INTERMODAL TRANSPORTATION OF HAZARDOUS MATERIALS WITH SUPPLIER SELECTION: APPLICATION IN TURKEY

A THESIS
SUBMITTED TO THE DEPARTMENT OF INDUSTRIAL
ENGINEERING
AND THE GRADUATE SCHOOL OF ENGINEERING AND SCIENCE OF
BILKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

by
Pelin Elaldı
November 2011

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

Assoc. Prof. Bahar Y. Kara (Advisor)

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

Asst. Prof. Osman Alp (Co-Advisor)

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

Asst. Prof. Alper Şen

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

Asst. Prof. Sibel Alumur Alev

Approved for the Graduate School of Engineering and Science

Prof. Dr. Levent Onural
Director of the Graduate School of Engineering and Science

ABSTRACT

INTERMODAL TRANSPORTATION OF HAZARDOUS MATERIALS WITH SUPPLIER SELECTION: APPLICATION IN TURKEY

Pelin Elaldı
M.S. in Industrial Engineering
Supervisor: Assoc. Prof. Bahar Y. Kara
Co-Supervisor: Assist. Prof. Osman Alp
November 2011

Fuel transportation constitutes a significant portion of hazardous materials transportation for decades. Fuel companies generally prefer highway transportation whereas railway transportation is also a potential alternative due to its advantages both from cost- and risk perspectives. The aim of this thesis is to investigate the potential benefits of using railways in conjunction to highways for fuel transportation in Turkey. In this thesis, we first investigate a quantitative risk model that could be used to assess the risk of railway transportation. Then, a mathematical model is developed which aims to answer the following three questions: What should be the routes of fuel products transported from suppliers to demand points and which transportation mode(s) should be used on these routes?, Where to open transfer units?, and Which suppliers should satisfy which demand points with what capacity?. The model has two possibly conflicting objectives of minimizing the total transportation risk and minimizing the total transportation cost. The proposed models are tested over Turkish network for which all required realistic data are collected.

Keywords: Hazardous Materials Transportation, Intermodal Transportation, Risk Analysis

ÖZET

TEHLİKELİ MADDE TAŞIMACILIĞINDA TEDARİKÇİ SEÇİMİ VE ÇOK MOD KULLANIMI: TÜRKİYE ÜZERİNDE UYGULAMA

Pelin Elaldı
Endüstri Mühendisliği Yüksek Lisans
Tez Yöneticisi: Doç Dr. Bahar Y. Kara
Eş-Tez Yöneticisi: Yrd. Doç. Dr. Osman Alp
Kasım 2011

Akaryakıt taşımacılığı yıllardır tehlikeli madde taşımacılığının önemli bir bölümünü oluşturmaktadır. Demiryolu ile taşımacılık risk ve maliyet açılarından avantajlı bir alternatif olsa da akaryakıt firmaları genellikle ürünlerini karayolu ile taşımaktadır. Bu çalışmanın amacı, akaryakıt taşımacılığında demiryollarının karayolları ile birlikte kullanımın oluşturacağı potansiyel faydaları araştırmaktır. Bu çalışmada, öncelikle demiryolu taşımacılığı riskini belirleyebilmek için kullanılabilecek nicel bir risk modeli araştırılmıştır. Daha sonra şu üç soruya cevap vermesi amaçlanan bir matematiksel model geliştirilmiştir: Akaryakıt ürünleri tedarikçilerden talep noktalarına kadar hangi rotaları izlemeli ve bu rotalar üzerinde hangi ulaştırma modu/ modları kullanılmalı? Nerelere transfer ünitesi açılmalı? ve Hangi tedarikçiler hangi talep noktalarının taleplerini hangi kapasite ile karşılamalı? Modelin biri taşıma riskinin enküçüklenmesi, diğeri taşıma maliyetini enküçüklenmesi olmak üzere iki tane amacı vardır. Sunulan modeller, elde edilebilecek bütün gerçekçi veriler toplanarak Türkiye ağı üzerinde test edilmiştir.

Anahtar Kelimeler: Tehlikeli Madde Taşımacılığı, Birden Fazla Ulaştırma Modu ile Taşımacılık, Risk Analizi

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Assoc. Prof. Bahar Y. Kara and Assist. Prof. Osman Alp for their invaluable guidance and support during my graduate study. They have supervised me with everlasting patience and encouragement throughout this thesis. I consider myself lucky to have a chance to work with them.

