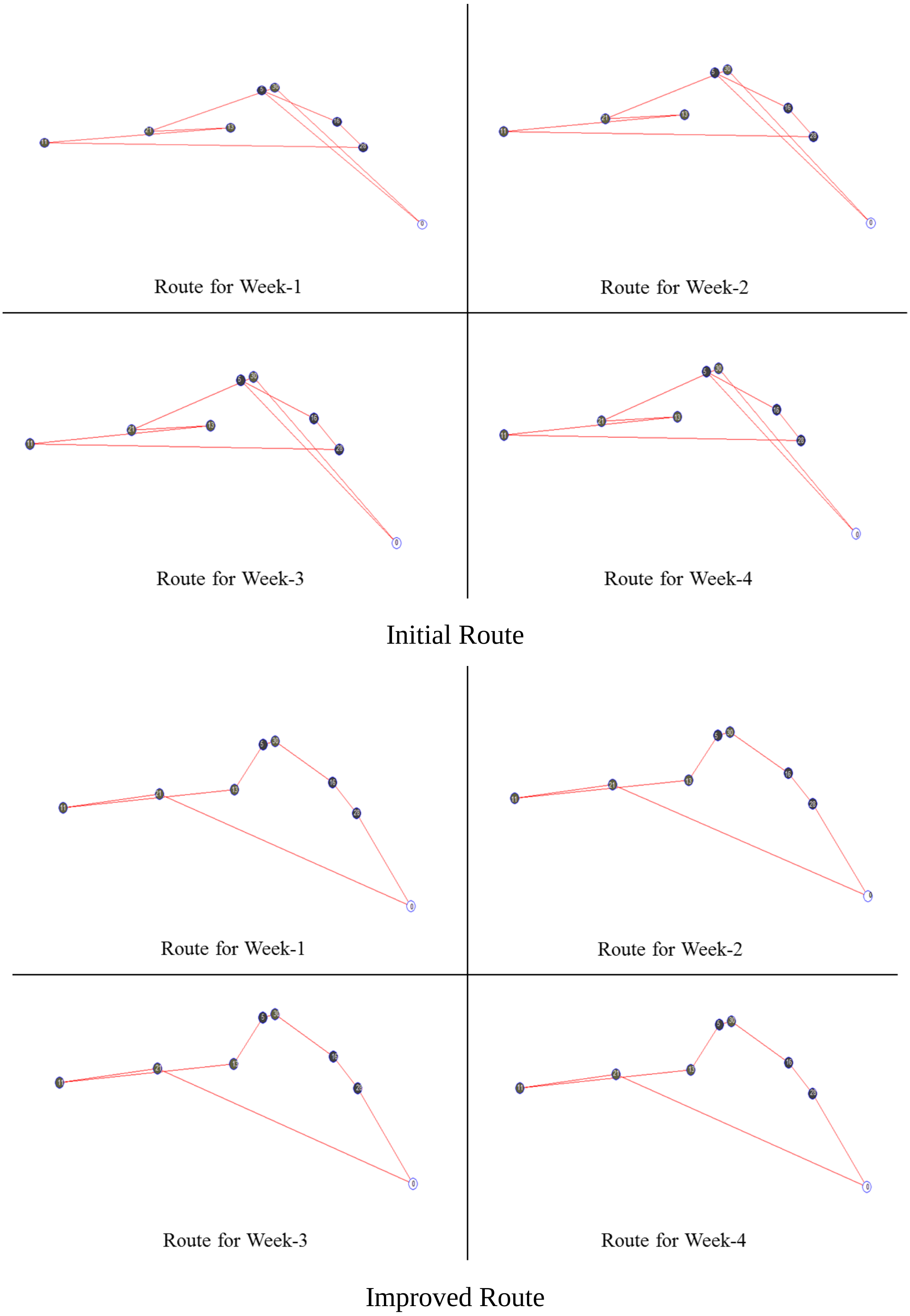
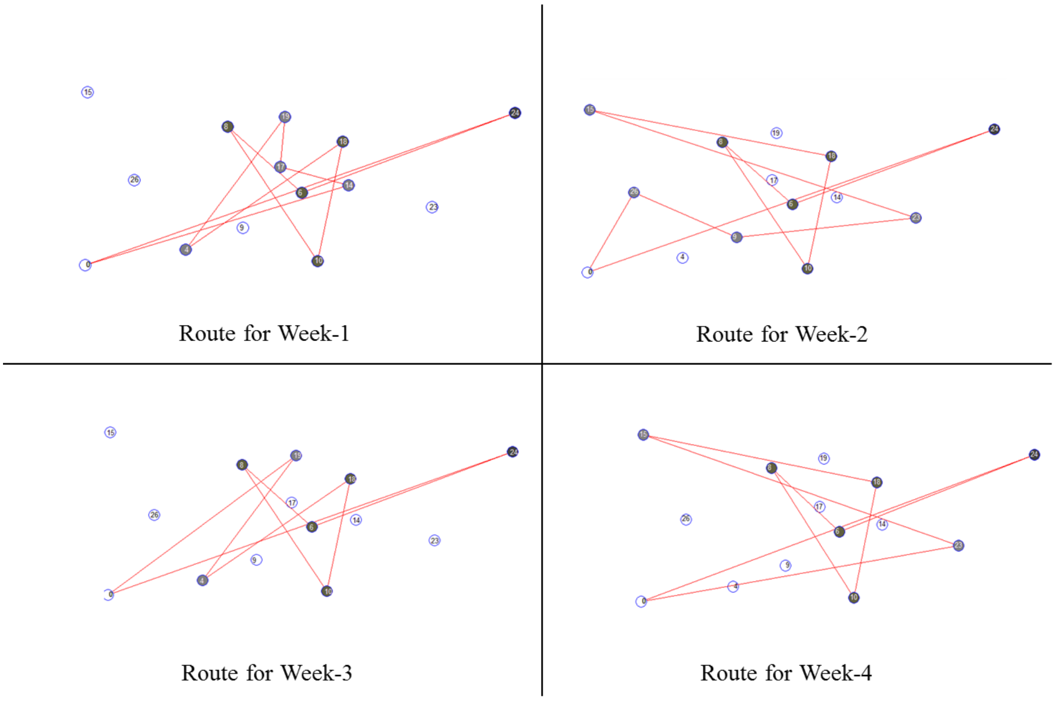
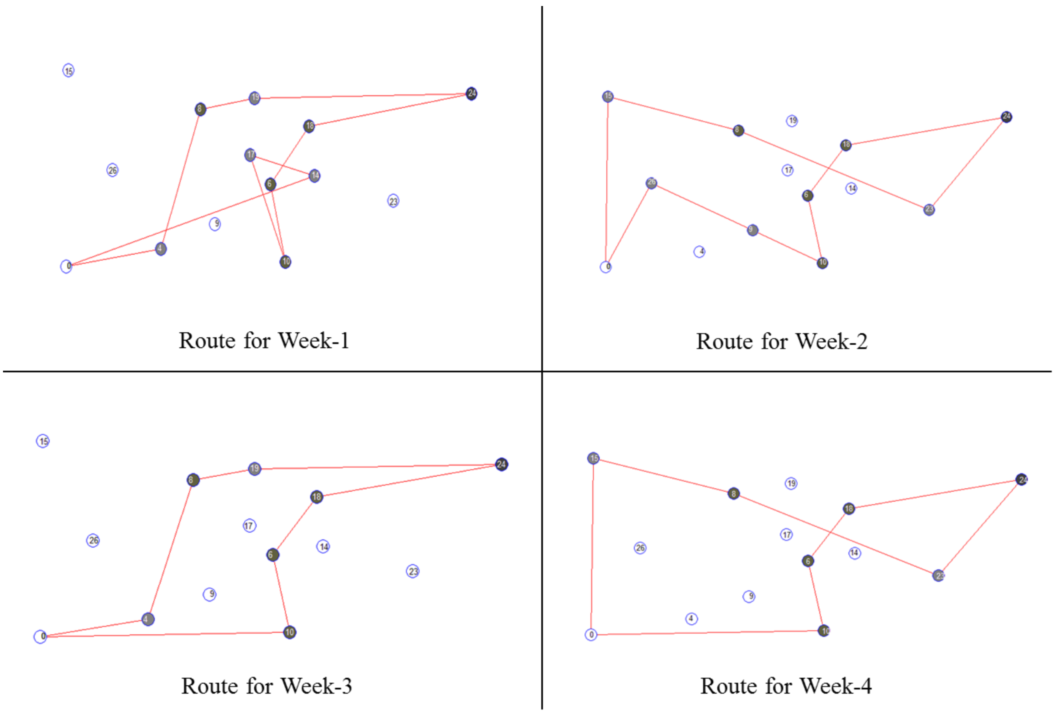


Figure-24: Initial & Improved Route-1 for doctor- 4 (V4)



Initial Route



Improved Route

Figure-25: Initial & Improved Route-1 for doctor- 5 (V5)

Besides the improvement algorithm-1, as mentioned in the solution methodology chapter, another algorithm called improvement algorithm-2 (RAI-2) was applied to get better routing cost improvement for the family physicians. The algorithm was constructed and the routes were obtained by running the algorithm on the results of both the optimal assignment model and the approximation algorithm. The initial routes are the same with the initial routes that were used in improvement algorithm-1 (again gathered by using RA). See figure-26 and figure-32 for the resulting routes of the improvement algorithm-2 after application of assignment model and approximation algorithm respectively.

Assignment Model Result	Schedule of initial placement										Schedule of Improved Placement-2										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	5	5	16	16	28	28	27	29	1	3	W-1	3	29	27	1	5	5	16	16	28	28
W-2	5	5	16	16	28	28	27	29	32	17	W-2	17	29	27	32	5	5	16	16	28	28
W-3	5	5	16	16	28	28	27	29	1	0	W-3	0	29	27	1	5	5	16	16	28	28
W-4	5	5	16	16	28	28	27	29	32	0	W-4	0	29	27	32	5	5	16	16	28	28
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	42	42	42	49	49	30	46	2	44	45	W-1	49	49	44	46	42	42	42	45	2	30
W-2	42	42	42	49	49	30	46	4	43	47	W-2	49	49	43	46	42	42	42	47	4	30
W-3	42	42	42	49	49	30	46	2	44	45	W-3	49	49	44	46	42	42	42	45	2	30
W-4	42	42	42	49	49	30	46	4	43	48	W-4	49	49	43	46	42	42	42	48	4	30
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	24	24	25	25	10	11	18	15	20	7	W-1	10	24	24	18	15	20	11	25	25	7
W-2	24	24	25	25	10	11	18	19	9	0	W-2	10	24	24	18	19	9	11	25	25	0
W-3	24	24	25	25	10	11	18	15	20	0	W-3	10	24	24	18	15	20	11	25	25	0
W-4	24	24	25	25	10	11	18	19	0	0	W-4	10	24	24	18	19	0	11	25	25	0
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	40	40	40	39	39	8	13	35	36	41	W-1	8	13	40	40	40	39	39	35	36	41
W-2	40	40	40	39	39	8	13	35	37	38	W-2	8	13	40	40	40	39	39	35	37	38
W-3	40	40	40	39	39	8	13	35	36	41	W-3	8	13	40	40	40	39	39	35	36	41
W-4	40	40	40	39	39	8	13	35	37	26	W-4	8	13	40	40	40	39	39	35	37	26
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	34	34	34	6	12	21	22	33	14	0	W-1	0	34	34	34	12	33	21	22	6	14
W-2	34	34	34	6	12	21	23	31	0	0	W-2	0	34	34	34	12	31	21	23	6	0
W-3	34	34	34	6	12	21	22	33	0	0	W-3	0	34	34	34	12	33	21	22	6	0
W-4	34	34	34	6	12	21	23	31	0	0	W-4	0	34	34	34	12	31	21	23	6	0

Figure-26: Initial and Improved Schedule-2 obtained by AM

The improved routes of the 5 doctors obtained using AM are presented consecutively in the figures – 27, 28, 29, 30 and 31 with the weekly representation of the routes in a monthly schedule.

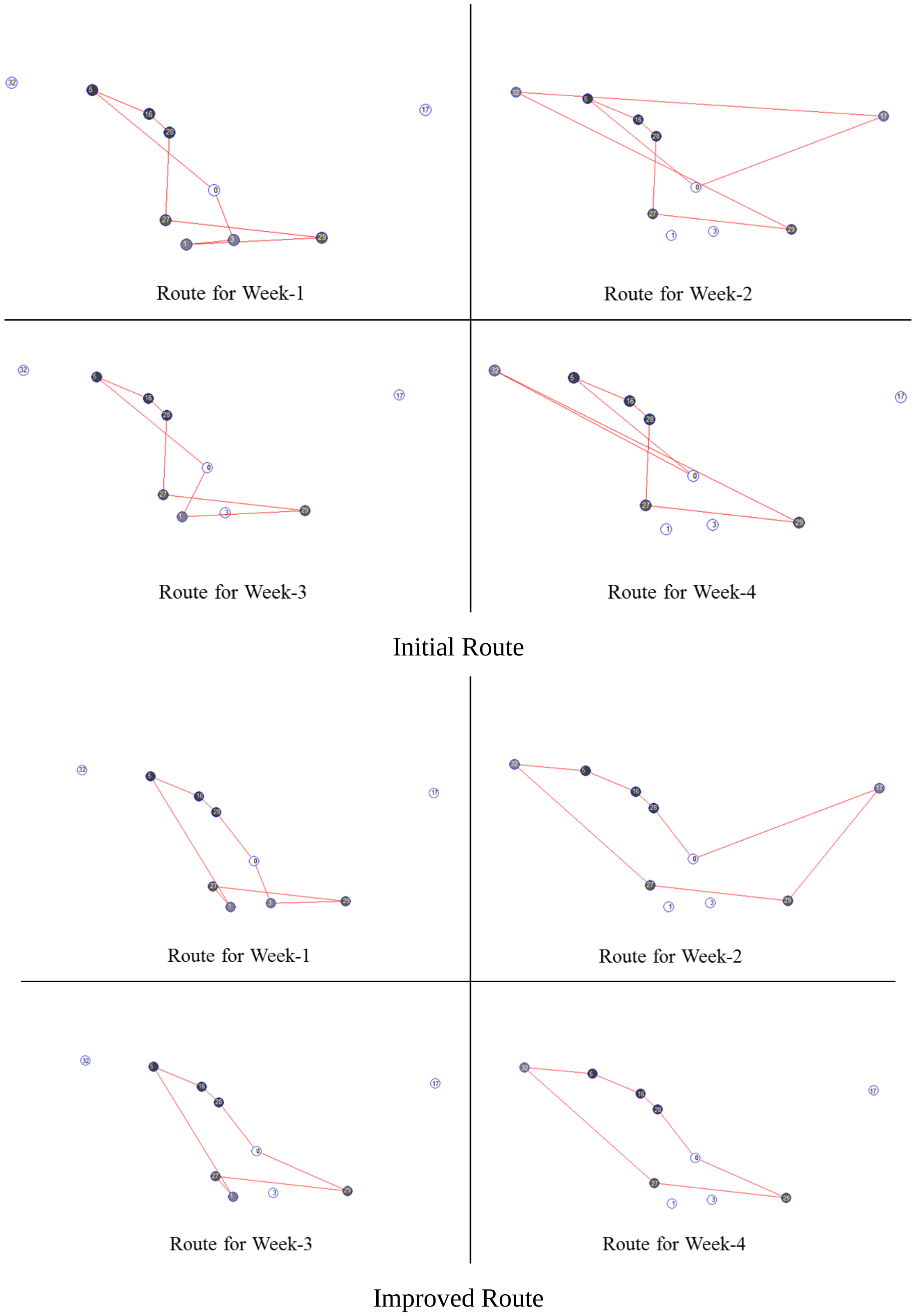
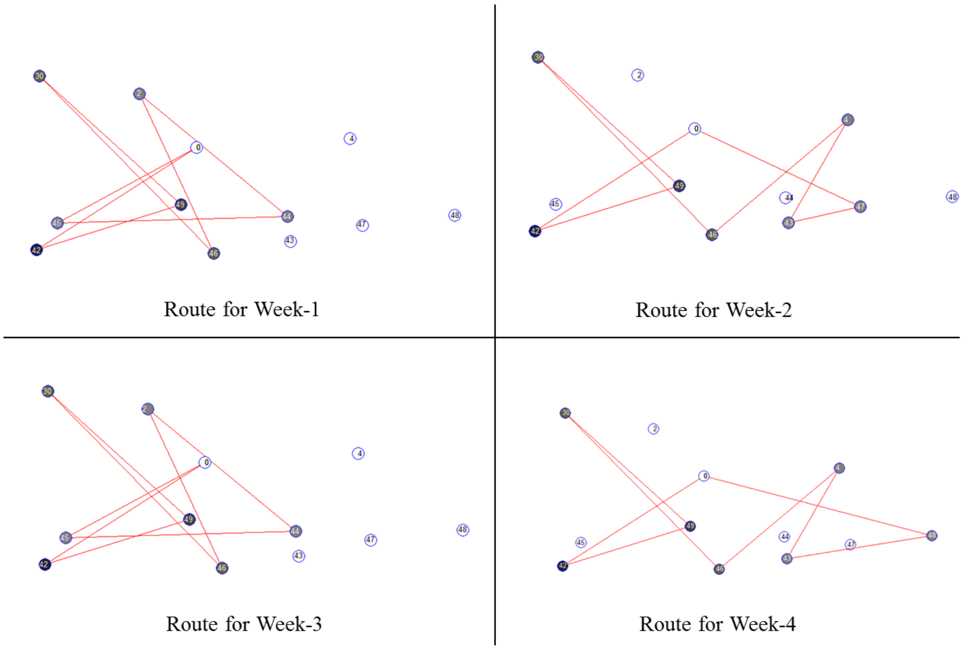
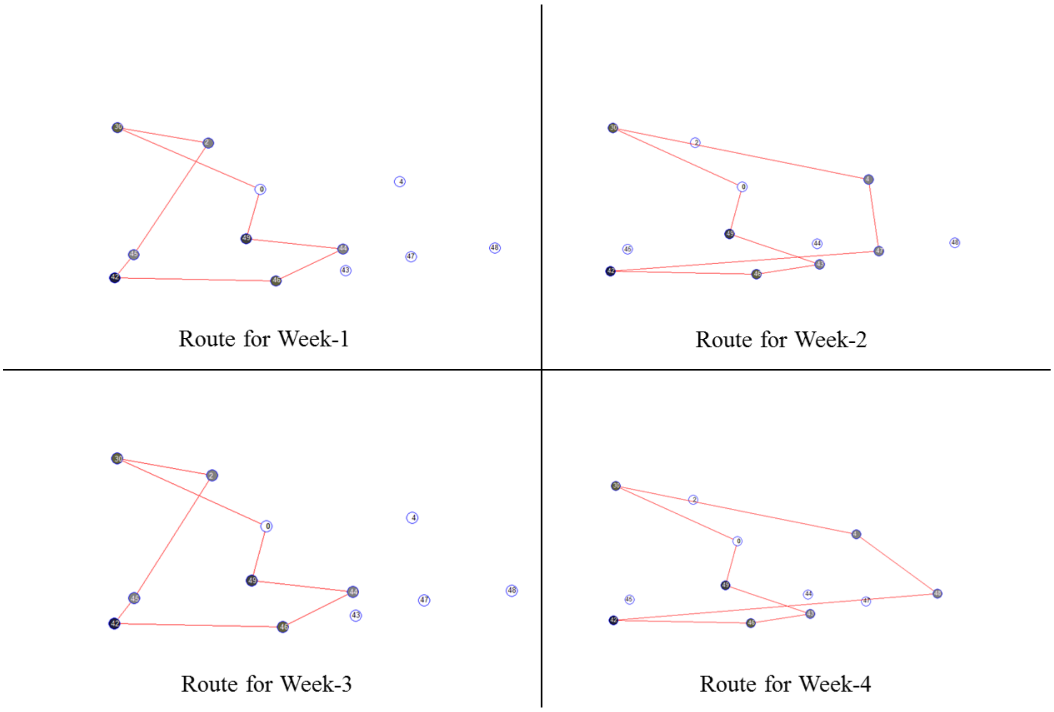


Figure-27: Initial & Improved Route-2 for doctor- 1 (V1)

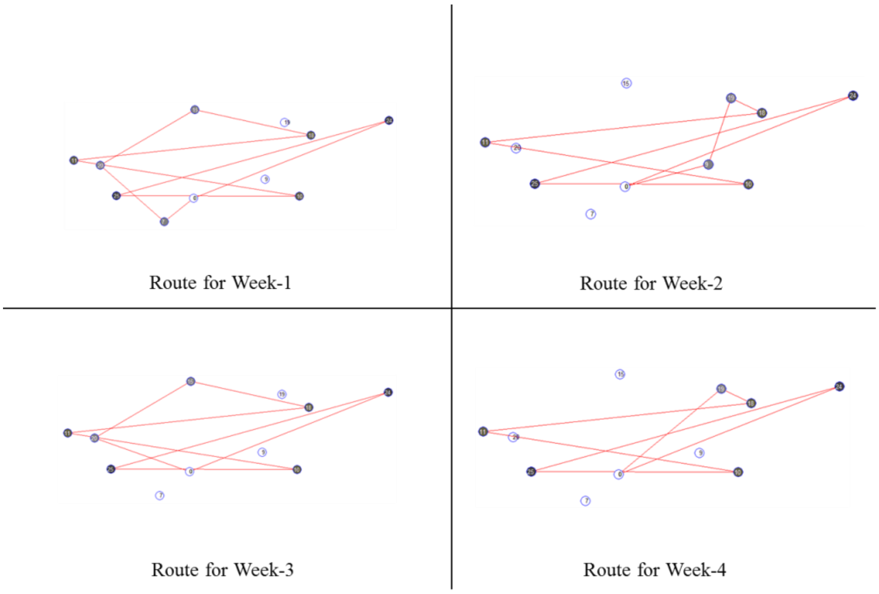


Initial Route

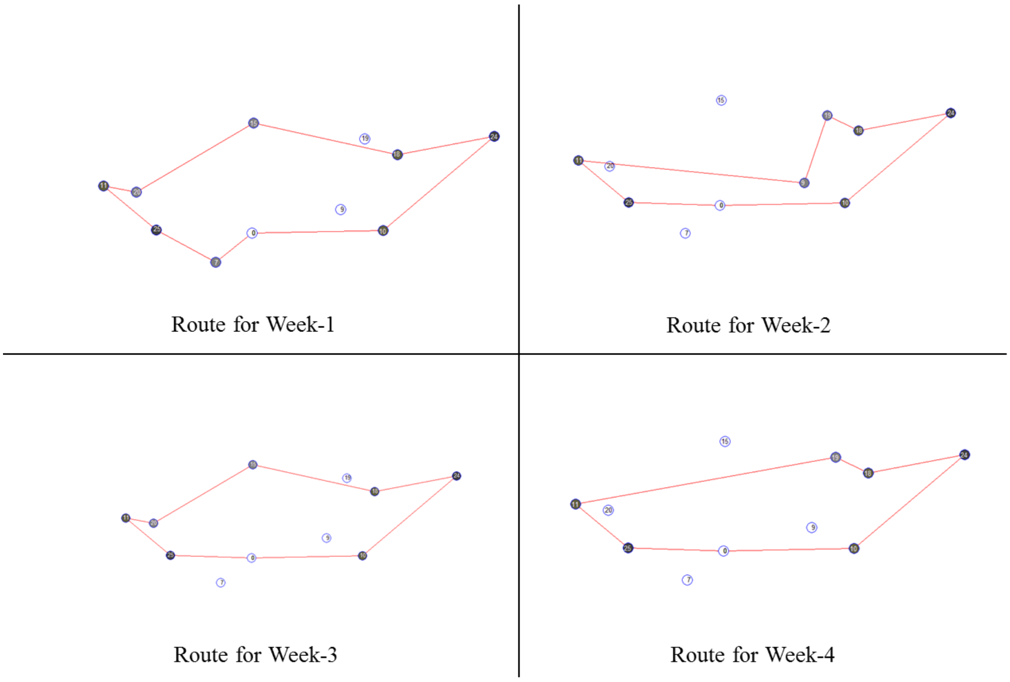


Improved Route

Figure-28: Initial & Improved Route-2 for doctor- 2 (V2)

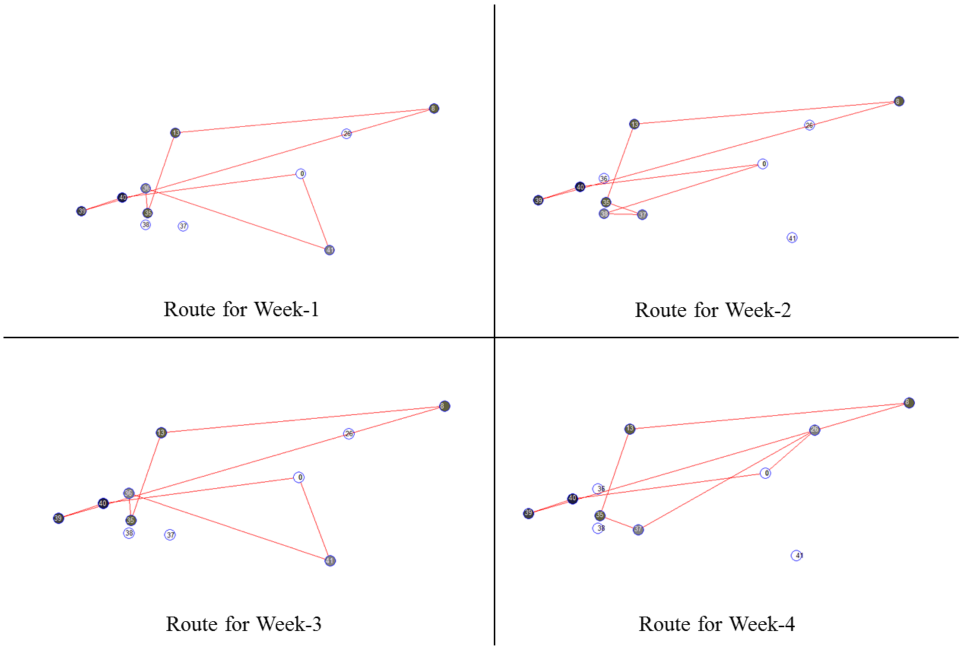


Initial Route

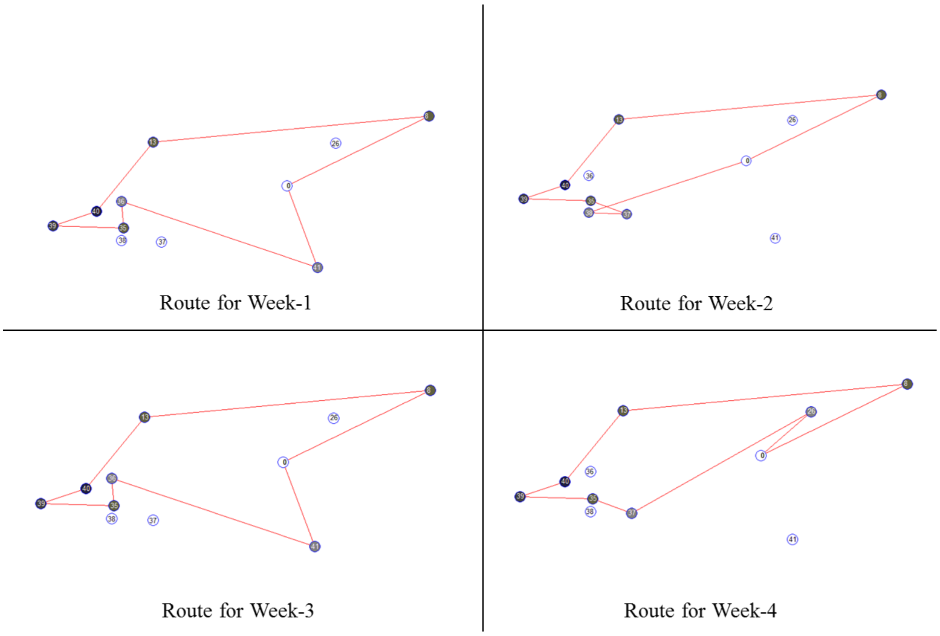


Improved Route

Figure-29: Initial & Improved Route-2 for doctor- 3 (V3)



Initial Route



Improved Route

Figure-30: Initial & Improved Route-2 for doctor- 4 (V4)

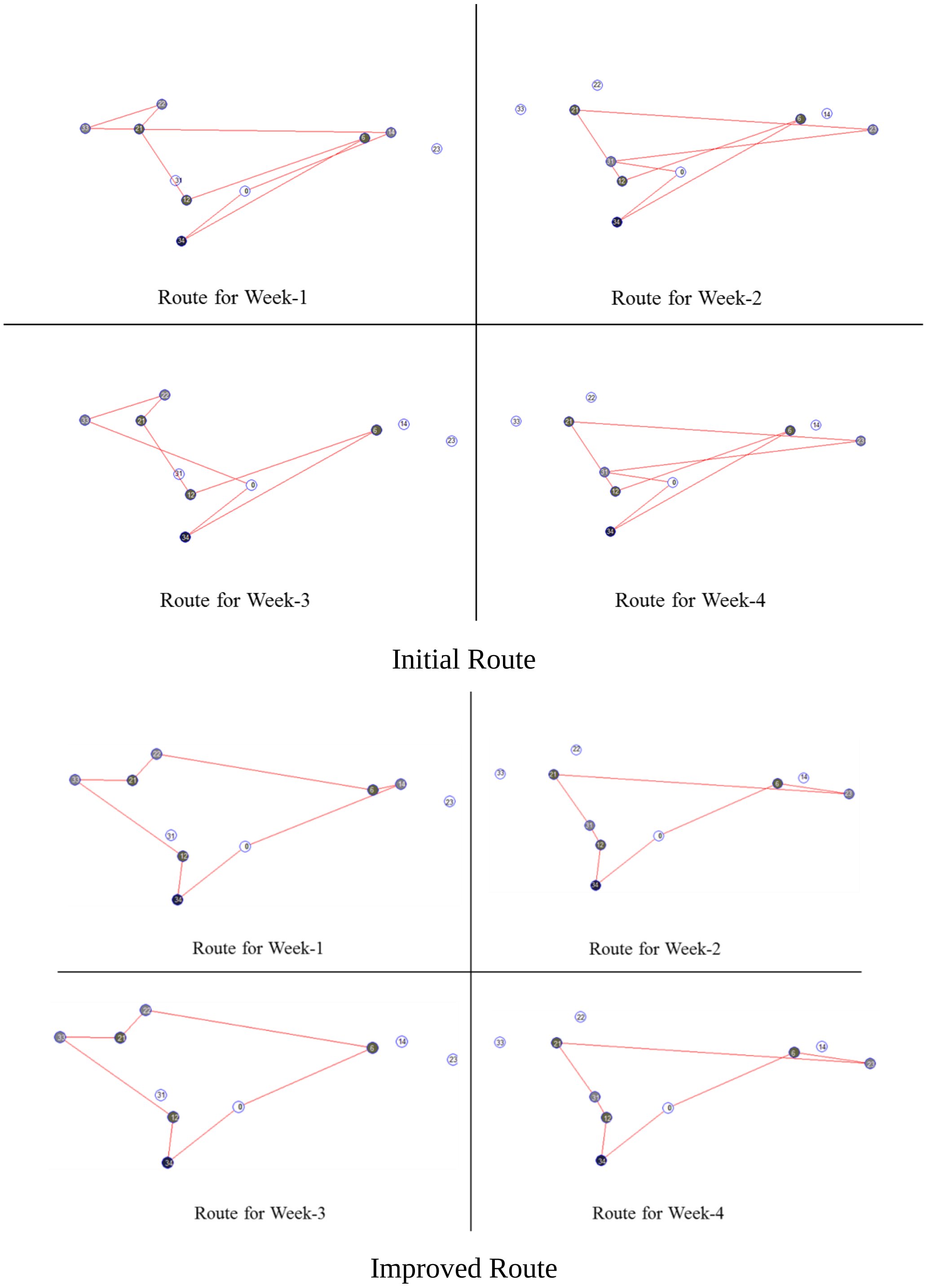
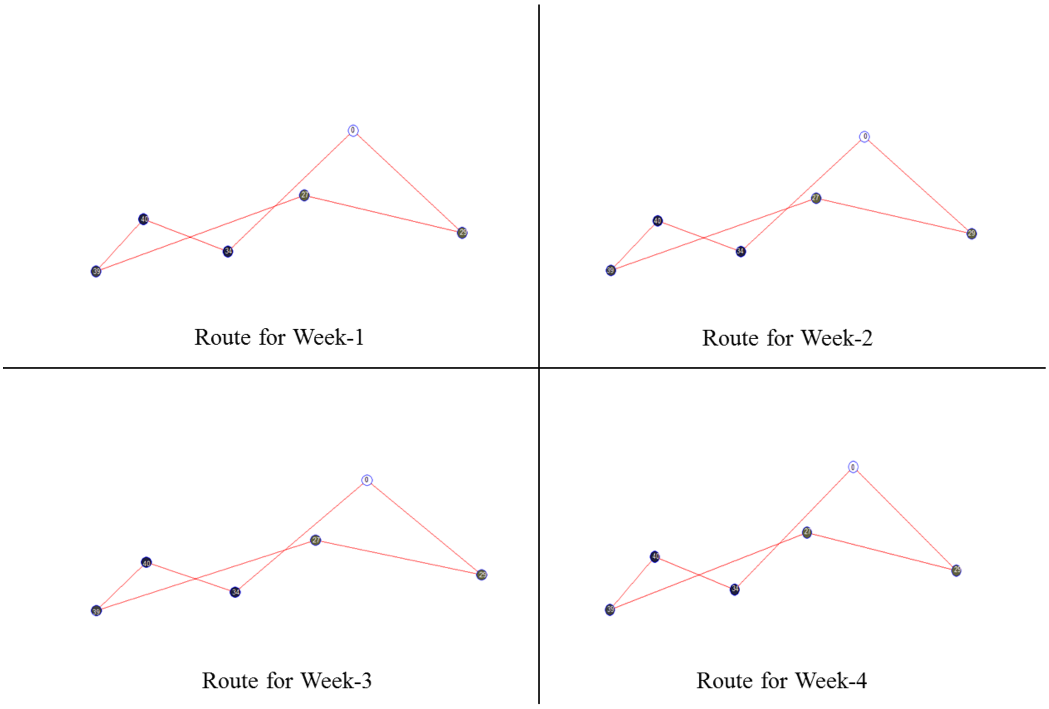


Figure-31: Initial & Improved Route-2 for doctor- 5 (V5)

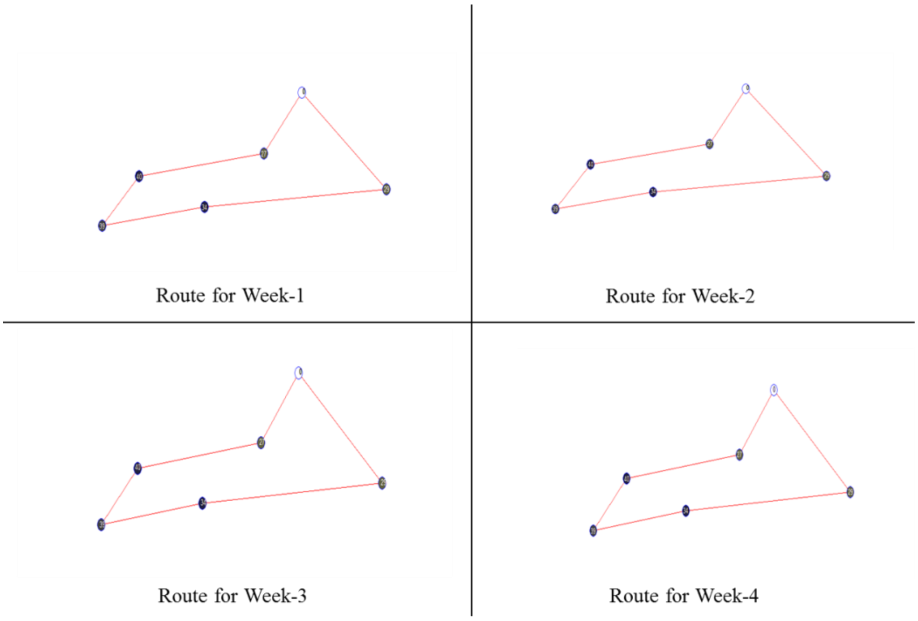
The improved routes of the 5 doctors gathered by using AA and improvement algorithm-2 are presented consecutively in the figures –33, 34, 35, 36 and 37 with the weekly representation of the routes in a monthly schedule.

Approximation algorithm result	Schedule of initial placement										Schedule of Improved Placement-2										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V1**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	34	34	34	40	40	40	39	39	27	29	W-1	29	34	34	34	39	39	40	40	40	27
W-2	34	34	34	40	40	40	39	39	27	29	W-2	29	34	34	34	39	39	40	40	40	27
W-3	34	34	34	40	40	40	39	39	27	29	W-3	29	34	34	34	39	39	40	40	40	27
W-4	34	34	34	40	40	40	39	39	27	29	W-4	29	34	34	34	39	39	40	40	40	27
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V2**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	25	25	12	35	1	36	31	20	7	3	W-1	49	49	45	37	42	42	42	46	44	47
W-2	25	25	12	35	2	22	32	33	0	0	W-2	49	49	43	41	42	42	42	46	48	38
W-3	25	25	12	35	1	36	31	20	0	0	W-3	49	49	45	37	42	42	42	46	44	0
W-4	25	25	12	35	2	22	32	33	0	0	W-4	49	49	43	41	42	42	42	46	0	0
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V3**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	42	42	42	49	49	46	37	45	44	47	W-1	49	49	45	37	42	42	42	46	44	47
W-2	42	42	42	49	49	46	41	43	48	38	W-2	49	49	43	41	42	42	42	46	48	38
W-3	42	42	42	49	49	46	37	45	44	0	W-3	49	49	45	37	42	42	42	46	44	0
W-4	42	42	42	49	49	46	41	43	0	0	W-4	49	49	43	41	42	42	42	46	0	0
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V4**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	5	5	16	16	28	28	11	13	21	30	W-1	28	28	16	16	30	5	5	13	11	21
W-2	5	5	16	16	28	28	11	13	21	30	W-2	28	28	16	16	30	5	5	13	11	21
W-3	5	5	16	16	28	28	11	13	21	30	W-3	28	28	16	16	30	5	5	13	11	21
W-4	5	5	16	16	28	28	11	13	21	30	W-4	28	28	16	16	30	5	5	13	11	21
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	**V5**	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	24	24	6	8	10	18	4	19	17	14	W-1	14	17	10	6	18	24	24	19	8	4
W-2	24	24	6	8	10	18	15	23	9	26	W-2	26	9	10	6	18	24	24	23	8	15
W-3	24	24	6	8	10	18	4	19	0	0	W-3	0	0	10	6	18	24	24	19	8	4
W-4	24	24	6	8	10	18	15	23	0	0	W-4	0	0	10	6	18	24	24	23	8	15

Figure-32: Initial and Improved Schedule-2 obtained by AA

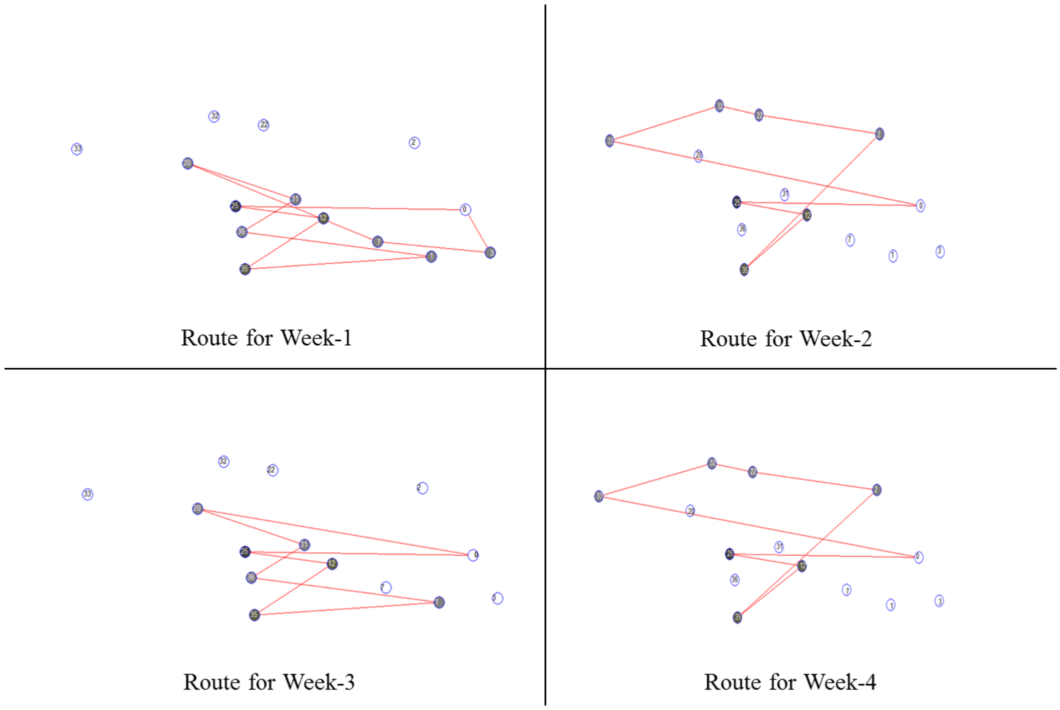


Initial Route

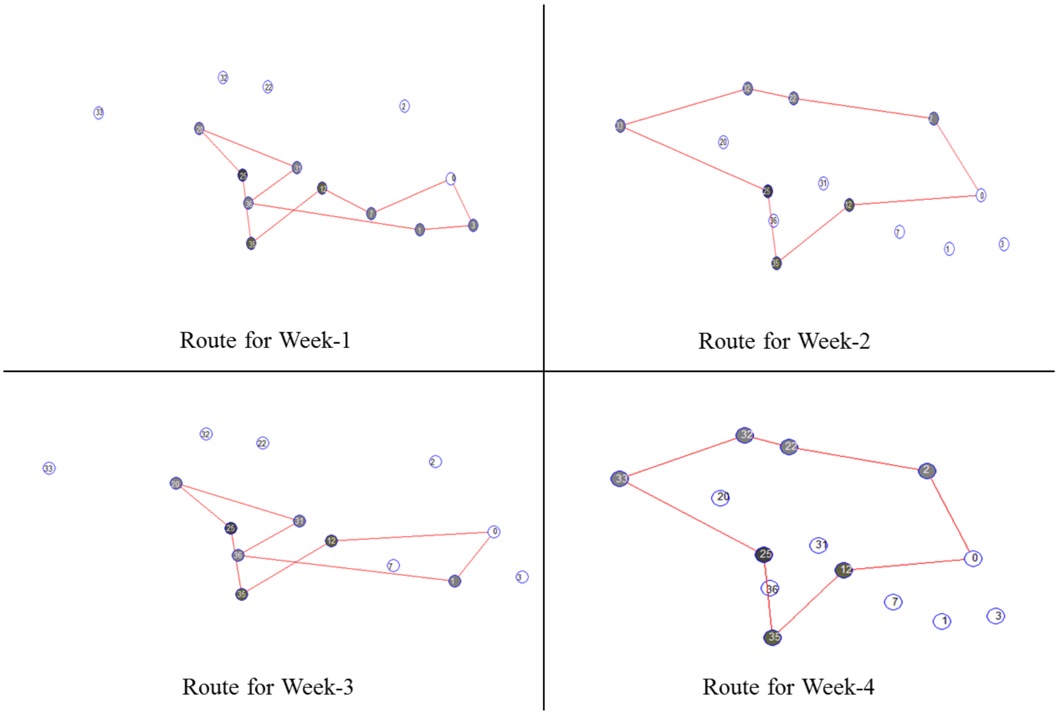


Improved Route

Figure-33: Initial & Improved Route-2 for doctor- 1 (V1)

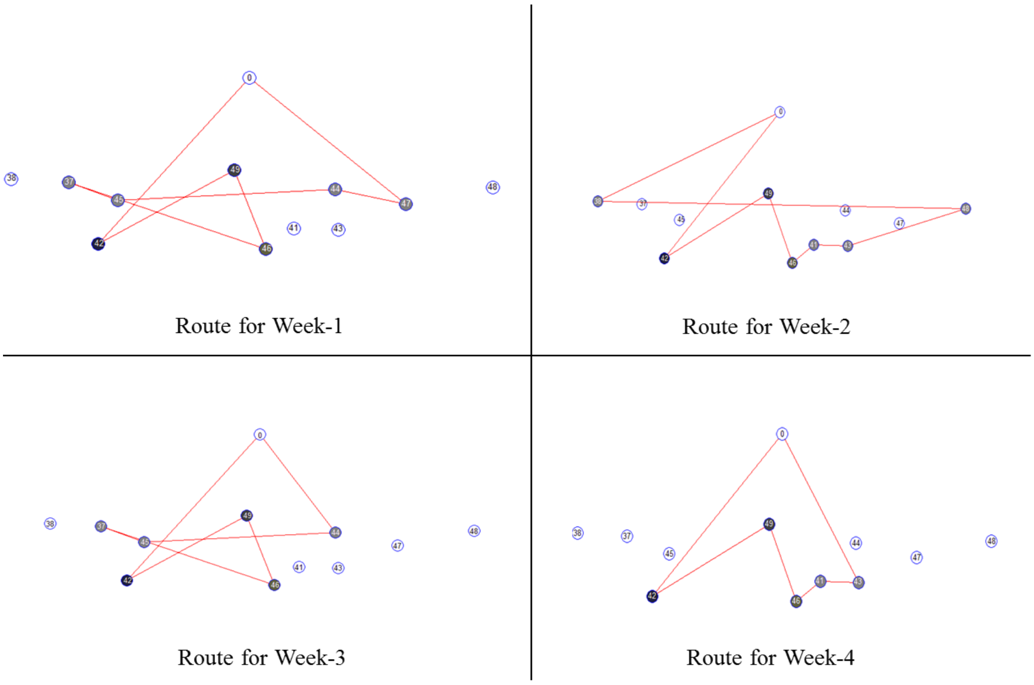


Initial Route

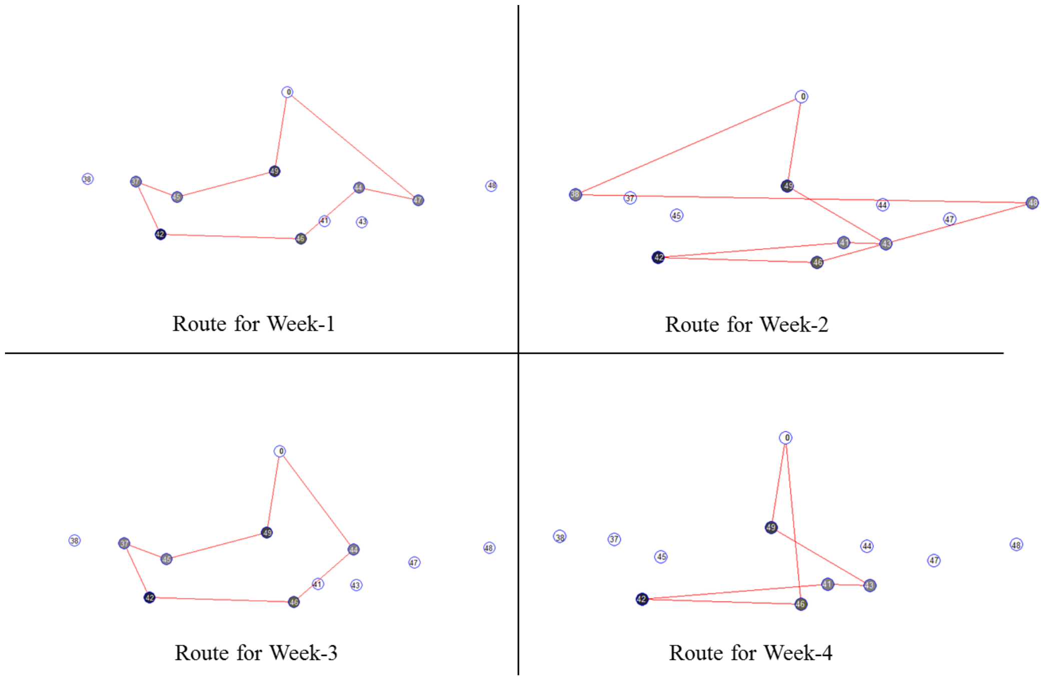


Improved Route

Figure-34: Initial & Improved Route-2 for doctor- 2 (V2)



Initial Route



Improved Route

Figure-35: Initial & Improved Route-2 for doctor- 3 (V3)

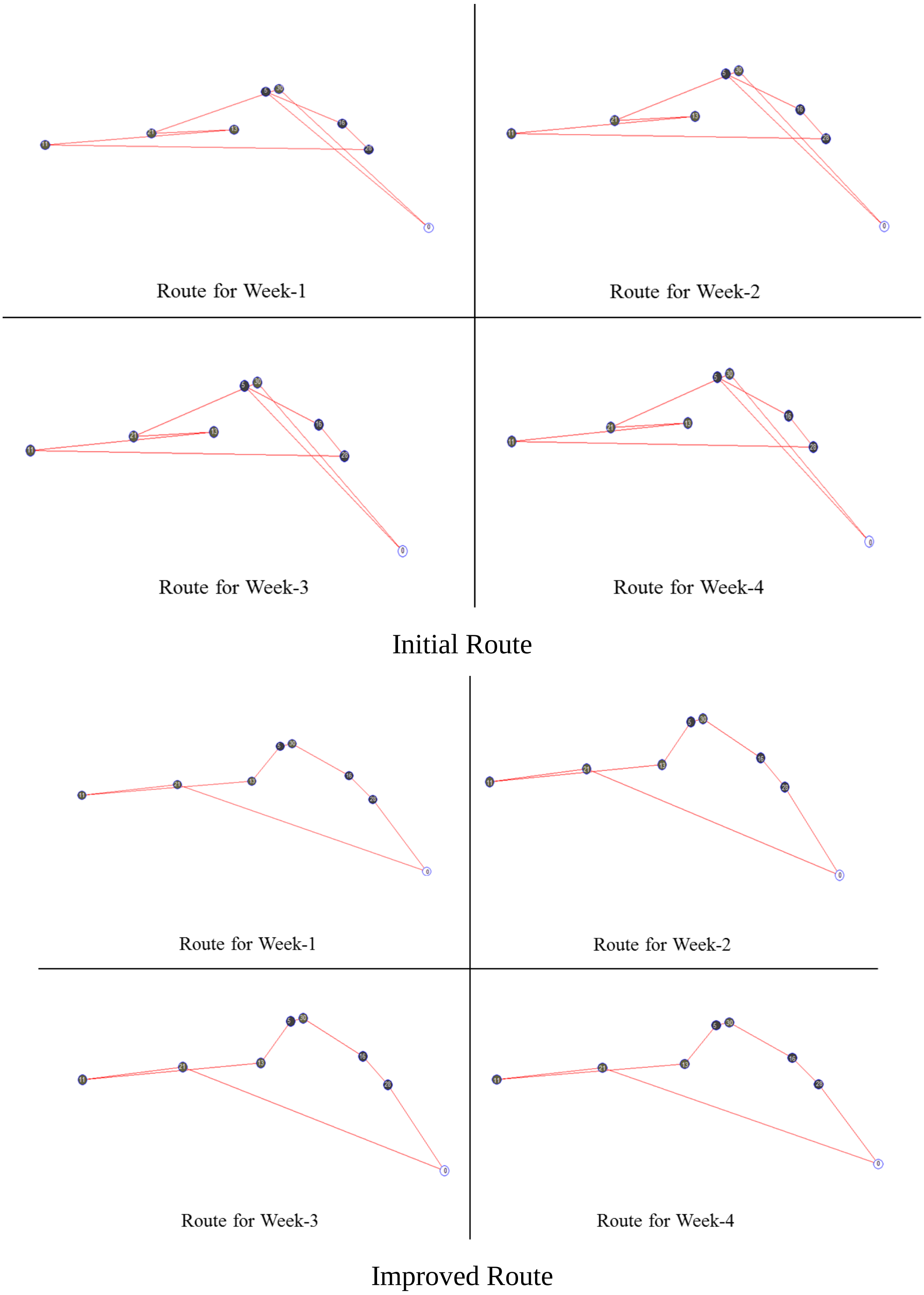


Figure-36: Initial & Improved Route-2 for doctor- 4 (V4)

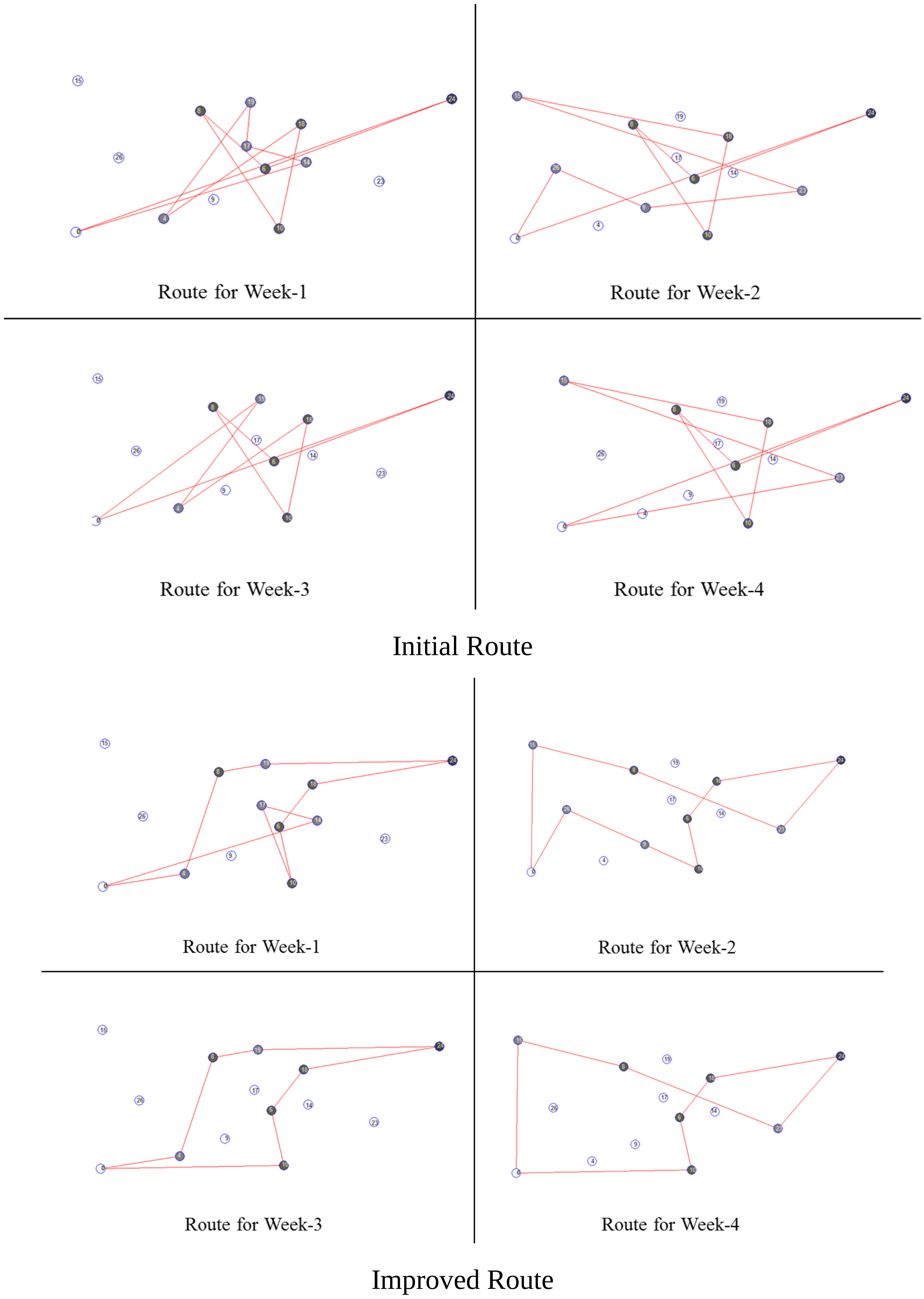


Figure-37: Initial & Improved Route-2 for doctor- 5 (V5)

In order to compare the results of the optimal assignment model and the approximation algorithm, CPU times and also the total cost of the travel routes are calculated for all doctors assigned. The results in table-8 indicate that, the total CPU time of the solutions gathered by AM is close to the one obtained by using AA with improvement algorithm-1 and 2. The reason of CPU time of AM being small in this case is that, we ran the integer programming algorithm until a feasible solution was found instead of running the algorithm for a couple of days to obtain the optimal solution. Therefore the results shown for AM are for a feasible solution rather than the optimal solution. In terms of total cost of initial routing, the solution obtained using AM is larger than the one from AA with improvement-1 and 2. The reason for this is the difference in clustering of villages in those two assignment methods (AA &AM). Therefore, it can be observed that the clustering of the AA is more cost efficient than that of AM. In addition, the routing cost of the improvement algorithms gathered by AA is smaller than the one gathered by AM. When the improvement in the initial total routing costs of AM and AA are compared, we can see that the percent cost saving in the routing with AM is more than the one with AA. In addition to all, improvement-2 is more cost efficient than improvement-1 when total cost of improvement results are compared. Also, the percent cost saving in improvement-1 is more than the one seen as a result of improvement-2. The improvement can be seen in the results of both methods (RA-1 & RA-2). See Table-8 for detailed comparison.

Results of Improvement-1	V	N	CPU DATA TAKING	CPU INITIAL SOL.	CPU IMPROVE MENT	TOTAL CPU	TOTAL COST INITIAL SOL.	TOTAL COST IMPROVEMENT-1	% COST SAVING
AA	5	49	5.62E-01	3.12E-02	6.52E+00	7.1	22500	16700	26
AM	5	49	9.37E-06	5.10E-02	6.49E+00	6.5	37919	23748	37
Results of Improvement-2	V	N	CPU DATA TAKING	CPU INITIAL SOL.	CPU IMPROVE MENT	TOTAL CPU	TOTAL COST INITIAL SOL.	TOTAL COST IMPROVEMENT -2	% COST SAVING
AA	5	49	3.90E-01	1.56E-02	4.65E+00	5.1	20821	16666	20
AM	5	49	1.16E-05	1.03E-01	5.71E+00	5.8	30092	23259	23

Table-8: Comparison of the Results of Improvement-1 & -2

Recall that the improvement algorithms 1 and 2 (RAI-1 &RAI-2) both involve solving a small TSP via GA. In real Burdur data case, we aimed to optimize the TSP instead of using GA. By this way, we could see the gap between the results of GA and TSP.

For improvement algorithms RAI-1 and RAI-2, we run the standard TSP in GAMS optimization software and we get the results for Burdur case. The results can be seen in table – 9, 10. In those figures we compare the results of improvements gathered by the genetic algorithm and TSP in terms of total cost. The difference between the resulting monthly schedules of the five doctors can be also observed. It can be seen that, for some cases TSP is better than genetic algorithm. For instance, for RAI-1 there is only 0.4 % difference between the solutions of GA and TSP solutions of Burdur case whereas for RAI-2 there is %2.5 difference between them.

RAI-1	GA										RAI-1	TSP									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	28	28	16	16	5	5	1	27	29	3	W-1	3	29	27	1	5	5	16	16	28	28
W-2	28	28	16	16	5	5	32	27	29	17	W-2	17	29	27	32	5	5	16	16	28	28
W-3	28	28	16	16	5	5	1	27	29	0	W-3	0	29	27	1	5	5	16	16	28	28
W-4	28	28	16	16	5	5	32	27	29	0	W-4	0	29	27	32	5	5	16	16	28	28
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	49	49	44	46	42	42	42	45	2	30	W-1	30	2	45	42	42	42	46	44	49	49
W-2	49	49	43	46	42	42	42	47	4	30	W-2	30	4	47	42	42	42	46	43	49	49
W-3	49	49	44	46	42	42	42	45	2	30	W-3	30	2	45	42	42	42	46	44	49	49
W-4	49	49	43	46	42	42	42	48	4	30	W-4	30	4	48	42	42	42	46	43	49	49
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	10	24	24	18	15	20	11	25	25	7	W-1	10	24	24	18	15	20	11	25	25	7
W-2	10	24	24	18	19	9	11	25	25	0	W-2	10	24	24	18	19	9	11	25	25	0
W-3	10	24	24	18	15	20	11	25	25	0	W-3	10	24	24	18	15	20	11	25	25	0
W-4	10	24	24	18	19	0	11	25	25	0	W-4	10	24	24	18	19	0	11	25	25	0
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	8	13	40	40	40	39	39	35	36	41	W-1	41	36	35	39	39	40	40	40	13	8
W-2	8	13	40	40	40	39	39	35	37	38	W-2	38	37	35	39	39	40	40	40	13	8
W-3	8	13	40	40	40	39	39	35	36	41	W-3	41	36	35	39	39	40	40	40	13	8
W-4	8	13	40	40	40	39	39	35	37	26	W-4	26	37	35	39	39	40	40	40	13	8
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	14	6	22	21	33	12	34	34	34	0	W-1	0	14	6	22	21	33	12	34	34	34
W-2	0	6	23	21	31	12	34	34	34	0	W-2	0	0	6	23	21	31	12	34	34	34
W-3	0	6	22	21	33	12	34	34	34	0	W-3	0	0	6	22	21	33	12	34	34	34
W-4	0	6	23	21	31	12	34	34	34	0	W-4	0	0	6	23	21	31	12	34	34	34
TOTAL COST	23748										TOTAL COST	23159.2									

Table-9: RAI-1 Result of Burdur case gathered by GA & TSP

RAI-2	GA									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	28	28	16	16	5	5	1	27	29	3
W-2	28	28	16	16	5	5	32	27	29	17
W-3	28	28	16	16	5	5	1	27	29	0
W-4	28	28	16	16	5	5	32	27	29	0
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	49	49	44	46	42	42	42	45	2	30
W-2	49	49	43	46	42	42	42	47	4	30
W-3	49	49	44	46	42	42	42	45	2	30
W-4	49	49	43	46	42	42	42	48	4	30
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	10	24	24	18	15	20	11	25	25	7
W-2	10	24	24	18	19	9	11	25	25	0
W-3	10	24	24	18	15	20	11	25	25	0
W-4	10	24	24	18	19	0	11	25	25	0
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	41	36	35	39	39	40	40	40	13	8
W-2	38	37	35	39	39	40	40	40	13	8
W-3	41	36	35	39	39	40	40	40	13	8
W-4	26	37	35	39	39	40	40	40	13	8
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	34	34	34	12	33	21	22	6	14	0
W-2	34	34	34	12	31	21	23	6	0	0
W-3	34	34	34	12	33	21	22	6	0	0
W-4	34	34	34	12	31	21	23	6	0	0
TOTAL COST	23259									

RAI-2	TSP									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	29	27	1	5	5	16	16	28	28
W-2	17	29	27	32	5	5	16	16	28	28
W-3	0	29	27	1	5	5	16	16	28	28
W-4	0	29	27	32	5	5	16	16	28	28
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	49	49	2	45	42	42	42	30	44	46
W-2	49	49	4	47	42	42	42	30	43	46
W-3	49	49	2	45	42	42	42	30	44	46
W-4	49	49	4	48	42	42	42	30	43	46
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	25	25	24	24	11	15	20	10	18	7
W-2	25	25	24	24	11	19	9	10	18	0
W-3	25	25	24	24	11	19	9	10	18	0
W-4	25	25	24	24	11	19	0	10	18	0
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	41	36	8	35	39	39	40	40	40	13
W-2	38	37	8	35	39	39	40	40	40	13
W-3	41	36	8	35	39	39	40	40	40	13
W-4	26	37	8	35	39	39	40	40	40	13
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	0	14	12	22	6	33	21	34	34	34
W-2	0	0	12	23	6	31	21	34	34	34
W-3	0	0	12	22	6	33	21	34	34	34
W-4	0	0	12	23	6	31	21	34	34	34
TOTAL COST	23159.2									

Table -10: RAI-2 Result of Burdur case gathered by GA & TSP

Chapter 8

Optional Schedule Selection (OSS)

8.1 Methodology

In this algorithm, a similar methodology with the algorithm described above (RA-I-1) is used with an optional selection strategy. The districts that require 12, 8 or 4 frequency of visits are ordered to reduce routing costs with the same methodology used in the first improvement phase of the routing algorithm (RAI-1). A schedule selection algorithm is also constructed to evaluate the selection between two schedule choices for the districts that require frequency of 2. One option is to visit the villages with frequency 2 at two consecutive slots at once; the other option is to visit them with one-week intervals (week 1 and 3 or week 2 and 4), as we did before. The selection between those two is important since it affects the total route cost of the doctors. This second option was the only option used in the previous chapters due to the constraint that the villages with frequency two has to be visited twice a month and these visits should have regular intervals in between. Here in this chapter we relax that constraint as explained below, so we have two options to choose from.

This optional scheduling algorithm constructs a different strategy to the scheduling of the doctors that are assigned to the districts with frequency 2. Instead of placing the villages into first and third or second and fourth weeks another option is placing the visit time slots of the villages with frequency 2 side by side to the same week. By visiting two consecutive slots at same week, the cost of the visit will be less than visiting the villages with one week interval at the same slot of two weeks. However, in this case, the visits to the villages with frequency 2 will not be periodic. Since visiting a village once for 2 consecutive slots is more cost efficient than visiting twice with one week time interval, we provide a model for that option. In this methodology, the placement of villages with frequency 2 into the schedule consecutively is possible only if there are 2 consecutive empty slots in a week. When that option of placing consecutively is possible, it is directly selected since it has less cost.

The placement into the schedule starts with placement of villages with high frequencies, i.e. more than 2 (12, 8 or 4) called as group-1. The villages from group-1 are ordered with a descending order of their frequencies and placed in that order. The highest frequency valued village is placed first. The number of consecutively placed slots is equal to $\lceil frequency\ value\ of\ village/4 \rceil$. All the villages in group-1 are placed similarly. This part is the same with the methodology used in the previous improvements. After the placement of the villages with frequency more than 2 is finished, we place the villages with frequency 2. If the cardinality of the villages with frequency 2 is less than four; the villages are placed consecutively to the same week. If the cardinality of the villages with frequency 2 is more than 4, we need a strategy to decide which nodes to be placed into the same week. To do this we use K-means clustering algorithm. It puts the nodes that are close to each other into the same cluster, and those nodes are placed consecutively into the same week. This method reduces the cost. If there is not enough space (consecutive empty clots in the schedule) for placing the villages with frequency 2 consecutively into the same week, then they are placed to the schedule with one week intervals (using the initial methodology). Finally, if there are villages with frequency 1, they are placed into the remaining empty slots in the schedule by checking using the nearest neighbor rule explained earlier until there is no village left in the remaining village set.

After this placement, the TSP methodology, used in the improvement algorithms previously, is applied. The goal is to further improve the route gathered from the initial placement of the villages. In TSP methodology, as described in the previous chapters, column to column distances are optimized to find a better routing solution in terms of the total routing cost. See Figure-38 for the flow chart of the algorithm.

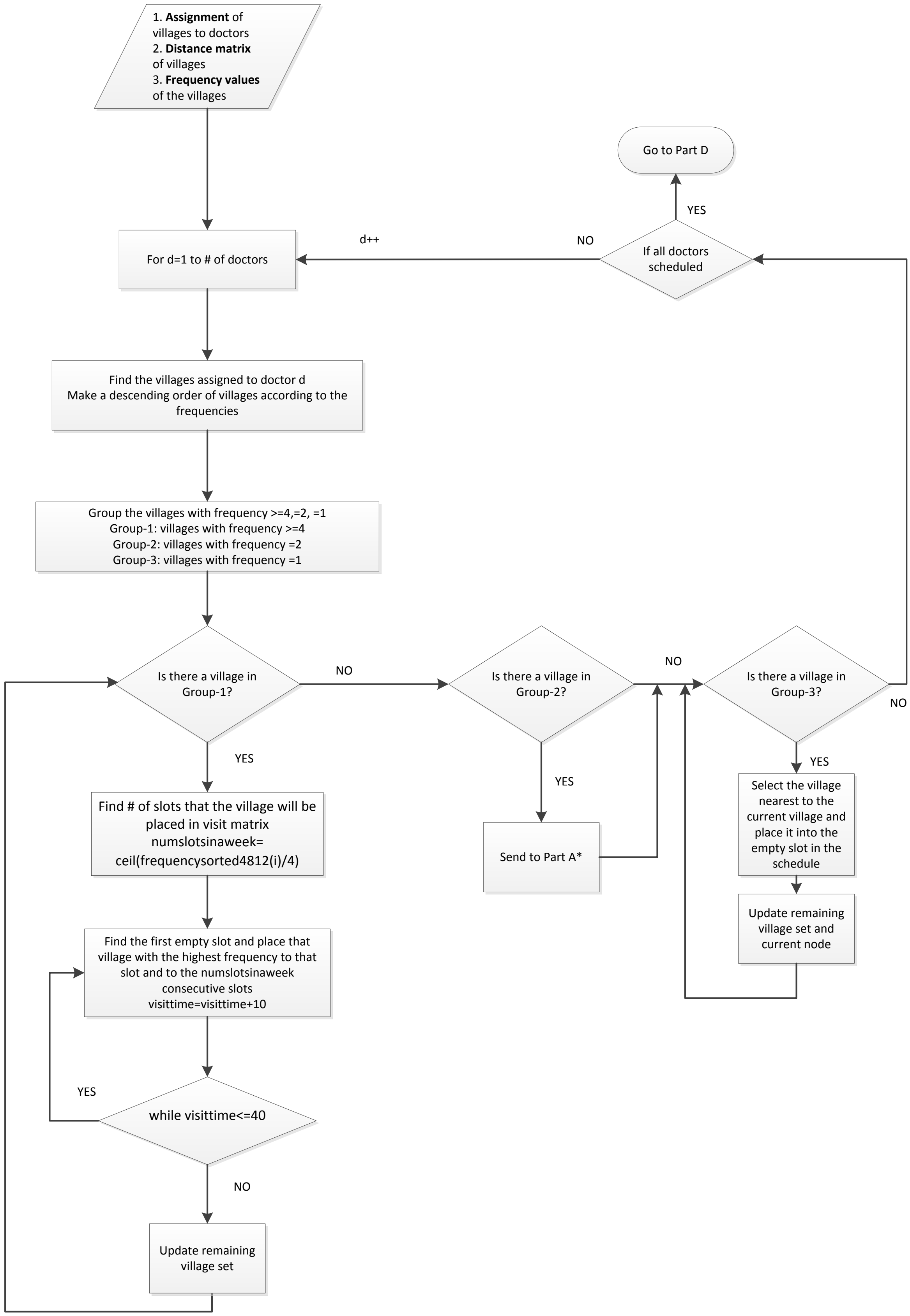


Figure-38: Flow Chart of the Optional Schedule Selection Algorithm (OSSA)

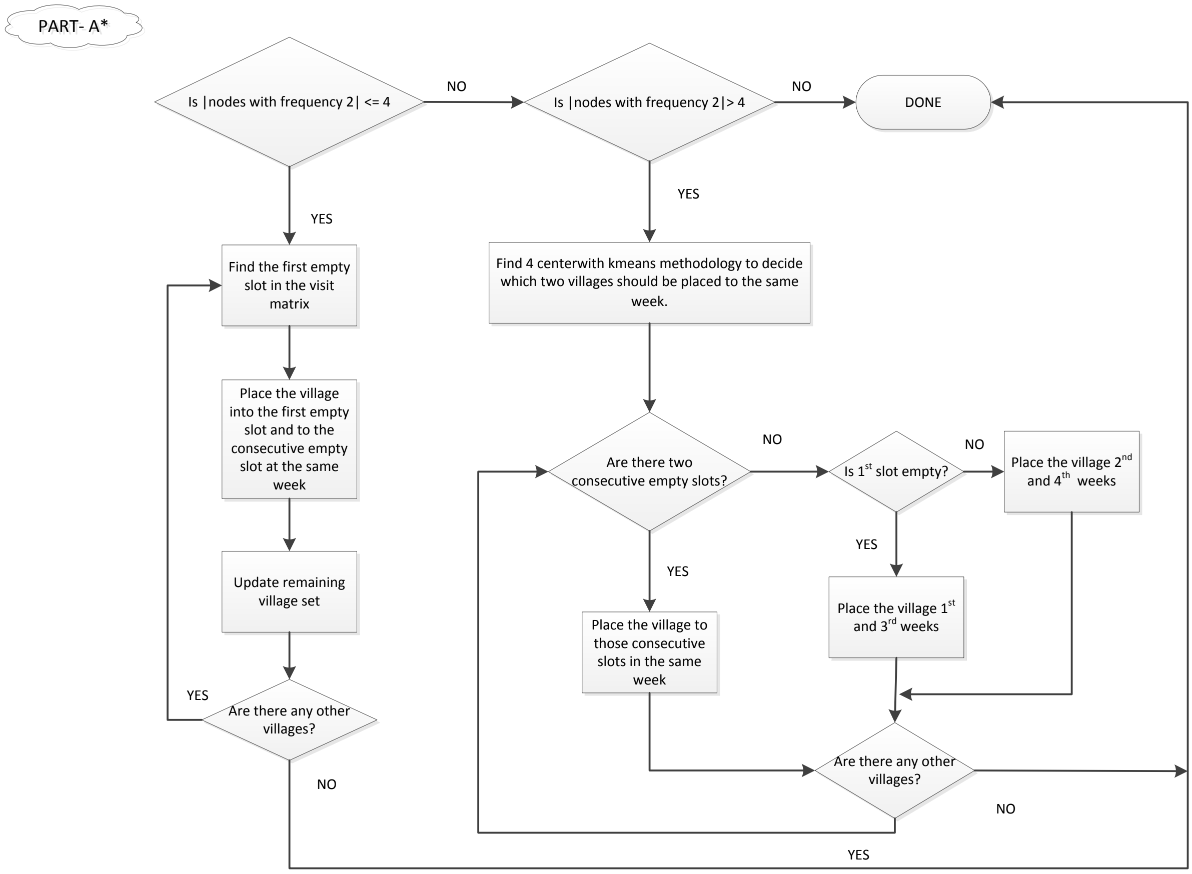


Figure-38(Cont'd): Flow Chart of the Optional Schedule Selection Algorithm (OSSA)

The complexity of the OSSA is calculated and we get $O(d * [num1^2 + num2^2 + n + n^9 logn])$, where n represents the number of villages, d represents the number of doctors and num1,2 represents the number of villages with frequency $1, 2$.

8.2 Results of Optional Schedule Selection Algorithm

8.2.1 Results for Burdur City

After the construction of the optional schedule selection algorithm, the algorithm is applied to the data of Burdur city, simulated data and extended data sets that are created. The results of Burdur city data is presented in illustration-4. As can be seen, since the AM and AA assignment results show variations, the schedule results of the optional schedule selection algorithm is different from each other. For the initial schedule and OSS algorithm resulting schedule that are constructed by using AA and AM, see illustration-4.

Illustration-4: Results of OSSA for Burdur city

Results of OSS algorithm with Assignment model (AM):

Assignment Model Result	Schedule of Initial placement (RA)										Schedule After OSSA											Schedule After Improvement										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	5	5	16	16	28	28	27	29	1	3	W-1	5	5	16	16	28	28	27	29	1	1	W-1	27	29	1	1	5	5	16	16	28	28
W-2	5	5	16	16	28	28	27	29	32	17	W-2	5	5	16	16	28	28	27	29	32	32	W-2	27	29	32	32	5	5	16	16	28	28
W-3	5	5	16	16	28	28	27	29	1	0	W-3	5	5	16	16	28	28	27	29	3	0	W-3	27	29	3	0	5	5	16	16	28	28
W-4	5	5	16	16	28	28	27	29	32	0	W-4	5	5	16	16	28	28	27	29	17	0	W-4	27	29	17	0	5	5	16	16	28	28
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	42	42	42	49	49	30	46	2	44	45	W-1	42	42	42	49	49	30	46	43	43	45	W-1	30	43	43	45	46	42	42	42	49	49
W-2	42	42	42	49	49	30	46	4	43	47	W-2	42	42	42	49	49	30	46	44	44	47	W-2	30	44	44	47	46	42	42	42	49	49
W-3	42	42	42	49	49	30	46	2	44	45	W-3	42	42	42	49	49	30	46	2	2	48	W-3	30	2	2	48	46	42	42	42	49	49
W-4	42	42	42	49	49	30	46	4	43	48	W-4	42	42	42	49	49	30	46	4	4	0	W-4	30	4	4	0	46	42	42	42	49	49
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	24	24	25	25	10	11	18	15	20	7	W-1	24	24	25	25	10	11	18	15	15	7	W-1	25	25	11	15	15	18	24	24	10	7
W-2	24	24	25	25	10	11	18	19	9	0	W-2	24	24	25	25	10	11	18	19	19	9	W-2	25	25	11	19	19	18	24	24	10	9
W-3	24	24	25	25	10	11	18	15	20	0	W-3	24	24	25	25	10	11	18	20	20	0	W-3	25	25	11	20	20	18	24	24	10	0
W-4	24	24	25	25	10	11	18	19	0	0	W-4	24	24	25	25	10	11	18	0	0	0	W-4	25	25	11	0	0	18	24	24	10	0
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	40	40	40	39	39	8	13	35	36	41	W-1	40	40	40	39	39	8	13	35	36	36	W-1	36	36	35	39	39	40	40	40	13	8
W-2	40	40	40	39	39	8	13	35	37	38	W-2	40	40	40	39	39	8	13	35	37	37	W-2	37	37	35	39	39	40	40	40	13	8
W-3	40	40	40	39	39	8	13	35	36	41	W-3	40	40	40	39	39	8	13	35	41	41	W-3	41	41	35	39	39	40	40	40	13	8
W-4	40	40	40	39	39	8	13	35	37	26	W-4	40	40	40	39	39	8	13	35	38	26	W-4	26	38	35	39	39	40	40	40	13	8
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	34	34	34	6	12	21	22	33	14	0	W-1	34	34	34	6	12	21	22	22	14	0	W-1	34	34	34	12	21	22	22	6	14	0
W-2	34	34	34	6	12	21	23	31	0	0	W-2	34	34	34	6	12	21	23	23	0	0	W-2	34	34	34	12	21	23	23	6	0	0
W-3	34	34	34	6	12	21	22	33	0	0	W-3	34	34	34	6	12	21	31	31	0	0	W-3	34	34	34	12	21	31	31	6	0	0
W-4	34	34	34	6	12	21	23	31	0	0	W-4	34	34	34	6	12	21	33	33	0	0	W-4	34	34	34	12	21	33	33	6	0	0

Results of OSS algorithm with Approximation algorithm (AA):

Approximation Algorithm Result	Schedule of Initial placement (RA)										Schedule After OSSA											Schedule After Improvement										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	34	34	34	40	40	40	39	39	27	29	W-1	34	34	34	40	40	40	39	39	27	29	W-1	29	34	34	34	39	39	40	40	40	27
W-2	34	34	34	40	40	40	39	39	27	29	W-2	34	34	34	40	40	40	39	39	27	29	W-2	29	34	34	34	39	39	40	40	40	27
W-3	34	34	34	40	40	40	39	39	27	29	W-3	34	34	34	40	40	40	39	39	27	29	W-3	29	34	34	34	39	39	40	40	40	27
W-4	34	34	34	40	40	40	39	39	27	29	W-4	34	34	34	40	40	40	39	39	27	29	W-4	29	34	34	34	39	39	40	40	40	27
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	25	25	12	35	1	36	31	20	7	3	W-1	25	25	12	35	22	22	33	33	3	0	W-1	0	22	22	25	25	33	33	35	12	3
W-2	25	25	12	35	2	22	32	33	0	0	W-2	25	25	12	35	31	31	32	32	7	0	W-2	0	31	31	25	25	32	32	35	12	7
W-3	25	25	12	35	1	36	31	20	0	0	W-3	25	25	12	35	20	20	1	1	0	0	W-3	0	20	20	25	25	1	1	35	12	0
W-4	25	25	12	35	2	22	32	33	0	0	W-4	25	25	12	35	2	2	36	36	0	0	W-4	0	2	2	25	25	36	36	35	12	0
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	42	42	42	49	49	46	37	45	44	47	W-1	42	42	42	49	49	46	37	37	41	41	W-1	49	49	37	37	42	42	42	46	41	41
W-2	42	42	42	49	49	46	41	43	48	38	W-2	42	42	42	49	49	46	43	43	38	0	W-2	49	49	43	43	42	42	42	46	38	0
W-3	42	42	42	49	49	46	37	45	44	0	W-3	42	42	42	49	49	46	45	45	47	0	W-3	49	49	45	45	42	42	42	46	47	0
W-4	42	42	42	49	49	46	41	43	0	0	W-4	42	42	42	49	49	46	44	44	48	0	W-4	49	49	44	44	42	42	42	46	48	0
V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V4	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	5	5	16	16	28	28	11	13	21	30	W-1	5	5	16	16	28	28	11	13	21	30	W-1	21	11	13	5	5	30	16	16	28	28
W-2	5	5	16	16	28	28	11	13	21	30	W-2	5	5	16	16	28	28	11	13	21	30	W-2	21	11	13	5	5	30	16	16	28	28
W-3	5	5	16	16	28	28	11	13	21	30	W-3	5	5	16	16	28	28	11	13	21	30	W-3	21	11	13	5	5	30	16	16	28	28
W-4	5	5	16	16	28	28	11	13	21	30	W-4	5	5	16	16	28	28	11	13	21	30	W-4	21	11	13	5	5	30	16	16	28	28
V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V5	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	24	24	6	8	10	18	4	19	17	14	W-1	24	24	6	8	10	18	4	4	26	0	W-1	0	10	6	24	24	18	8	4	4	26
W-2	24	24	6	8	10	18	15	23	9	26	W-2	24	24	6	8	10	18	15	15	9	0	W-2	0	10	6	24	24	18	8	15	15	9
W-3	24	24	6	8	10	18	4	19	0	0	W-3	24	24	6	8	10	18	19	19	17	0	W-3	0	10	6	24	24	18	8	19	19	17
W-4	24	24	6	8	10	18	15	23	0	0	W-4	24	24	6	8	10	18	23	23	14	0	W-4	0	10	6	24	24	18	8	23	23	14

In order to compare the results constructed by using AA and AM, total routing cost for the family physicians and the run time of the algorithm are calculated. As can be seen from the table-11, for Burdur city the total CPU time spent for the AM for initial routing and for optional schedule selection algorithm in total is more than AA. When the results are compared in terms of total routing cost, it can be seen that AA is more cost effective than the AM. Therefore, AA is more useful than AM in general since its CPU time is less and it gives better results in terms of total routing cost of the doctors. In addition to all, the percent cost saving for the AM is more than the one seen in AA when the change in initial and improved routing total cost results are compared. It can be concluded also that OSSA outperforms, RAI-1 and RAI-2 in terms of total routing cost for Burdur case.

Results of OSSA	V	N	CPU DATA TAKING	CPU INITIAL SOL.	CPU OSSA	TOTAL CPU	TOTAL COST INITIAL SOL.	TOTAL COST OSSA	% COST SAVING
AA	5	49	0.6864044	0.1872012	6.28684	7	20518	16262.89	21
AM	5	49	8.92E-06	2.738792	8.887808	12	32510	22174.59	32

Table-11: Comparison of AA and AM results

8.2.2 Results for Extended Data

In addition to the Burdur case, 90 instances are generated to evaluate results with different data. The village locations that are used in the instances of the extended data are constructed by using the real village locations of Burdur case. However, the frequency values were changed for each of the 90 instance. The details about the extended data will be given in the following chapter. See illustration-5 for the detailed representation of the schedules gathered as a result of the optional schedule selection algorithm for the first instance of extended data set.

Illustration-5: Result of OSSA for Instance-1 in Extended Data Set

Results of OSS algorithm with Assignment Model (AM):

Assignment Model Result	Schedule of Initial placement (RA)									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	8	8	9	9	10	10	15	19
W-2	3	3	8	8	9	9	10	10	15	23
W-3	3	3	8	8	9	9	10	10	15	19
W-4	3	3	8	8	9	9	10	10	15	24
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	4	4	5	5	6	6	7	7	11	21
W-2	4	4	5	5	6	6	7	7	11	20
W-3	4	4	5	5	6	6	7	7	11	22
W-4	4	4	5	5	6	6	7	7	11	25
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	2	2	12	13	14	16	17
W-2	1	1	1	2	2	12	13	14	16	18
W-3	1	1	1	2	2	12	13	14	16	17
W-4	1	1	1	2	2	12	13	14	16	18

	Schedule After OSSA									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	8	8	9	9	10	10	15	19
W-2	3	3	8	8	9	9	10	10	15	23
W-3	3	3	8	8	9	9	10	10	15	19
W-4	3	3	8	8	9	9	10	10	15	24
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	4	4	5	5	6	6	7	7	11	21
W-2	4	4	5	5	6	6	7	7	11	22
W-3	4	4	5	5	6	6	7	7	11	20
W-4	4	4	5	5	6	6	7	7	11	25
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	2	2	12	13	14	16	17
W-2	1	1	1	2	2	12	13	14	16	18
W-3	1	1	1	2	2	12	13	14	16	17
W-4	1	1	1	2	2	12	13	14	16	18

	Schedule After Improvement									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	9	9	10	10	19	8	8	15
W-2	3	3	9	9	10	10	23	8	8	15
W-3	3	3	9	9	10	10	19	8	8	15
W-4	3	3	9	9	10	10	24	8	8	15
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	7	7	21	11	5	5	6	6	4	4
W-2	7	7	22	11	5	5	6	6	4	4
W-3	7	7	20	11	5	5	6	6	4	4
W-4	7	7	25	11	5	5	6	6	4	4
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	12	13	16	2	2	17	14
W-2	1	1	1	12	13	16	2	2	18	14
W-3	1	1	1	12	13	16	2	2	17	14
W-4	1	1	1	12	13	16	2	2	18	14

Results of OSS algorithm with Approximation algorithm (AA):

Approximation Algorithm Result	Schedule of Initial placement (RA)									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	3	3	4	4	7	7	19
W-2	1	1	1	3	3	4	4	7	7	23
W-3	1	1	1	3	3	4	4	7	7	19
W-4	1	1	1	3	3	4	4	7	7	24
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	11	12	13	15	16	22
W-2	2	2	5	5	11	12	13	15	16	21
W-3	2	2	5	5	11	12	13	15	16	20
W-4	2	2	5	5	11	12	13	15	16	25
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	6	6	8	8	9	9	10	10	14	17
W-2	6	6	8	8	9	9	10	10	14	18
W-3	6	6	8	8	9	9	10	10	14	17
W-4	6	6	8	8	9	9	10	10	14	18

	Schedule After OSSA									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	3	3	4	4	7	7	19
W-2	1	1	1	3	3	4	4	7	7	23
W-3	1	1	1	3	3	4	4	7	7	19
W-4	1	1	1	3	3	4	4	7	7	24
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	11	12	13	15	16	21
W-2	2	2	5	5	11	12	13	15	16	22
W-3	2	2	5	5	11	12	13	15	16	20
W-4	2	2	5	5	11	12	13	15	16	25
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	6	6	8	8	9	9	10	10	14	17
W-2	6	6	8	8	9	9	10	10	14	18
W-3	6	6	8	8	9	9	10	10	14	17
W-4	6	6	8	8	9	9	10	10	14	18

	Schedule After Improvement									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	7	7	1	1	1	3	3	4	4	19
W-2	7	7	1	1	1	3	3	4	4	23
W-3	7	7	1	1	1	3	3	4	4	19
W-4	7	7	1	1	1	3	3	4	4	24
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	16	2	2	15	5	5	13	11	21	12
W-2	16	2	2	15	5	5	13	11	22	12
W-3	16	2	2	15	5	5	13	11	20	12
W-4	16	2	2	15	5	5	13	11	25	12
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	9	9	10	10	6	6	14	17	8	8
W-2	9	9	10	10	6	6	14	18	8	8
W-3	9	9	10	10	6	6	14	17	8	8
W-4	9	9	10	10	6	6	14	18	8	8

8.2.3 Results for Simulated Data

Moreover, we also changed the simulated data set by creating another 90 instances, but this time we also modified the coordinates of the locations. However, the frequency values in 90 instance are the same with the frequency values of the instance used in extended data set. See illustration-6 for the detailed representation of the schedules gathered as a result of the optional schedule selection algorithm for the first instance of simulated data set.

Illustration-6: Result of OSSA for Instance-1 in Simulated Data Set

Results of OSS algorithm with Assignment Model (AM):

Assignment Model Result	Schedule of Initial placement (RA)									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	4	4	7	7	10	10	11	17
W-2	3	3	4	4	7	7	10	10	11	19
W-3	3	3	4	4	7	7	10	10	11	17
W-4	3	3	4	4	7	7	10	10	11	19
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	6	6	8	8	12	15	18
W-2	1	1	1	6	6	8	8	12	15	25
W-3	1	1	1	6	6	8	8	12	15	18
W-4	1	1	1	6	6	8	8	12	15	23
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	9	9	13	14	16	20
W-2	2	2	5	5	9	9	13	14	16	24
W-3	2	2	5	5	9	9	13	14	16	21
W-4	2	2	5	5	9	9	13	14	16	22

	Schedule After OSSA									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	4	4	7	7	10	10	11	17
W-2	3	3	4	4	7	7	10	10	11	19
W-3	3	3	4	4	7	7	10	10	11	17
W-4	3	3	4	4	7	7	10	10	11	19
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	6	6	8	8	12	15	18
W-2	1	1	1	6	6	8	8	12	15	25
W-3	1	1	1	6	6	8	8	12	15	18
W-4	1	1	1	6	6	8	8	12	15	23
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	9	9	13	14	16	24
W-2	2	2	5	5	9	9	13	14	16	22
W-3	2	2	5	5	9	9	13	14	16	20
W-4	2	2	5	5	9	9	13	14	16	21

	Schedule After Improvement									
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	4	4	10	10	7	7	3	3	11	17
W-2	4	4	10	10	7	7	3	3	11	19
W-3	4	4	10	10	7	7	3	3	11	17
W-4	4	4	10	10	7	7	3	3	11	19
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	8	8	12	1	1	1	6	6	15	18
W-2	8	8	12	1	1	1	6	6	15	25
W-3	8	8	12	1	1	1	6	6	15	18
W-4	8	8	12	1	1	1	6	6	15	23
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	5	5	13	14	9	9	16	24
W-2	2	2	5	5	13	14	9	9	16	22
W-3	2	2	5	5	13	14	9	9	16	20
W-4	2	2	5	5	13	14	9	9	16	21

Results of OSS algorithm with Approximation algorithm (AA):

Approximation algorithm Result	Schedule of Initial placement (RA)										Schedule After OSSA											Schedule After Improvement										
V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V1	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	1	1	1	6	6	12	15	17	19	25	W-1	1	1	1	6	6	12	15	17	17	21	W-1	12	1	1	1	6	6	15	17	17	21
W-2	1	1	1	6	6	12	15	18	23	22	W-2	1	1	1	6	6	12	15	18	18	24	W-2	12	1	1	1	6	6	15	18	18	24
W-3	1	1	1	6	6	12	15	17	19	24	W-3	1	1	1	6	6	12	15	19	19	23	W-3	12	1	1	1	6	6	15	19	19	23
W-4	1	1	1	6	6	12	15	18	21	20	W-4	1	1	1	6	6	12	15	25	22	20	W-4	12	1	1	1	6	6	15	25	22	20
V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V2	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	2	2	8	8	9	9	11	13	14	16	W-1	2	2	8	8	9	9	11	13	14	16	W-1	9	9	16	14	13	11	8	8	2	2
W-2	2	2	8	8	9	9	11	13	14	16	W-2	2	2	8	8	9	9	11	13	14	16	W-2	9	9	16	14	13	11	8	8	2	2
W-3	2	2	8	8	9	9	11	13	14	16	W-3	2	2	8	8	9	9	11	13	14	16	W-3	9	9	16	14	13	11	8	8	2	2
W-4	2	2	8	8	9	9	11	13	14	16	W-4	2	2	8	8	9	9	11	13	14	16	W-4	9	9	16	14	13	11	8	8	2	2
V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2	V3	M-1	M-2	T-1	T-2	W-1	W-2	TH-1	TH-2	F-1	F-2
W-1	3	3	4	4	5	5	7	7	10	10	W-1	3	3	4	4	5	5	7	7	10	10	W-1	4	4	10	10	3	3	7	7	5	5
W-2	3	3	4	4	5	5	7	7	10	10	W-2	3	3	4	4	5	5	7	7	10	10	W-2	4	4	10	10	3	3	7	7	5	5
W-3	3	3	4	4	5	5	7	7	10	10	W-3	3	3	4	4	5	5	7	7	10	10	W-3	4	4	10	10	3	3	7	7	5	5
W-4	3	3	4	4	5	5	7	7	10	10	W-4	3	3	4	4	5	5	7	7	10	10	W-4	4	4	10	10	3	3	7	7	5	5

As can be observed from the OSSA result constructed with AM in illustration-6, for the doctors that have two villages with frequency 2, the placement of those villages in the schedule does not changed since consecutive placement of those villages is not possible. For an example, see doctor-1's (V1) schedule in assignment model resulting schedule. In addition to this, for the doctors which have more than two villages with frequency 2, consecutive placement gives better results. For an example, see doctor-1(V1)'s schedule in approximation algorithm resulting schedule.

Chapter 9

Computational Results

The algorithms are implemented in Matlab programming language and run on a personal computer with a 2.30 GHz Intel Core i5-2410M processor and 4GB RAM. The results of the computational experiments are summarized in the following sections with data used.

The results are not compared with available benchmark instances in literature since none of them consider dedicated doctor visits and their frequency structure is different from the frequency structure of the villages considered in this study. Thus, the benchmark instances that are available in the literature [61] are not suitable for our problem. For this reason, we could not evaluate the results of our codes by using them. Instead, we used extended and simulated data that are generated for the comparisons. In extended data, the frequency values are generated to fit the total working hour of a doctor which is 40, and the real Burdur network is used for all 90 instances. In simulated data, a new network is generated but the frequency values for 90 instances are the same with the ones used in extended data. Therefore, in total 181 instances are evaluated. See Appendix-4 for the real and simulated data frequency values in 90 instances.

9.1 Extended Data

As it is mentioned previously, in addition to the instance of Burdur case, 90 instances are generated to evaluate results with different data. The village locations that are used in the instances of the extended data are constructed by using the real village locations of Burdur case.

For given number of doctors and villages, the frequencies for the villages are generated randomly that satisfies the fulfillment of the total working time slot which is 40 slots in total for each doctor. By this way every doctor will have an equal working time in a month.

9.1.1 Computational Results for Extended Data

In order to compare the resulting performance of the algorithms constructed we used the total travel cost of all the doctors and CPU time of the algorithms as performance measures.

When routing results for all 90 instances are evaluated for three improvement algorithms, it is concluded that total routing cost of initial solution constructed by improvement algorithm-2 (RAI-2) is less than initial solution cost of OSSA and improvement algorithm-1(RAI-1). The reason is that the initial placement is made by using the nearest neighboring methodology in the second improvement algorithm whereas the same methodology (RA) is used to find initial placement in RAI-1 and OSSA. For the details of initial routing cost comparison of the algorithms gathered by construction of the AM and AA for 90 instances, see figure-39 and figure-40.

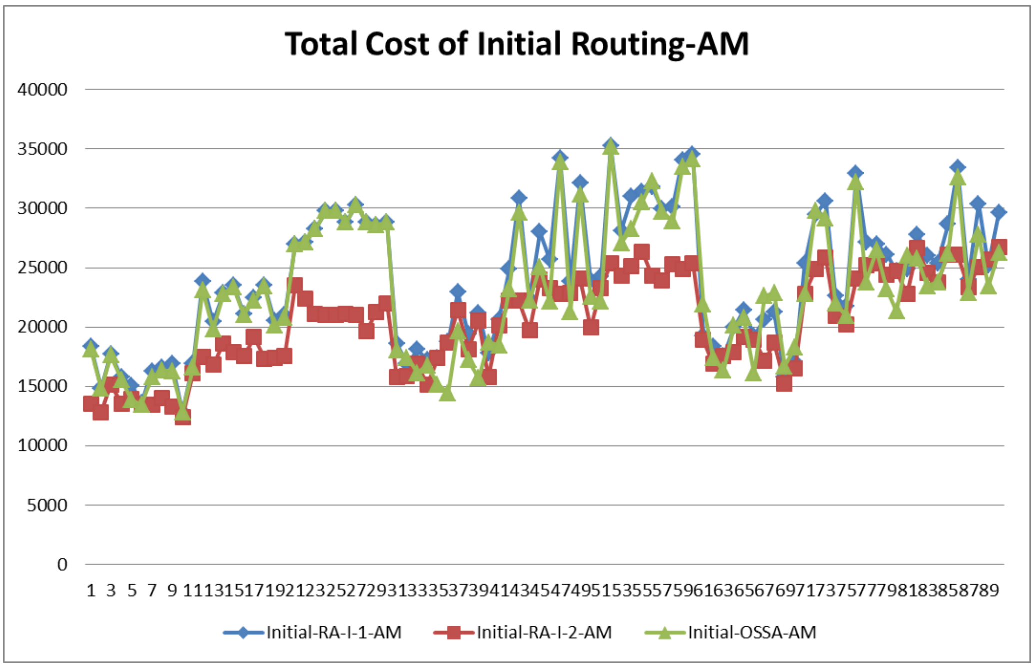


Figure – 39: Comparison of the Initial Routing Cost of Algorithms with AM

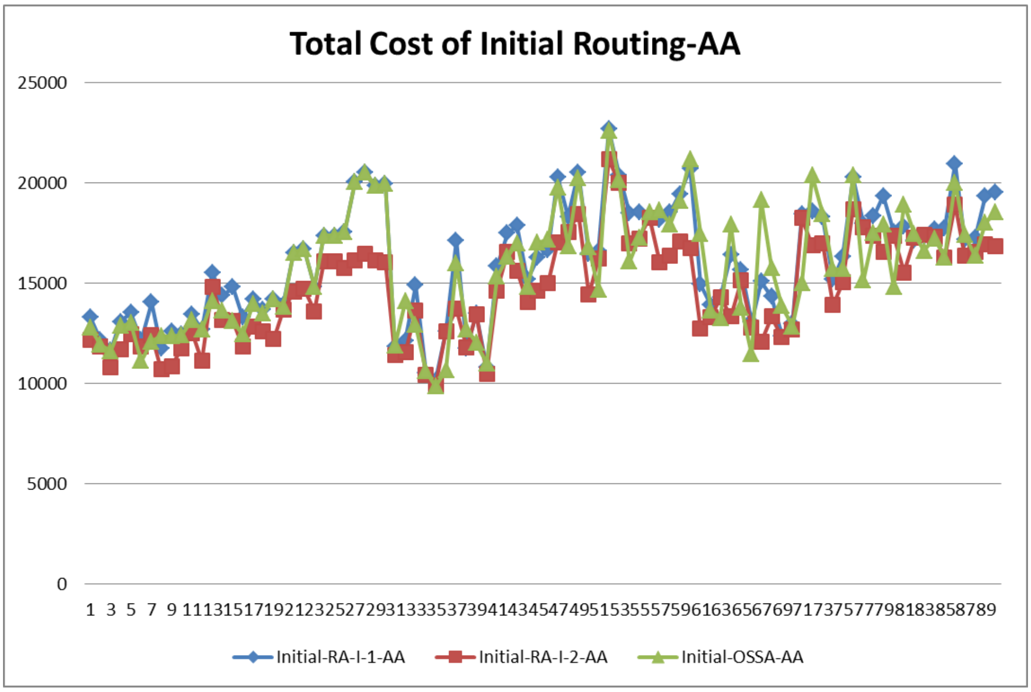


Figure – 40: Comparison of the Initial Routing Cost of Algorithms with AA

When the resulting total cost of the improved routing is compared for the algorithms that are constructed, it can be seen that there is not a significant difference between improvement algorithm-1 and 2, in general. However, for some instances which include many villages with frequency 2, it can be seen that the OSSA outperforms other algorithms (RA-I-1 and RA-2) because it considers consecutive placement of villages in those instances. See figure-41 and 42 for evaluation of improved routing cost constructed by using AM and AA.

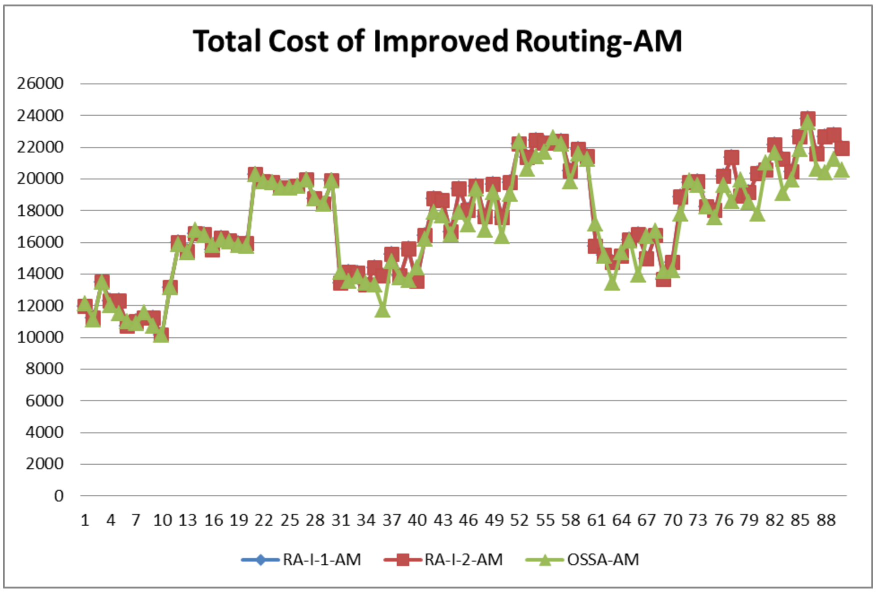


Figure – 41: Comparison of Total Cost of the Improved Routing with AM

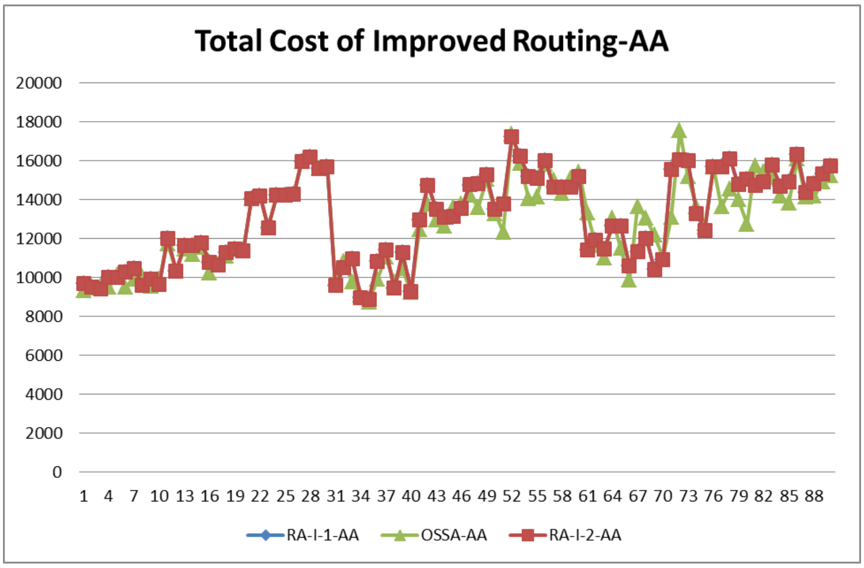


Figure – 42: Comparison of Total Cost of the Improved Routing with AA

When the difference between initial placement and improved placement results are compared for the three algorithms, it can be observed that for all algorithms initial placement is improved after construction of the TSP based improvement methodology. It can be concluded that the OSSA gives the least costly results in general when all improvement algorithms are compared for 90 instances. See figure-43, 44 and 45 for detailed comparison charts.

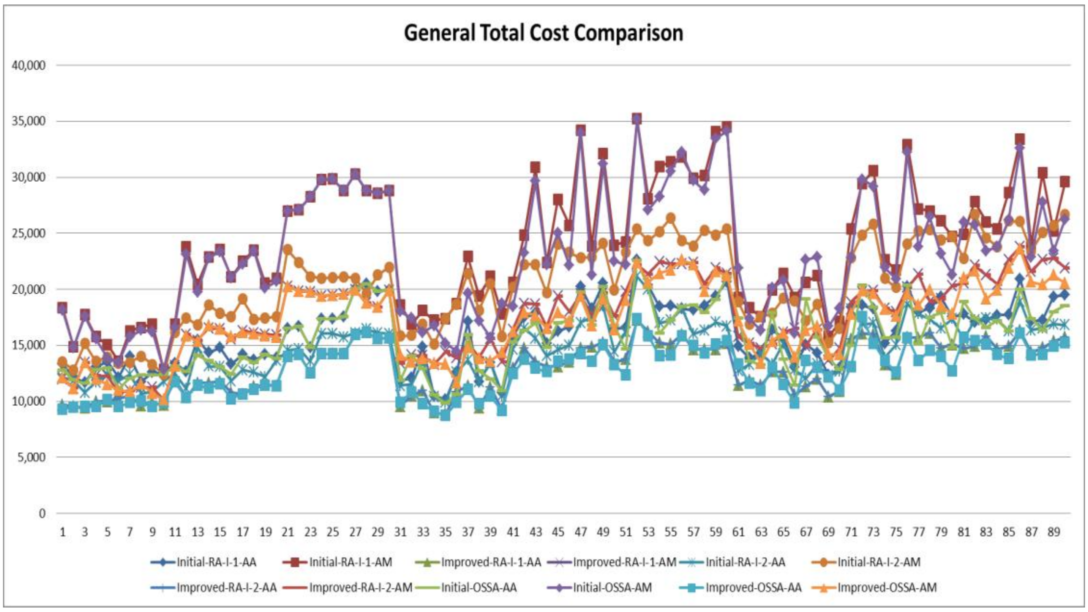


Figure – 43: Total Cost Comparison of Initial & Improved Routing - AA&AM

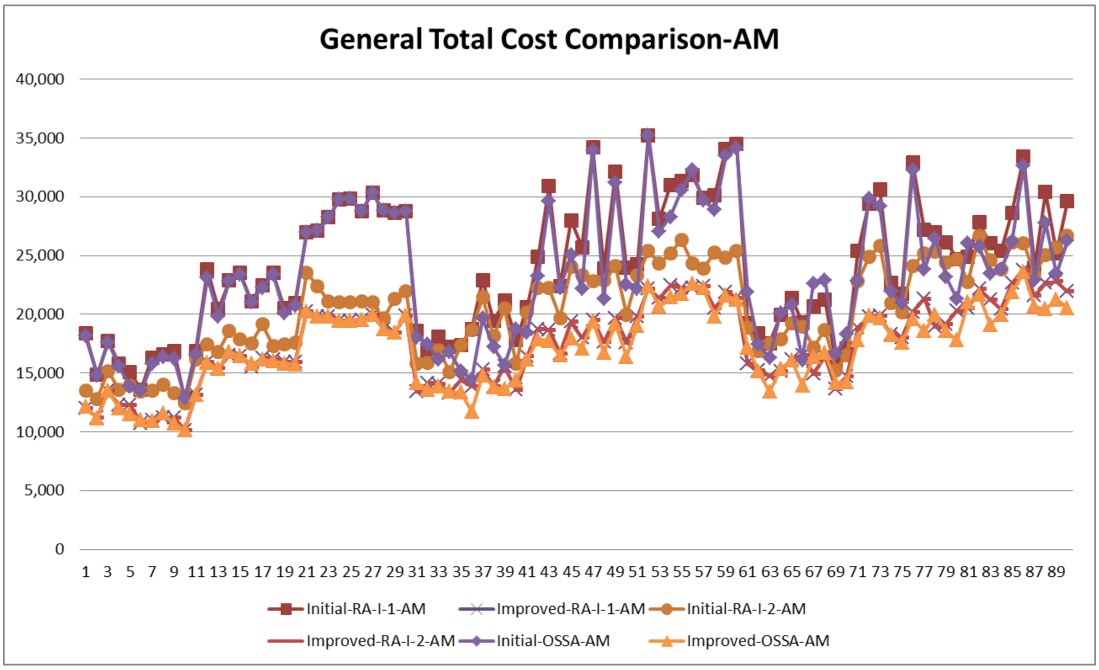


Figure – 44: General Total Cost Comparison-AM

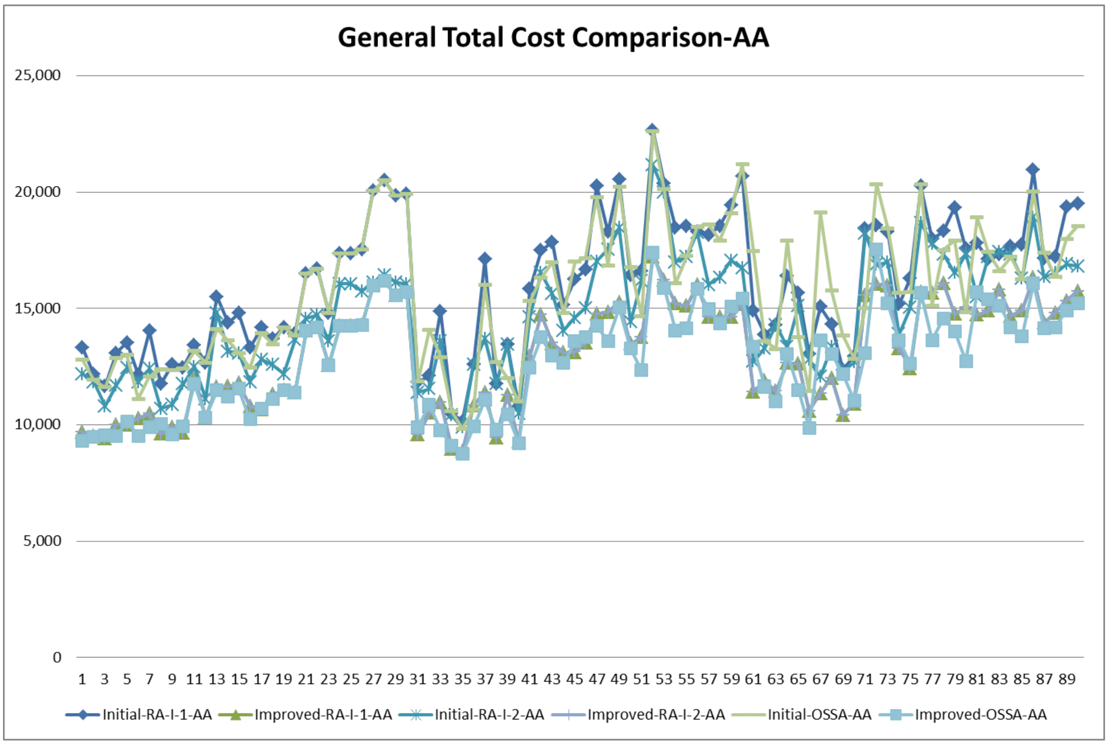


Figure – 45: General Total Cost Comparison-AA

In addition to these, when the CPU times of the algorithms are compared, it can be seen that for 90 instances, OSSA outperforms the other improvement algorithms whereas improvement algorithm-2's run time less than improvement algorithm-1. See figure-46, 47 for CPU of improvement algorithms constructed by using AA and AM.

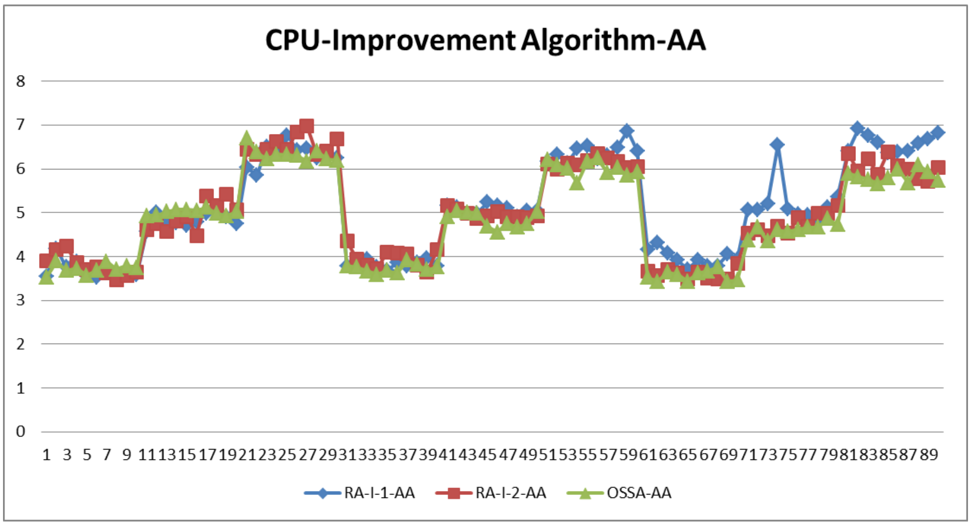


Figure-46: CPU Comparison Chart of Improvement Algorithms- AA

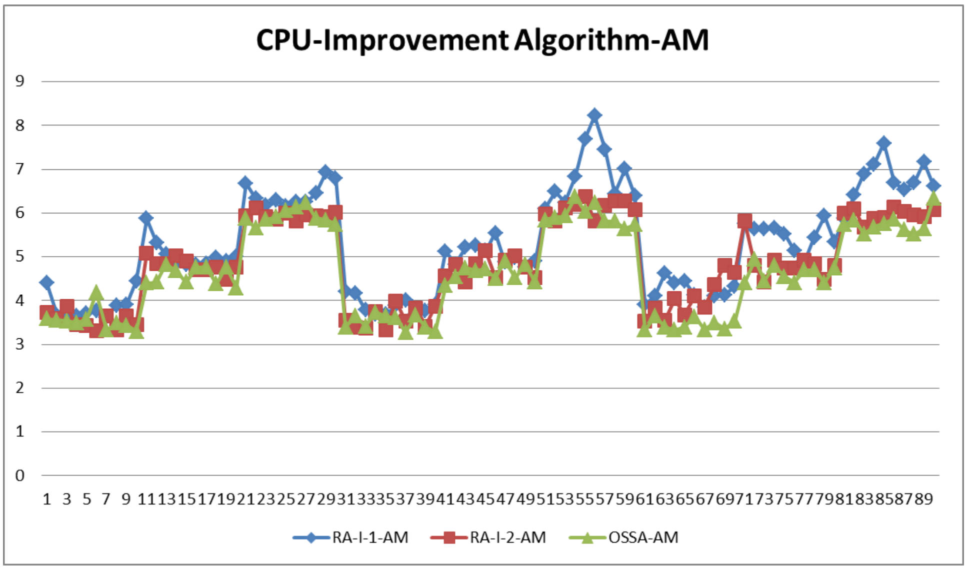


Figure-47: CPU Comparison Chart of Improvement Algorithms- AM

Moreover, in terms of percent cost saving in between initial and improved routing, improved routing algorithm-2 is less than the other algorithms in terms of cost savings. Since, it already constructs better initial solution with the nearest neighbor methodology. Moreover, the percent cost saving results for 90 instances are similar for the OSSA and improvement algorithm-1. See figure-48 and 49 for detailed comparison in terms of percent cost saving in algorithms constructed by AA and AM.

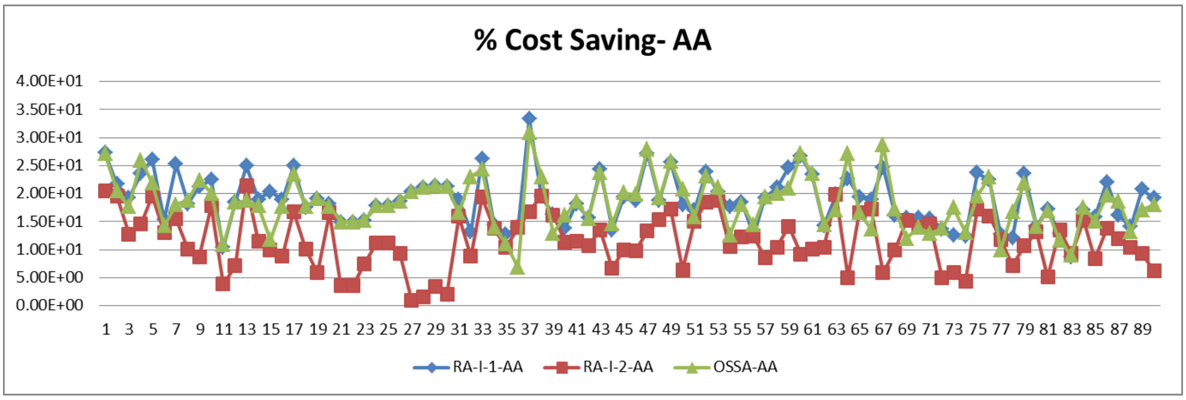


Figure-48: % Cost Saving for Improvement Algorithms-AA

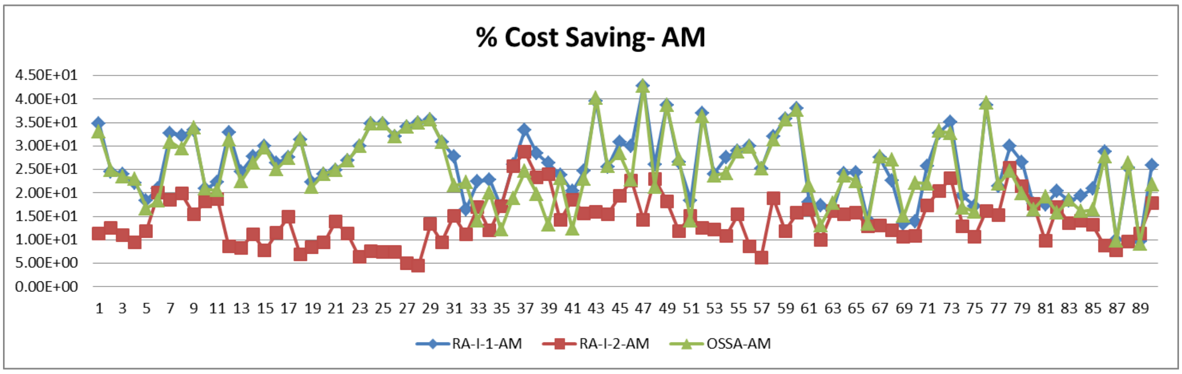


Figure-49: % Cost Saving for Improvement Algorithms-AM

Furthermore, when the percent change in initial routing cost is compared for three algorithms, it can be seen that highest change is concluded in the result of the OSSA whereas the least change is seen in the result of the RAI-2. The percent change represents the difference between the results of AM and AA gathered after construction of the same algorithm. Since the construction of AM and AA results in different village to doctor assignments, the results show variations. See figure-50 for detailed representation of the percent change in initial routing cost for all the algorithms.

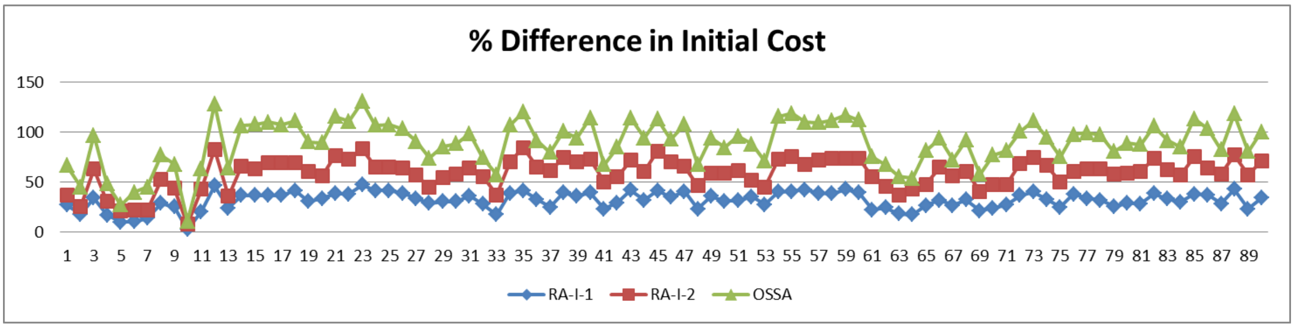


Figure-50: % Initial Cost Change between AA & AM

When the percent change in improved routing cost is compared for three algorithms, it can be seen that highest change is again concluded in the result of the OSSA. The one with the least percent change is seen in the results of the improvement algorithm-1 whereas again highest change is observed in the results of OSSA. See figure-51 for detailed representation of the percent change in improved routing cost for all the algorithms.

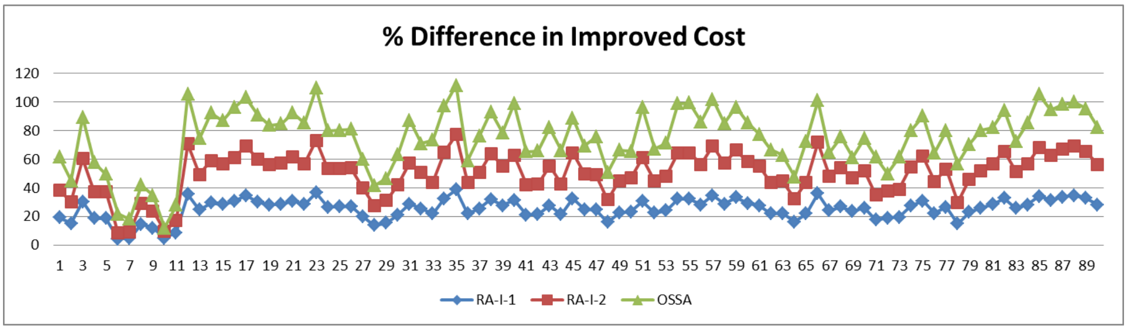


Figure-51: % Improved Cost Change between AA & AM

9.2 Simulated Data

The methodology applied to extended data can also be applied to hypothetical data sets other than Burdur city to make a cost effective schedule for the family physicians. The generated data satisfies the requirements of the model such as having same frequency values with extended data. However, the village locations that are used in simulated data sets are generated randomly.

9.2.1 Computational Results for Simulated Data

As it is mentioned before, the total routing costs of initial and improved solutions are used as performance measures in the previous comparisons for the extended data. Therefore, by using the same performance measures we evaluated the results of the simulated data.

After construction of AA or AM we gathered an assignment for each doctor. By using those assignment results we get those initial placements in the initial solution phase. When the assignment model and approximation algorithm's resulting performance are compared, it can be seen that for 90 simulated instances total cost of initial routing is similar for all algorithms constructed by AA & AM. See figure-52 and 53.

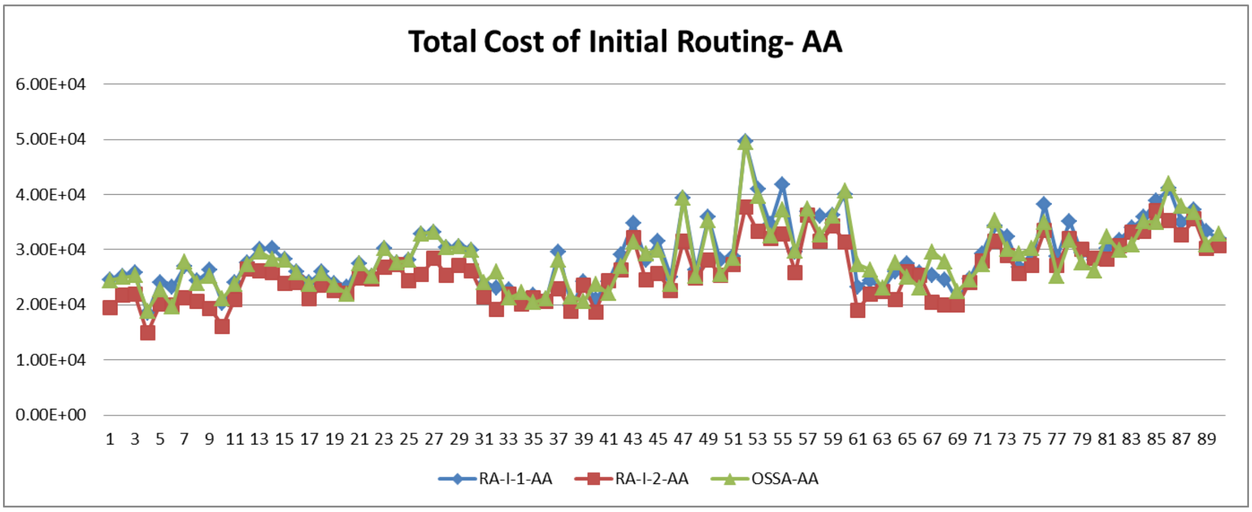


Figure – 52: Initial Routing Total Cost Comparison- AA

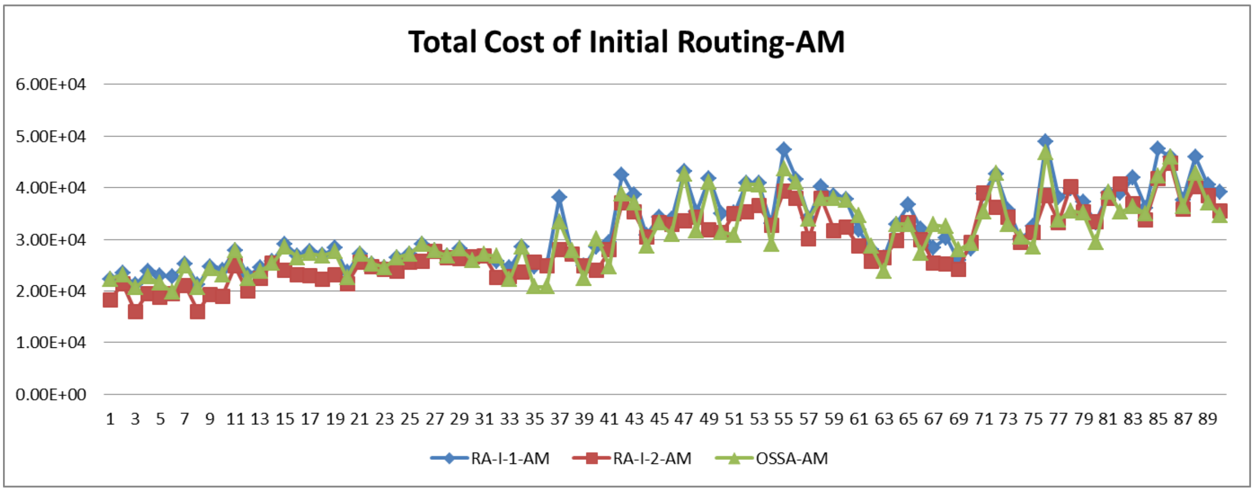


Figure – 53: Initial Routing Total Cost Comparison - AM

The improved routing total cost results are compared for three algorithms by using the assignment results constructed by using the AA and AM. In terms of total cost of improved routing, the algorithms also show similar results. See figure-54 and 55 for details.

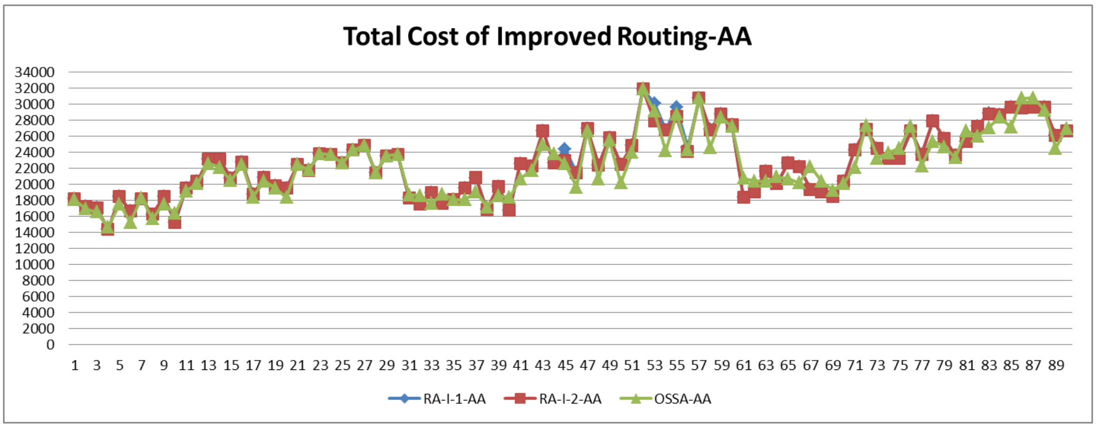


Figure – 54: Improved Routing Total Cost Comparison- AA

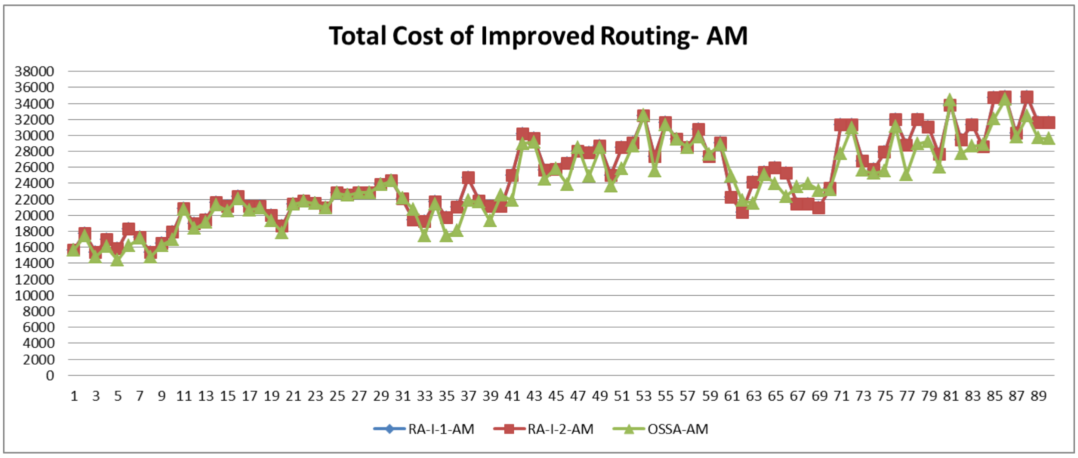


Figure – 55: Improved Routing Total Cost Comparison- AM

When the difference between initial placement and improved placement results are compared for the three algorithms, it can be observed that for all algorithms initial placement is improved after construction of the TSP based improvement methodology. It can be concluded that the OSSA gives the least costly results in general when all improvement algorithms are compared for 90 instances. See figure-56 for detailed comparison chart.

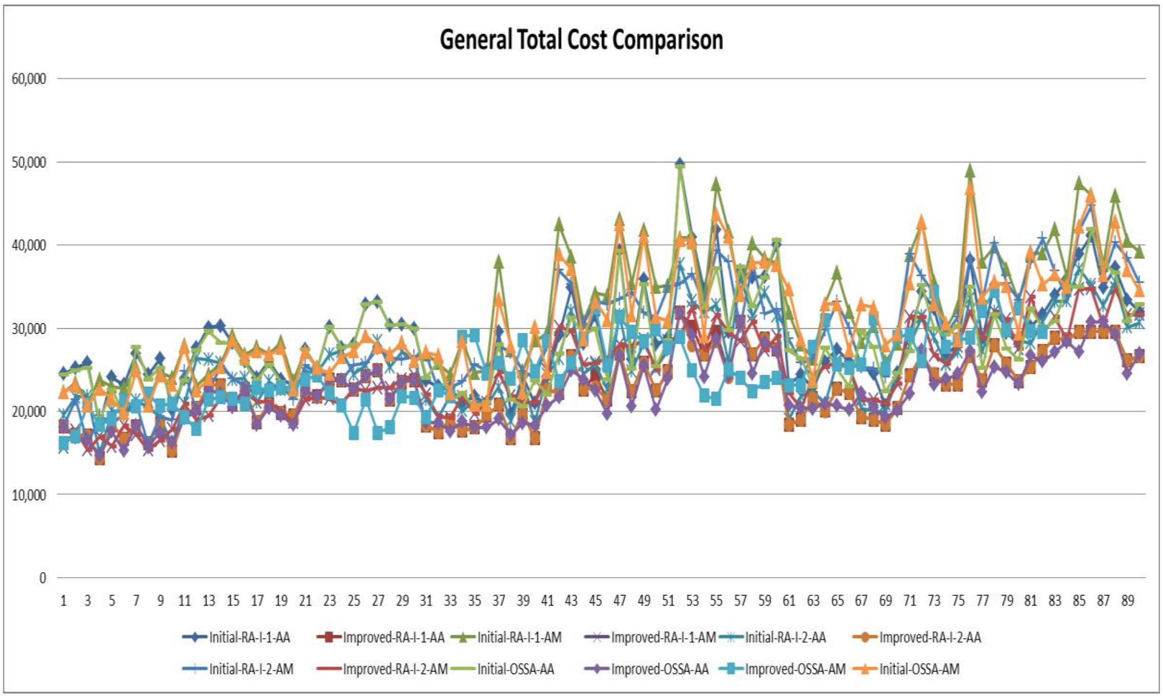


Figure – 56: General Total Cost Comparison- AM

When the CPU time of improvement algorithms are compared, it can be realized that the OSSA outperforms the other improvement algorithms. Moreover, the improvement algorithm-1 outperforms improvement algorithm-2 in terms of CPU time spent for the results constructed by using AA. However, for the results constructed by using AM, it can be concluded that OSSA outperforms the others whereas RAI-2 spent less CPU time when compared with RAI-1. See figure-57 and 58 for details.

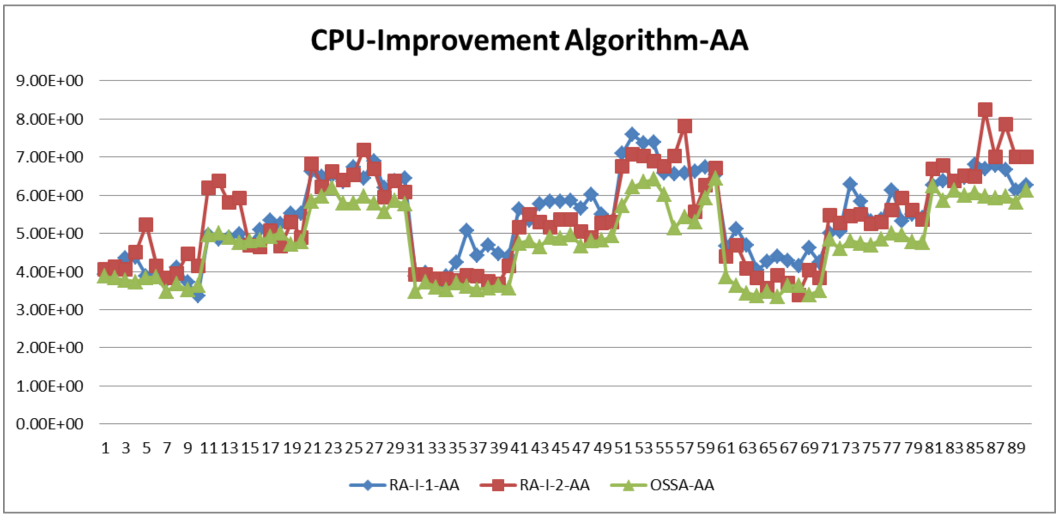


Figure-57: CPU Comparison of Algorithms for AA

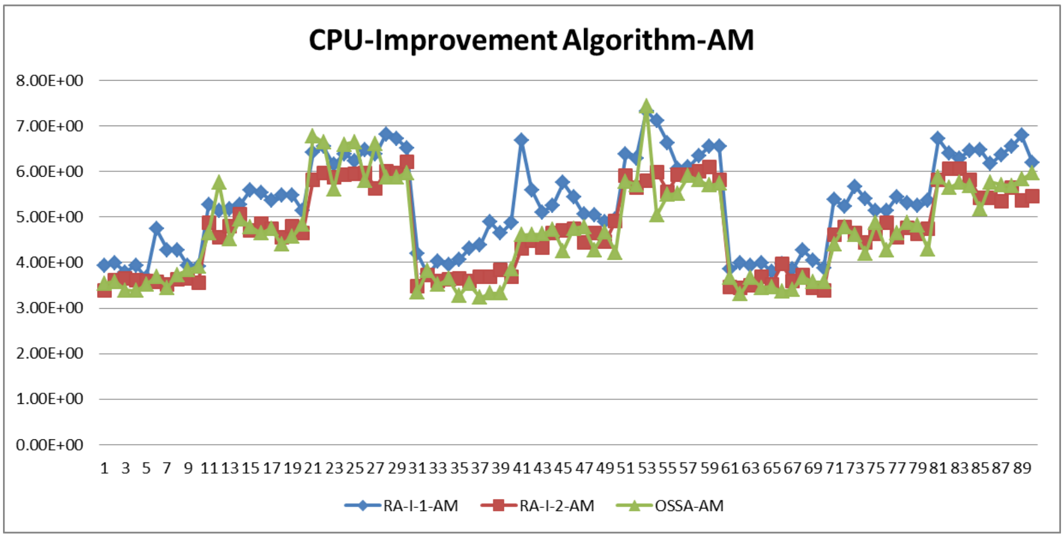


Figure-58: CPU Comparison of Algorithms for AM

The percent cost saving is calculated by the difference between initial and improved routing costs. When those results in the figure-59 and 60 are evaluated, it can be concluded that least cost saving can be seen in RAI-2 whereas RA-I-1 and OSSA shows better results.

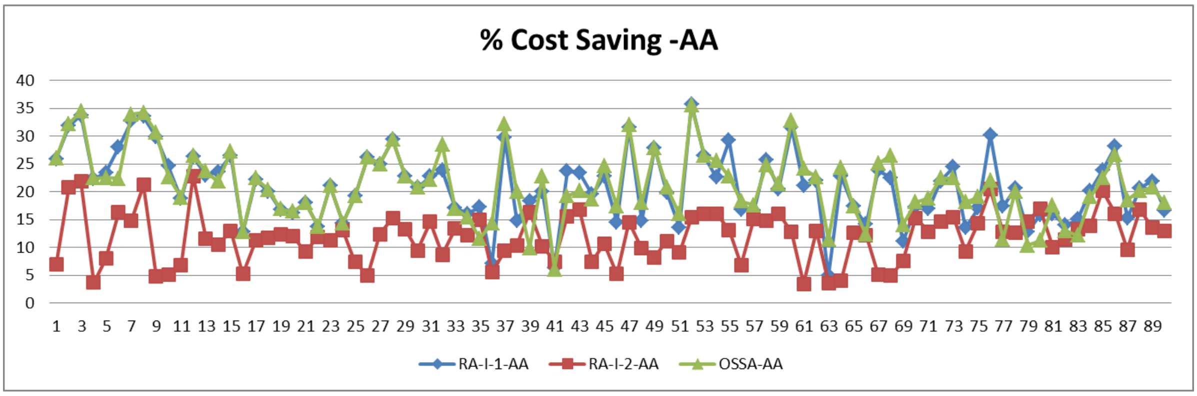


Figure-59: % Cost Saving for Improvement Algorithms-AA

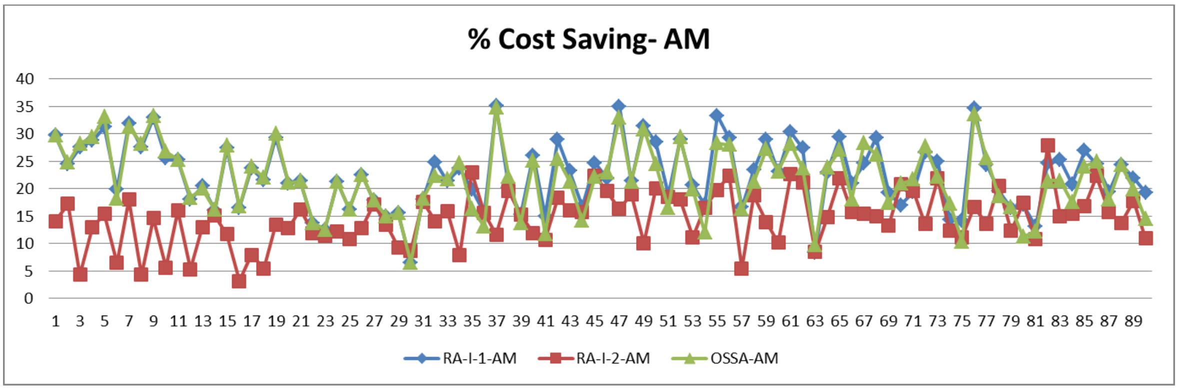


Figure-60: % Cost Saving for Improvement Algorithms-AM

When the percent difference in initial routing cost is compared for three improvement algorithms, it is concluded that the percent change for all algorithms are similar that are constructed with AA and AM. For the first 30 instance, AM gives better results than AA. However, for the last 60 instances the AA gives better results when compared with AM initial routing cost. See figure-61 for details.

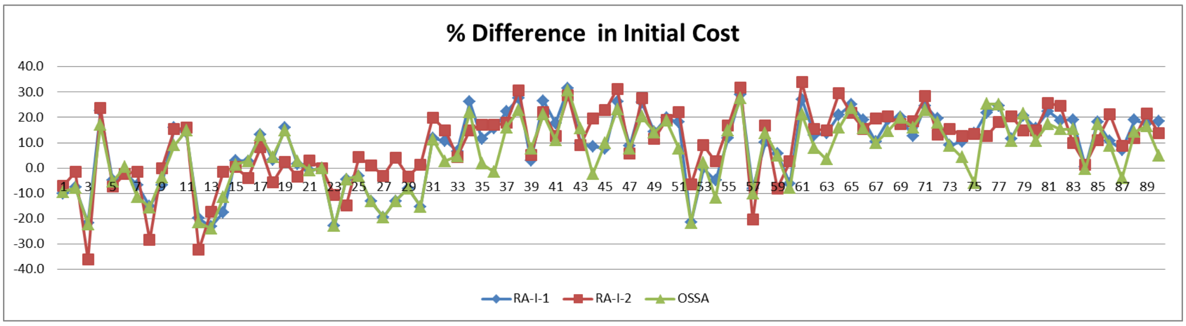


Figure-61: % Initial Cost Change between AA &AM

When the percent difference in improved routing cost is compared for three algorithms, it can be seen that the percent difference for all algorithms are similar constructed with AA and AM. For the first 28 instance, AM gives better results than AA. However, for the last 62 instances the AA gives better results when compared with AM initial routing cost. See figure-62 for detailed representation of the percent change in improved routing cost for all the algorithms.

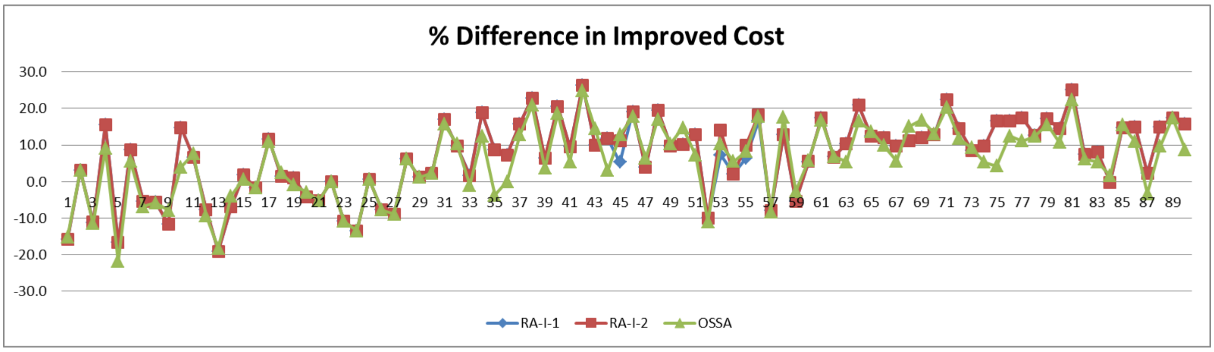


Figure-62: % Improved Cost Change between AA &AM

Chapter 10

Conclusion

In this study, the scheduling problem of family physicians was addressed. This problem is important because providing periodic healthcare services to the rural areas is a significant problem in the world. The main reason of this is the difficulty of reaching healthcare services in urban areas because of the remoteness of rural areas. Especially in Turkey, special services, namely mobile healthcare services (MHS), are provided to the rural areas by using vehicles with a family physician and a healthcare worker to satisfy the healthcare service needs of the residents in these rural parts. Therefore, there is a major need for a cost effective schedule for the family physicians which will give MHSs to the people living in rural parts to provide healthcare services periodically.

To provide a cost effective schedule for the family physicians that give periodic MHS, we generated a BIP model. That model finds the villages that are assigned to each doctor by considering the distances between villages and the monthly service capacity of each physician. Since that model is NP-hard it is almost impossible to find an optimal solution in a reasonable time limit. Therefore, we constructed a heuristic algorithm to find doctor to village assignments. According to the villages assigned to each doctor we found a weekly route for each doctor to minimize the total route cost by using a routing algorithm. The aim of this algorithm is to minimize the cost of traveling those villages in all of the models and algorithms that are constructed. After the construction of initial routes for each doctor, the routes are improved to get less costly routes by using two different improvement algorithms. These improvement algorithms are called as improvement algorithm 1&2 (RAI-1, RAI-2). In addition to these, an optional schedule selection algorithm is constructed which considers different options in the visit of villages with frequency 2. The first option is a consecutive visit in the same week, and the other option is two visits with one week break. The results of those three algorithms are analyzed and compared with each other in chapter 9.

To evaluate the results of the model and algorithms, we implemented the algorithms in Burdur city. With this case study, the results of the improvement algorithms are compared in terms of the cost effectiveness and CPU time spent. In addition to this implementation, the system is also applied to the extended and simulated data to evaluate the results in different data sets. All of the data sets include 90 instances. Therefore, we compared the results for 181 instances, in total.

As a result of the comparisons of approximation algorithm (AA) and assignment model (AM) using the Burdur data, it is concluded that there is not a significant difference between the results of those algorithms. When the results of the two improvement algorithms are evaluated, it can be concluded that AA outperforms AM in terms of total cost of the initial routing and the improved routing algorithms. Moreover, AM spent days to get the optimal result whereas AA finds a solution in maximum 8 seconds. However, when the two improvement algorithms are compared it is found out that there is a significant difference between the total cost results. The improvement algorithm-2 outperforms improvement algorithm-1 in terms of total cost of routing. When the improvement in the initial total routing costs of AM and AA are compared for both of the improvement algorithms, we can see that the percent cost saving gathered as a result of the routing with AM is more than the one with AA.

The algorithms are also applied to simulated and extended data sets. When the results of extended and simulated data runs are compared, it is observed that the three algorithms give near results in terms of CPU time, % cost saving and total cost of routings. However, OSSA gives the best results in general when compared in terms of total cost of the routing gathered after application of the improvement based on TSP methodology, especially when the instance includes many villages with frequency 2. When the two algorithms are compared in general, improvement algorithm-2 (RAI-2) outperforms improvement algorithm-1 (RAI-1) in terms of total cost of the improved routing.

When the percent difference in initial routing and improved routing costs are compared for the three improvement algorithms, it is concluded that the percent change for all algorithms are similar that are constructed with AA and AM. For the first 30 instance, AM gives better results than AA. However, for the last 60 instances the AA gives better results when compared with AM initial routing and improved routing cost.

All in all, we can conclude that by using those schedules generated for the family physicians, more effective mobile healthcare services can be provided to the people that live in rural areas.

The problem that is addressed in this study can be also applied to delivery problems in real life. However, the delivery of the goods should be made at the same day of each week of a month. Also, the person that is responsible from the delivery of the goods should have been assigned to the shops that he should be providing service. Also, in that case the delivery can be possible in determined visit frequencies as explained in this problem. There is no other algorithm that solves that problem with those specific features. Therefore, we think that by using our solution methodology, a cost effective solution can be also gathered for the delivery problems that include same constraints with this problem.

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APPENDIX

Appendix-1: Coordinates of Villages in Burdur Data & Extended Data Set.

NO	VILLAGE	x	y	NO	VILLAGE	x	y
1	BUCAK Hospital (DEPOT)	633	402	26	KUSBABA	484	408
2	ALKAYA	611	315	27	KUYUBASI	676	514
3	AVDANCIK	600	525	28	SEYDIKOY	594	354
4	BELOREN	649	322	29	SUSUZ	597	494
5	BESKONAK	721	422	30	TASYAYLA	720	326
6	BOGAZKOY	535	562	31	UGURLU	543	565
7	COBANPINAR	823	497	32	UZUMLUBEL	523	421
8	BAGARCIK	576	342	33	YUVA	470	574
9	DEMIRLI	758	584	34	YURUEGIL	381	514
10	DUTALAN	771	451	35	Çeltikçi merkez	533	312
11	ELSAZLI	837	407	36	Kuzköy	490	292
12	HEYBELI	402	499	37	Çebiş	488	361
13	INCIRDERE	541	386	38	Güvenli	523	255
14	KARAALILER	516	517	39	Tekkeköy	488	259
15	KARACOREN	864	507	40	Ovacık	428	297
16	KARAOT	635	629	41	Bağsaray	466	336
17	KARAPINAR	581	524	42	DEREKOY	660	189
18	KARASEKI	804	531	43	YESILBASKOY	541	168
19	KARGI	859	564	44	CAMLIDERE	687	188
20	KAVACIK	808	597	45	HISAR	685	245
21	KECILI	453	487	46	KIPRIT	553	229
22	KESTEL	453	488	47	YAZIR	643	160
23	KIZILCAAGAC	502	558	48	YUMRUTAS	728	224
24	KIZILLI	937	478	49	ASAGIYUMRUTAS	781	247
25	KIZILSEKI	1010	602	50	CANAKLI	624	272

Appendix-2: Coordinates of Villages in Simulated Data Set.

VILLAGE	x	y	VILLAGE	x	y
DEPOT	550	524	D-25	380	749
D-1	558	757	D-26	931	196
D-2	560	540	D-27	487	688
D-3	836	621	D-28	266	545
D-4	815	314	D-29	914	801
D-5	680	513	D-30	982	744
D-6	441	967	D-31	495	913
D-7	830	592	D-32	200	902
D-8	580	569	D-33	332	401
D-9	416	308	D-34	468	729
D-10	945	540	D-35	635	278
D-11	888	662	D-36	336	127
D-12	595	711	D-37	643	770
D-13	660	456	D-38	740	550
D-14	628	431	D-39	300	532
D-15	287	989	D-40	206	914
D-16	371	134	D-41	367	649
D-17	524	897	D-42	387	656
D-18	307	922	D-43	482	873
D-19	860	817	D-44	557	825
D-20	275	189	D-45	177	619
D-21	303	336	D-46	336	265
D-22	254	402	D-47	821	316
D-23	305	712	D-48	126	898
D-24	492	223	D-49	936	126

Appendix-3: Population Sizes and Visit Frequencies of Villages in Burdur Data & Extended Data Set.

NO	VILLAGE	POPULATION	FREQUENCY	NO	VILLAGE	POPULATION	FREQUENCY
1	ALKAYA	236	2	26	KUYUBASI	131	1
2	AVDANCIK	391	2	27	SEYDIKOY	699	4
3	BELOREN	60	1	28	SUSUZ	1057	8
4	BESKONAK	376	2	29	TASYAYLA	663	4
5	BOGAZKOY	1009	8	30	UGURLU	554	4
6	COBANPINAR	606	4	31	UZUMLUBEL	229	2
7	BAGARCIK	181	1	32	YUVA	285	2
8	DEMIRLI	542	4	33	YURUEGIL	499	2
9	DUTALAN	112	1	34	Çeltikçi merkez	2489	12
10	ELSAZLI	693	4	35	Kuzköy	538	4
11	HEYBELI	567	4	36	Çebiş	425	2
12	INCIRDERE	539	4	37	Güvenli	202	2
13	KARAALILER	549	4	38	Tekkeköy	75	1
14	KARACOREN	178	1	39	Ovacık	1008	8
15	KARAOT	213	2	40	Bağsaray	1992	12
16	KARAPINAR	1066	8	41	DEREKOY	303	2
17	KARASEKI	170	1	42	YESILBASKOY	1509	12
18	KARGI	502	4	43	CAMLIDERE	260	2
19	KAVACIK	301	2	44	HISAR	249	2
20	KECILI	242	2	45	KIPRIT	283	2
21	KESTEL	895	4	46	YAZIR	780	4
22	KIZILCAAGAC	208	2	47	YUMRUTAS	146	1
23	KIZILLI	497	2	48	ASAGIYUMRUTAS	91	1
24	KIZILSEKI	1093	8	49	CANAKLI	1330	8
25	KUSBABA	1022	8	Total Frequency = 187			

Appendix-4: Number of Villages, Number of Doctors and Frequency Sets Used in 90 Instances of Extended & Simulated Data Sets.

RUN NO	COMBINATION		NUMBER OF [12,8,4,2,1] VALUED VILLAGES	FREQUENCY SETS
1		SET-1	1 9 6 3 6	frequency=[12 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 2 2 2 1 1 1 1 1 1];
2		SET-2	1 7 10 5 2	frequency=[12 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 1 1];
3		SET-3	2 6 10 1 6	frequency=[12 12 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 2 1 1 1 1 1 1];
4		SET-4	1 11 2 1 10	frequency=[12 8 8 8 8 8 8 8 8 8 8 8 4 4 2 1 1 1 1 1 1 1 1 1 1];
5	V=3,	SET-5	1 9 4 9 2	frequency=[12 8 8 8 8 8 8 8 8 8 4 4 4 4 2 2 2 2 2 2 2 2 2 1 1];
6	N=25	SET-6	1 10 1 11 2	frequency=[12 8 8 8 8 8 8 8 8 8 8 4 2 2 2 2 2 2 2 2 2 2 2 1 1];
7		SET-7	2 6 9 4 4	frequency=[12 12 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 2 2 2 2 1 1 1 1];
8		SET-8	1 8 9 1 6	frequency=[12 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 2 1 1 1 1 1 1];
9		SET-9	2 6 8 7 2	frequency=[12 12 8 8 8 8 8 8 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 1 1];
10		SET-10	1 10 4 2 8	frequency=[12 8 8 8 8 8 8 8 8 8 8 4 4 4 4 2 2 1 1 1 1 1 1 1 1];
11		SET-1	5 9 4 5 2	frequency=[12 12 12 12 12 8 8 8 8 8 8 8 8 8 4 4 4 4 2 2 2 2 2 1 1];
12		SET-2	3 13 3 2 4	frequency=[12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 2 2 1 1 1 1];
13		SET-3	4 11 4 2 4	frequency=[12 12 12 12 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 2 2 1 1 1 1];
14		SET-4	4 11 3 5 2	frequency=[12 12 12 12 8 8 8 8 8 8 8 8 8 8 8 4 4 4 2 2 2 2 2 1 1];
15	V=4,	SET-5	1 16 3 3 2	frequency=[12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 2 2 2 1 1];
16	N=25	SET-6	3 13 2 5 2	frequency=[12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 2 2 2 2 2 1 1];
17		SET-7	4 9 9 1 2	frequency=[12 12 12 12 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 2 1 1];
18		SET-8	2 14 4 3 2	frequency=[12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 2 2 2 1 1];
19		SET-9	2 15 2 2 4	frequency=[12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 2 2 1 1 1 1];
20		SET-10	2 15 1 5 2	frequency=[12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 2 2 2 2 2 1 1];
21		SET-1	1 23 1 0 0	frequency=[12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4];
22		SET-2	2 21 2 0 0	frequency=[12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4];
23		SET-3	3 19 3 0 0	frequency=[12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4];
24		SET-4	4 17 4 0 0	frequency=[12 12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4];
25	V=5,	SET-5	5 15 5 0 0	frequency=[12 12 12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4];
26	N=25	SET-6	6 13 6 0 0	frequency=[12 12 12 12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4];
27		SET-7	7 11 7 0 0	frequency=[12 12 12 12 12 12 12 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4];
28		SET-8	8 9 8 0 0	frequency=[12 12 12 12 12 12 12 12 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4];
29		SET-9	9 7 9 0 0	frequency=[12 12 12 12 12 12 12 12 12 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4];
30		SET-10	10 5 10 0 0	frequency=[12 12 12 12 12 12 12 12 12 12 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4];

RUN NO	COMBINATION		NUMBER OF [12,8,4,2,1] VALUED VILLAGES	FREQUENCY SETS
31		SET-1	2 5 5 8 20	frequency=[12 12 8 8 8 8 8 4 4 4 4 4 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
32		SET-2	2 5 6 5 22	frequency=[12 12 8 8 8 8 8 4 4 4 4 4 4 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
33		SET-3	2 2 6 26 4	frequency=[12 12 8 8 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1];
34		SET-4	4 3 3 6 24	frequency=[12 12 12 12 8 8 8 4 4 4 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
35	V=3,	SET-5	4 2 3 13 18	frequency=[12 12 12 12 8 8 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
36	N=40	SET-6	4 1 2 23 10	frequency=[12 12 12 12 8 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1];
37		SET-7	1 1 15 17 6	frequency=[12 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1];
38		SET-8	2 6 2 10 20	frequency=[12 12 8 8 8 8 8 8 4 4 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
39		SET-9	1 5 4 22 8	frequency=[12 8 8 8 8 8 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1];
40		SET-10	4 2 7 1 26	frequency=[12 12 12 12 8 8 4 4 4 4 4 4 4 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
41		SET-1	7 3 2 16 12	frequency=[12 12 12 12 12 12 12 8 8 8 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
42		SET-2	1 10 9 12 8	frequency=[12 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1];
43		SET-3	4 1 19 12 4	frequency=[12 12 12 12 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1];
44		SET-4	3 10 2 11 14	frequency=[12 12 12 8 8 8 8 8 8 8 8 8 8 4 4 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
45	V=4,	SET-5	6 1 13 8 12	frequency=[12 12 12 12 12 12 8 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
46	N=40	SET-6	5 5 6 12 12	frequency=[12 12 12 12 12 8 8 8 8 8 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
47		SET-7	1 4 26 3 6	frequency=[12 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 1 1 1 1 1 1];
48		SET-8	5 4 7 16 8	frequency=[12 12 12 12 12 8 8 8 8 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1];
49		SET-9	3 1 25 5 6	frequency=[12 12 12 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 1 1 1 1 1 1];
50		SET-10	5 4 9 10 12	frequency=[12 12 12 12 12 8 8 8 8 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
51		SET-1	12 1 2 15 10	frequency=[12 12 12 12 12 12 12 12 12 12 12 12 8 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1];
52		SET-2	3 6 28 1 2	frequency=[12 12 12 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 1 1];
53		SET-3	1 15 13 5 6	frequency=[12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 1 1 1 1 1 1];
54		SET-4	8 4 9 17 2	frequency=[12 12 12 12 12 12 12 12 8 8 8 8 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1];
55	V=5,	SET-5	1 15 11 11 2	frequency=[12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 1 1];
56	N=40	SET-6	1 19 5 1 14	frequency=[12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
57		SET-7	8 4 14 2 12	frequency=[12 12 12 12 12 12 12 12 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
58		SET-8	8 3 14 9 6	frequency=[12 12 12 12 12 12 12 12 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1];
59		SET-9	3 13 11 3 10	frequency=[12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 2 2 2 1 1 1 1 1 1 1 1 1 1];
60		SET-10	4 10 15 1 10	frequency=[12 12 12 12 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 1 1 1 1 1 1 1 1 1 1];

Appendix-4 (Cont'd): Number of Villages, Number of Doctors and Frequency Sets Used in 90 Instances of Extended & Simulated Data Sets.

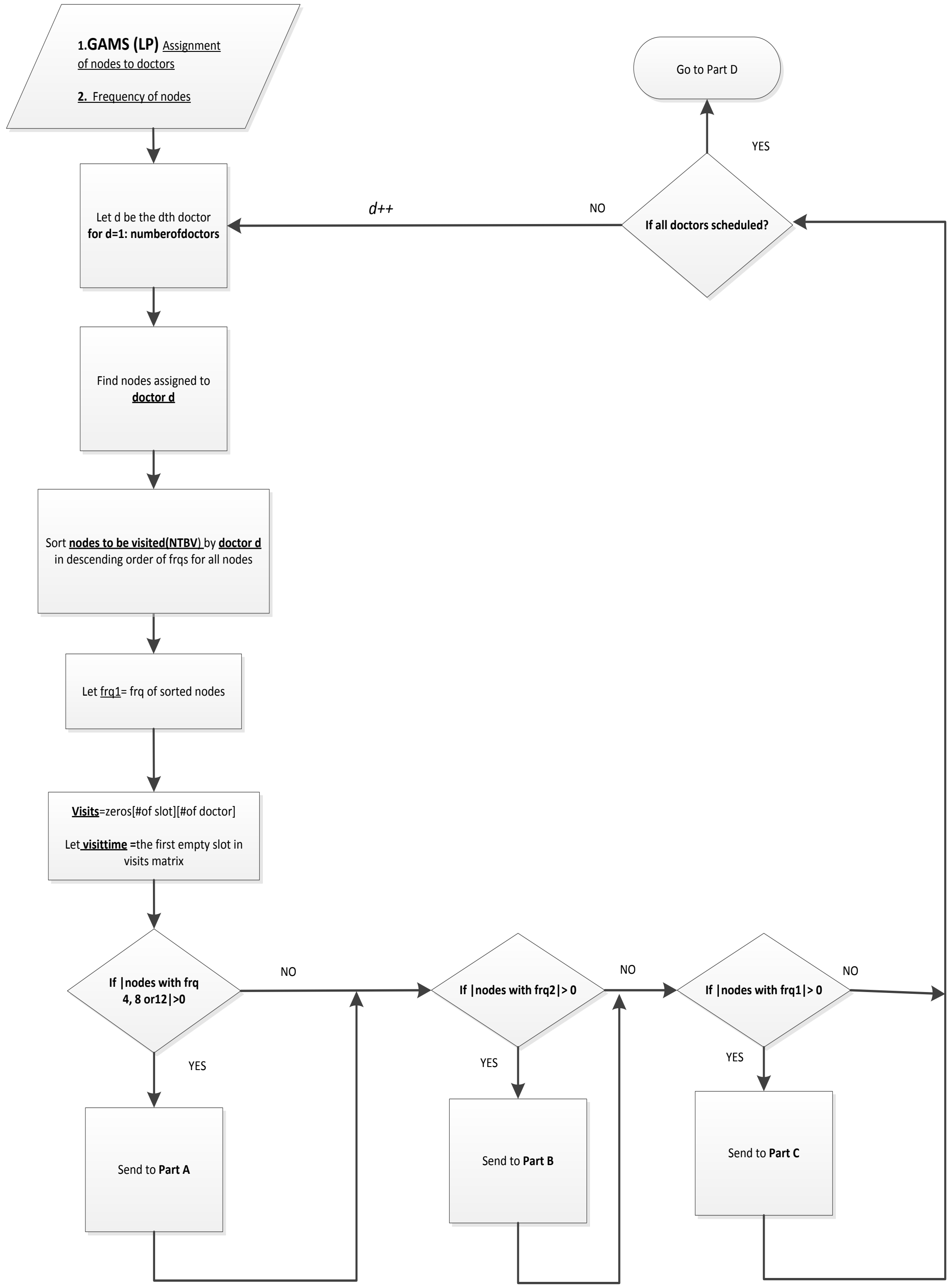
RUN NO	COMBINATION		NUMBER OF [12,8,4,2,1] VALUED VILLAGES	FREQUENCY SETS
61	V=3, N=49	SET-1	3 1 10 1 34	frequency=[12 12 12 8 4 4 4 4 4 4 4 4 4 4 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
62		SET-2	2 3 7 7 30	frequency=[12 12 8 8 8 4 4 4 4 4 4 4 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
63		SET-3	1 3 3 30 12	frequency=[12 8 8 8 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
64		SET-4	1 3 11 6 28	frequency=[12 8 8 8 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
65		SET-5	1 2 8 22 16	frequency=[12 8 8 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
66		SET-6	1 3 5 24 16	frequency=[12 8 8 8 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
67		SET-7	2 2 11 2 32	frequency=[12 12 8 8 4 4 4 4 4 4 4 4 4 4 4 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
68		SET-8	2 2 10 5 30	frequency=[12 12 8 8 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
69		SET-9	4 2 2 7 34	frequency=[12 12 12 12 8 8 4 4 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
70		SET-10	3 1 6 13 26	frequency=[12 12 12 8 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
71	V=4, N=49	SET-1	4 1 10 30 4	frequency=[12 12 12 12 8 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1];
72		SET-2	2 4 19 4 20	frequency=[12 12 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
73		SET-3	2 4 15 16 12	frequency=[12 12 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
74		SET-4	6 4 3 8 28	frequency=[12 12 12 12 12 12 8 8 8 8 4 4 4 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
75		SET-5	6 1 6 20 16	frequency=[12 12 12 12 12 12 8 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
76		SET-6	1 4 21 9 14	frequency=[12 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
77		SET-7	4 3 7 25 10	frequency=[12 12 12 12 8 8 8 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1];
78		SET-8	3 4 11 17 14	frequency=[12 12 12 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
79		SET-9	1 10 5 15 18	frequency=[12 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
80		SET-10	5 2 4 30 8	frequency=[12 12 12 12 12 8 8 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1];
81	V=5, N=49	SET-1	9 6 3 1 30	frequency=[12 12 12 12 12 12 12 12 12 8 8 8 8 8 8 4 4 4 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
82		SET-2	8 5 4 16 16	frequency=[12 12 12 12 12 12 12 12 8 8 8 8 8 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
83		SET-3	8 5 2 22 12	frequency=[12 12 12 12 12 12 12 12 8 8 8 8 8 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];
84		SET-4	7 8 2 12 20	frequency=[12 12 12 12 12 12 12 8 8 8 8 8 8 8 8 4 4 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
85		SET-5	9 1 8 21 10	frequency=[12 12 12 12 12 12 12 12 12 8 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1];
86		SET-6	1 14 11 9 14	frequency=[12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 4 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
87		SET-7	10 3 4 8 24	frequency=[12 12 12 12 12 12 12 12 12 12 8 8 8 4 4 4 4 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
88		SET-8	3 14 3 11 18	frequency=[12 12 12 8 8 8 8 8 8 8 8 8 8 8 8 8 8 4 4 4 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
89		SET-9	6 8 2 23 10	frequency=[12 12 12 12 12 12 8 8 8 8 8 8 8 8 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1];
90		SET-10	7 5 7 18 12	frequency=[12 12 12 12 12 12 12 8 8 8 8 8 4 4 4 4 4 4 4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1];

Appendix-5: Distance matrix of 49 villages in Burdur Data.

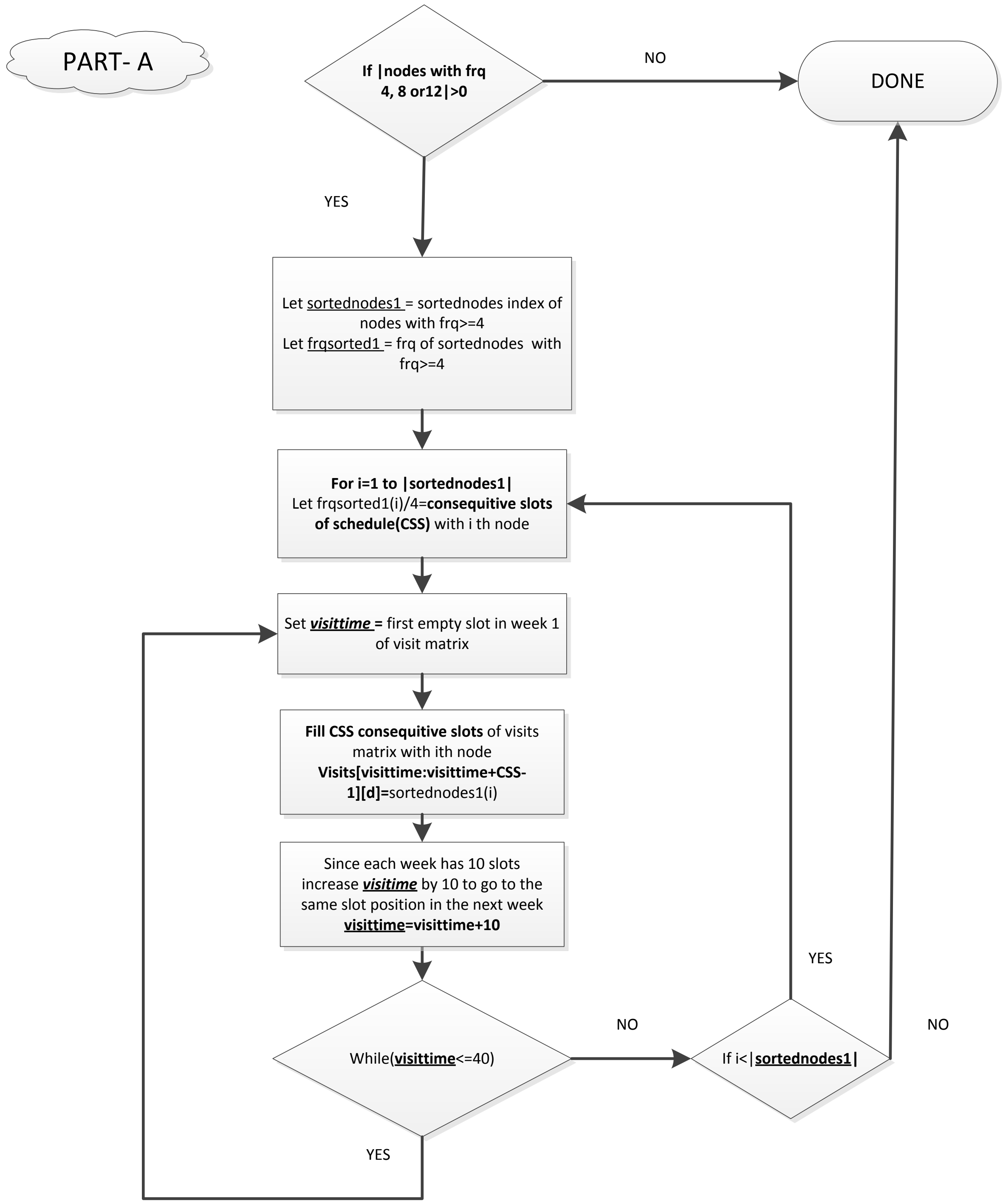
	VILLAGES																																																
	i1	i2	i3	i4	i5	i6	i7	i8	i9	i10	i11	i12	i13	i14	i15	i16	i17	i18	i19	i20	i21	i22	i23	i24	i25	i26	i27	i28	i29	i30	i31	i32	i33	i34	i35	i36	i37	i38	i39	i40	i41	i42	i43	i44	i45	i46	i47	i48	i49
i1	0	210	39	153	258	279	44	307	210	244	278	100	223	318	315	211	290	351	344	234	234	266	364	491	157	209	43	180	110	259	138	295	304	78	123	131	107	135	184	147	135	163	148	102	104	158	148	183	45
i2	210	0	209	159	75	225	185	169	186	265	200	151	84	265	110	19	204	262	220	152	152	103	340	417	165	77	171	31	232	70	129	139	219	223	258	199	281	289	286	232	341	362	348	293	300	368	327	332	254
i3	39	209	0	123	266	247	76	284	178	206	304	126	236	284	307	213	260	320	318	256	257	278	328	457	186	194	64	180	71	265	160	309	330	116	162	166	143	173	222	184	133	188	139	85	134	162	126	152	56
i4	153	159	123	0	233	127	166	166	58	117	328	184	226	166	224	173	137	198	195	276	276	258	223	340	237	102	144	143	96	228	198	293	352	218	265	241	259	284	319	269	241	311	236	181	256	273	198	185	179
i5	258	75	266	233	0	295	224	224	261	339	147	176	49	334	120	60	271	324	275	111	110	33	411	477	162	149	216	92	300	9	142	66	161	250	274	206	307	307	286	236	393	394	404	351	333	416	389	400	303
i6	279	225	247	127	295	0	292	109	69	91	421	303	308	42	230	244	39	76	101	370	370	327	116	214	350	148	270	226	200	288	309	361	442	344	391	362	385	411	443	392	348	433	338	287	380	382	289	254	300
i7	44	185	76	166	224	292	0	303	223	269	234	56	185	332	293	182	296	360	345	190	191	228	386	506	113	199	22	153	145	225	95	255	260	52	99	90	102	121	155	110	175	177	190	146	115	194	192	226	85
i8	307	169	284	166	224	109	303	0	134	194	366	294	251	131	131	187	70	103	52	320	320	257	208	253	326	108	282	184	261	216	286	288	383	353	396	350	404	423	437	383	407	469	402	347	410	439	361	338	340
i9	210	186	178	58	261	69	223	134	0	79	372	239	263	109	224	204	87	143	151	320	320	289	168	283	290	114	202	179	135	255	250	325	395	276	323	297	316	342	376	326	285	365	276	223	311	318	231	204	232
i10	244	265	206	117	339	91	269	194	79	0	445	297	339	104	300	281	128	159	192	392	392	367	123	261	353	193	249	255	142	334	314	403	468	318	366	352	349	379	424	378	281	380	265	222	335	314	213	170	252
i11	278	200	304	328	147	421	234	366	372	445	0	179	115	462	267	181	403	462	418	52	52	116	535	617	122	274	241	195	362	156	144	101	26	228	225	163	272	255	204	175	403	359	422	380	309	416	426	455	318
i12	100	151	126	184	176	303	56	294	239	297	179	0	133	345	261	144	300	364	340	134	135	176	407	516	61	186	62	122	189	179	39	201	205	74	107	59	132	138	144	90	230	218	246	202	157	248	247	277	141
i13	223	84	236	226	49	308	185	251	263	339	115	133	0	348	163	65	288	346	303	70	69	43	423	501	114	160	181	84	279	55	96	73	135	206	226	158	262	260	237	188	358	350	371	320	290	379	362	378	268
i14	318	265	284	166	334	42	332	131	109	104	462	345	348	0	259	284	65	57	106	411	411	366	79	174	393	188	310	267	231	326	352	400	483	384	431	403	424	450	484	433	378	468	365	317	417	411	314	273	336
i15	315	110	307	224	120	230	293	131	224	300	267	261	163	259	0	118	195	233	176	231	230	151	338	376	268	122	278	140	315	112	236	174	279	333	367	306	390	398	391	338	441	470	444	387	408	469	416	409	357
i16	211	19	213	173	60	244	182	187	204	281	181	144	65	284	118	0	223	281	238	133	133	86	359	436	151	96	170	34	242	56	118	122	200	217	249	188	275	281	274	220	344	358	352	298	296	369	334	342	256
i17	290	204	260	137	271	39	296	70	87	128	403	300	288	65	195	223	0	64	66	354	354	303	143	218	343	129	275	210	222	263	302	337	423	348	395	359	394	417	443	390	371	448	362	310	393	404	316	285	315
i18	351	262	320	198	324	76	360	103	143	159	462	364	346	57	233	281	64	0	61	413	413	357	116	156	406	190	338	271	276	316	365	389	481	412	458	423	456	480	507	454	425	508	413	363	454	458	364	326	375
i19	344	220	318	195	275	101	345	52	151	192	418	340	303	106	176	238	66	61	0	372	371	308	176	202	375	156	324	235	285	267	335	339	435	396	441	398	445	465	484	430	434	505	427	373	448	467	381	351	373
i20	234	152	256	276	111	370	190	320	320	392	52	134	70	411	231	133	354	413	372	0	1	86	484	569	85	225	194	144	312	119	96	89	77	192	198	131	242	231	192	152	363	331	380	335	277	378	381	406	275
i21	234	152	257	276	110	370	191	320	320	392	52	135	69	411	230	133	354	413	371	1	0	85	484	569	86	225	195	144	312	118	97	88	77	193	199	132	243	232	193	153	364	332	380	336	278	379	381	407	275
i22	266	103	278	258	33	327	228	257	289	367	116	176	43	366	151	86	303	357	308	86	85	0	442	510	151	179	224	115	318	42	139	36	129	248	266	197	304	299	271	225	401	392	414	363	333	422	403	418	311
i23	364	340	328	223	411	116	386	208	168	123	535	407	423	79	338	359	143	116	176	484	484	442	0	144	458	263	365	340	265	403	418	477	557	437	484	464	470	500	540	492	400	503	383	343	458	433	329	279	375
i24	491	417	457	340	477	214	506	253	283	261	617	516	501	174	376	436	218	156	202	569	569	510	144	0	561	345	484	427	400	468	520	541	635	558	605	575	598	625	657	606	541	639	525	483	590	575	472	422	508
i25	157	165	186	237	162	350	113	326	290	353	122	61	114	393	268	151	343	406	375	85	86	151	458	561	0	219	123	142	250	168	41	167	148	108	116	47	158	149	124	74	281	247	299	259	192	295	306	338	195
i26	209	77	194	102	149	148	199	108	114	193	274	186	160	188	122	96	129	190	156	225	225	179	263	345	219	0	180	81	193	142	179	215	295	247	290	242	301	317	330	275	325	371	326	269	310	356	295	287	248
i27	43	171	64	144	216	270	22	282	202	249	241	62	181	310	278	170	275	338	324	194	195	224	365	484	123	180	0	140	129	217	98	253	266	74	121	106	122	142	176	129	178	193	190	142	132	200	187	215	87
i28	180	31	180	143	92	226	153	184	179	255	195	122	84	267	140	34	210	271	235	144	144	115	340	427	142	81	140	0	208	89	104	150	217	193	229	172	250	259	260	205	311	331	319	264	269	337	300	308	224
i29	110	232	71	96	300	200	145	261	135	142	362	189	279	231	315	242	222	276	285	312	312	318	265	400	250	193	129	208	0	297	219	352	388	188	232	235	209	241	293	254	150	239	142	88	193	183	102	100	110
i30	259	70	265	228	9	288	225	216	255	334	156	179	55	326	112	56	263	316	267	119	118	42	403	468	168	142	217	89	297	0	145	74	170	253	278	211	311	311	292	242	394	397	404	350	336	417	388	397	304
i31	138	129	160	198	142	309	95	286	250	314	144	39	96	352	236	118	302	365	335	96	97	139	418	520	41	179	98	104	219	145	0	162	170	109	133	69	166	166	156	102	269	254	285	239	194	287	284	311	180
i32	295	139	309	293	66	361	255	288	325	403	101	201	73	400	174	122	337	389	339	89	88	36	477	541	167	215	253	150	352	74	162	0	107	269	283	214	323	316	280	238	429	412	443	393	355	449	435	451	339
i33	304	219	330	352	161	442	260	383	395	468	26	205	135	483	279	200	423	481	435	77	77	129	557	635	148	295	266	217	388	170	170	107	0	253	247	187	295	277	222	197	428	381	447	406	333	440	452	481	343
i34	78	223	116	218	250	344	52	353	276	318	228	74	206	384	333	217	348	412	396	192	193	248	437	558	108	247	74	193	188	253	109	269	253	0	47	67	58	70	106	71	177	144	198	166	85	188	214	256	99
i35	123	258	162	265	274	391	99	396	323	366	225	107	226	431	367	249	395	458	441	198	199	266	484	605	116	290	121	229	232	278	133	283	247	47	0	69	50	33	62	50	199	134	223	201	89	202	248	294	135
i36	131	199	166	241	206	362	90	350	297	352	163	59	158	403	306	188	359	423	398	131	132	197	464	575	47	242	106	172	235	211	69	214	187	67	69	0	112	102	88	33	243	200	264	229	147	254	276	314	163
i37	107	281	143	259	307	385	102	404	316	349	272	132	262	424	390	275	394	456	445	242	243	304	470	598	158	301	122	250	209	311	166	323	295	58	50	112	0	35	104	99	152	89	177	162	40	153	207	258	102
i38	135	289	173	284	307	411	121	423	342	379	255	138	260	450	398	281	417	480	465	231	232	299	500	625	149	317	142	259	241	311	166	316	277	70	33	102	35	0	71	80	186	105	211	197	72	184	243	293	137
i39	184	286	222	319	286	443	155	437	376	424	204	144	237	484	391	274	443	507	484	192	193	271	540	657	124	330	176	260	293	292	156	280	222	106	62	88	104	71	0	54	256	171	281	262	142	255	309	357	198
i40	147	232	184	269	236	392	110	383	326	378	175	90	188	433	338	220	390	454	430	152	153	225	492	606	74	275	129	205	254	242	102	238	197	71	50	33	99	80	54	0	243	184	266	237	138	250	285	327	170
i41	135	341	133	241	393	348	175	407	285	281	403	230	358	378	441	344	371	425	434	363	364	401	400	541	281	325	178	311	150	394	269	429	428	177	199	243	152	186	256	243	0	121	27	61	114	34	76	134	90
i42	163	362	188	311	394	433	177	469	365	380	359	218	350	468	470	358	448	508	505	331	332	392	503	639	247	371	193	331	239	397	254	412	381	144	134	200	89	105	171	184	121	0	147	163	62	102	195	253	133
i43	148	348	139	236	404	338	190	402	276	265	422	246	371	365	444	352	362	413	427	380	380	414	383	525	299	326	190	319	142	404	285	443	447	198	223	264	177	211	281	266	27	147	0	57	140	52	55	111	105
i44	102	293	85	181	351	287	146	347	223	222	380	202	320	317	387	298	310	363	373	335	336	363	343	483	259	269	142	264	88	350	239	393	406	166	201	229	162	197	262	237	61	163	57	0	133	95	48	96	67
i45	104	300	134	256	333	380	115	410	311	335	309	157	290	417	408	296	393	454	448	277	278	333	458	590	192	310	132	269	193	336	194	355	333	85	89	147	40	72	142	138	114	62	140	133	0	113	175	229	83
i46	158	368	162	273	416	382	194	439	318	314	416	248	379	411	469	369	404	458	467	378	379	422	433	575	295	356	200	337	183	417	287	449	440	188	202	254	153	184	255	250	34	102	52	95	113	0	106	163	114
i47	148	327	126	198	389	289	192	361	231	213	426	247	362	314	416	334	316	364	381	381	381	403	329	472	306	295	187	300	102	388	284	435	452	214	248	276	207	243	309	285	76	195	55	48	175	106	0	58	115
i48	183	332	152	185	400	254	226	338	204	170	455	277	378	273	409	342	285	326	351	406	407	418	279	422	338	287	215	308	100	397	311	451	481	256	294	314	258	293	357	327	134	253	111	96	229	163	58	0	159
i49	45	254	56	179	303	300	85	340	232	252	318	141	268	336	357	256	315	375	373	275	275	311	375	508	195	248	87	224	110	304	180	339	343	99	135	163	102	137	198	170	90	133	105	67	83	114	115	159	0

VILLAGES

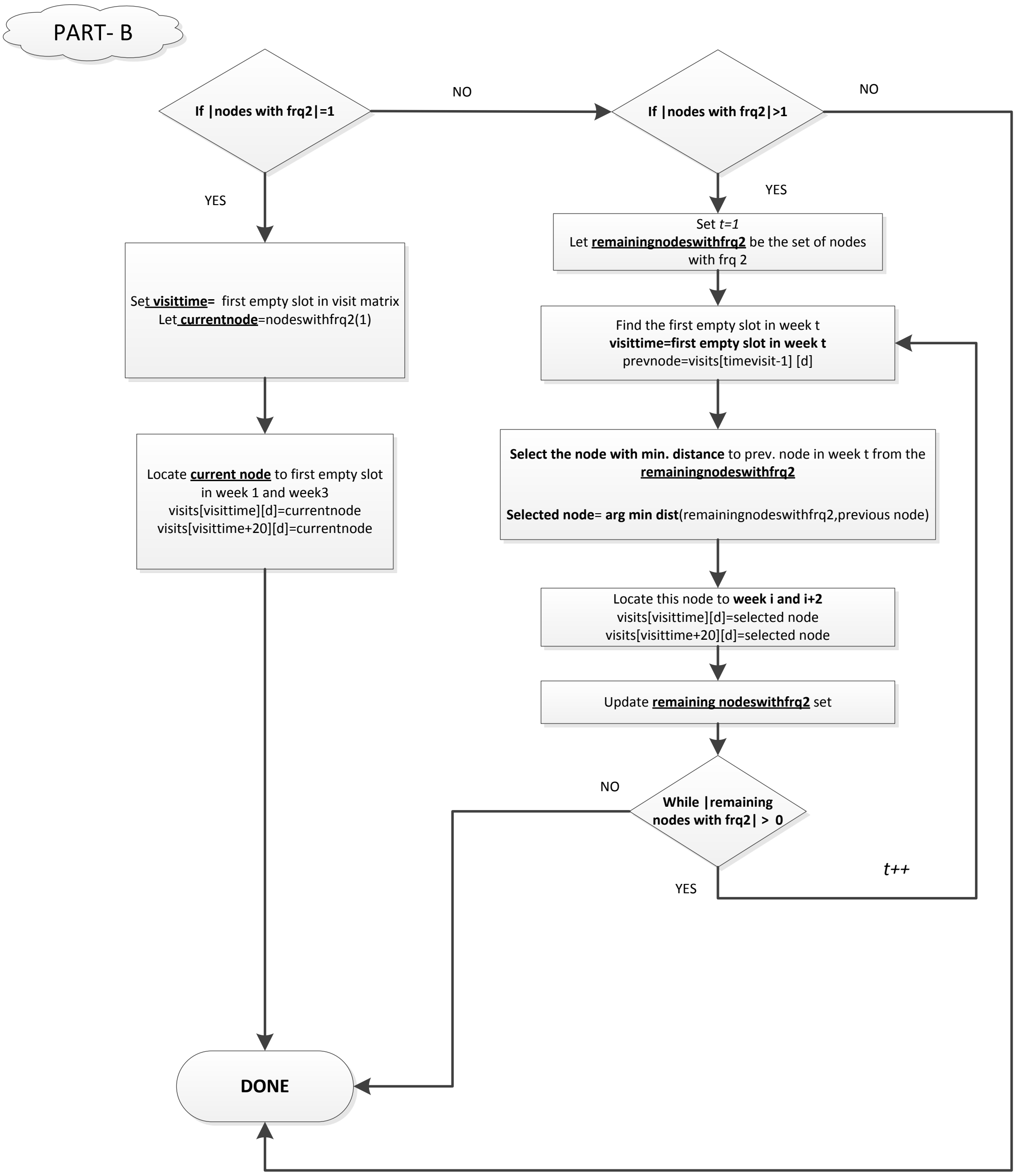
Appendix-6: Flow Chart of the Routing Algorithm (RA).



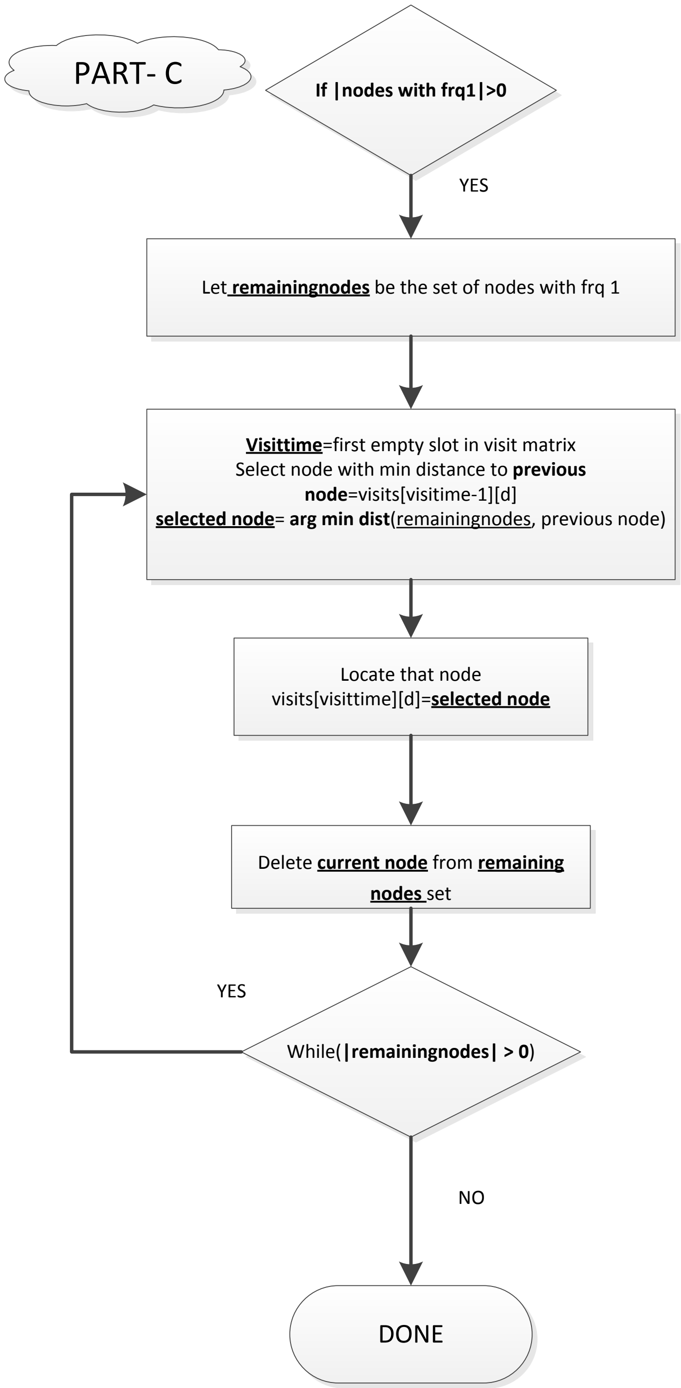
Appendix-6 (Cont'd): Flow Chart of the Routing Algorithm (RA).



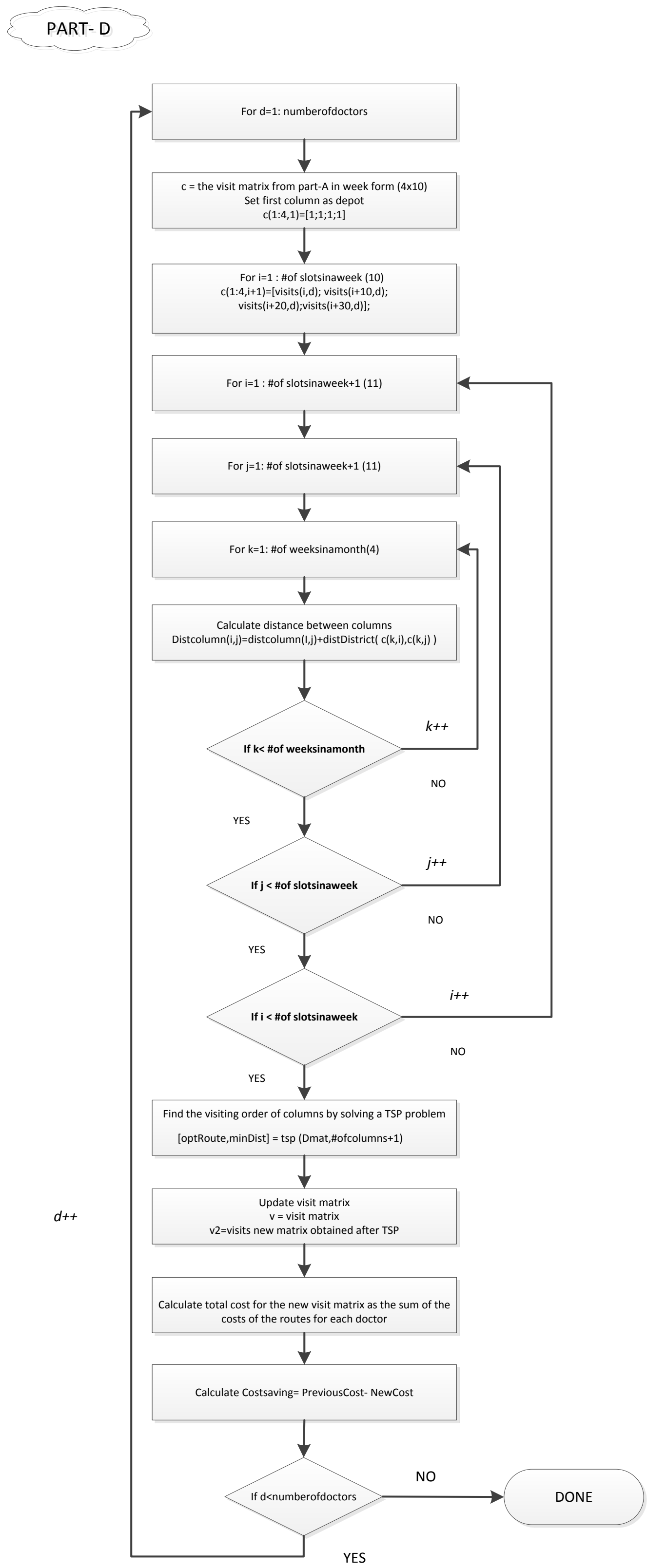
Appendix-6 (Cont'd): Flow Chart of the Routing Algorithm (RA).



Appendix-6 (Cont'd): Flow Chart of the Routing Algorithm (RA).



Appendix-7: Flow Chart of the Improvement Algorithm-1(RAI-1).



Appendix-8: Flow Chart of the Improvement Algorithm-2 (RAI-2).