I am also grateful to Asst. Prof. Alper Şen and Asst. Prof. Sibel Alumur Alev for accepting to read and review this thesis. Their comments and suggestions have been invaluable.

I also would like to express my deepest gratitude to my family for their eternal love, support and trust at all stages of my life and especially during my graduate study. I feel very lucky that I belong to this family.

I am indeed grateful to Doruk Özdemir for his morale support, patience, encouragement and endless love since I met him.

I would like to thank to my precious friends Müge Muhafız, Fevzi Yılmaz, Nurcan Bozkaya, and Onur Uzunlar for their endless support, motivation and wholehearted love. Life and the graduate study would not have been bearable without them. I also would like to thank my cousin Özge Aksoy and my dear friend Zeynep Şagar for their friendship and support.

Finally, I would like to acknowledged financial support of The Scientific and Technological Research Council of Turkey (TUBITAK) for the Graduate Study Scholarship Program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

A hazardous material (hazmat) can be defined as any material that could harm people, property or the environment. Hazmats include explosive and pyrotechnics, gasses, flammable and combustible liquids, flammable-combustible and dangerous-when-wet solids, oxidizers and organic peroxides, poisonous and infectious materials, radioactive materials, corrosive materials (acidic or basic), and hazardous wastes. The source of hazardous materials can be industrial and chemical plants, petroleum refineries, medical stations such as hospitals and clinics. Some possible accidents/incidents that impose risk to people, property and the environment could be an explosion in storage or processing facilities, leak of hazmats from their containers directly to the atmosphere, or an explosion or a leak due to a traffic accident involving hazmat-carrying vehicles. Consequently, such incidents might have catastrophic consequences. Hence, transportation of these materials should be handled with extreme care.

In this study, we focus on the transportation of fuel products. Fuel products belong to the class of flammable-combustible liquids. In the current fuel distribution system of Turkey, fuel transportation is materialized by using highways. An alternative to highways is railroad transportation. Even though Turkey has a sparse railroad network, railroad alternative could be a preferred alternative over highways as the transportation cost and risk of railways could be lower than those of the highways. Thus, a combination of railway and highway transportation alternatives should be considered together. This type of transportation is referred as "intermodal transportation" in the literature.

In the literature, there are number of studies that deal with measuring highway transportation risk of hazardous materials. However, there are just a few studies that focus on railway transportation risk. In this study, we adapt the risk model conducted by Glickman et al. (2007) and modify the model to our case by making a few changes. We collected all the required data specialized on Turkey as realistic as possible.

Due to the nature of products being transported, societal risk should also be considered as a performance measure as transportation cost. Therefore, this problem has multiple and possibly conflicting objectives and priority of these performance measures may differ among the perspectives. Thus, the aim of this thesis is to find routes between supply points and demand points on a given network composed of highways and railways; and locate the transshipment points on that network, so that selected risk and/or cost measures are optimized in an appropriate manner.

In the next chapter, we explain the current fuel distribution system of Turkey. Fuel companies, fuel consumption in Turkey and the main steps of fuel distribution system are the main topics of this chapter. In Chapter 3, we define the problem considered in this study by presenting its structure and parameters. In Chapter 4, the related literature is examined in three main parts, which are hazardous materials transportation, intermodal transportation, and intermodal transportation of hazardous materials. In

Chapter 5, we introduce a transportation risk model for highway and railway transportation and a mathematical model to obtain efficient solutions for the problem defined in Chapter 3. We discuss the analyses and the computational results of the given model in Chapter 6 and finally in Chapter 7, we conclude the thesis by briefly summarizing our efforts and contributions of the thesis.

Chapter 2

Fuel Transportation in Turkey

Petroleum products are the outputs of the distillation of crude oil under different heat and pressure. Basically, there are three main product groups;

White products: Automotive fuels, coal oil, aircraft fuel
Black Products: Fuel oil and heating oil
Oils: engine oil, industrial oil

Automotive fuel consumption is continuously increasing every year in Turkey. According to PETDER (2010), total consumption of the white products (Gasoline, diesel fuels and LPG auto-gas) increased by 1.9% since 2009 and reach to 18.4 million tons in 2010 (See Figure 2.1).

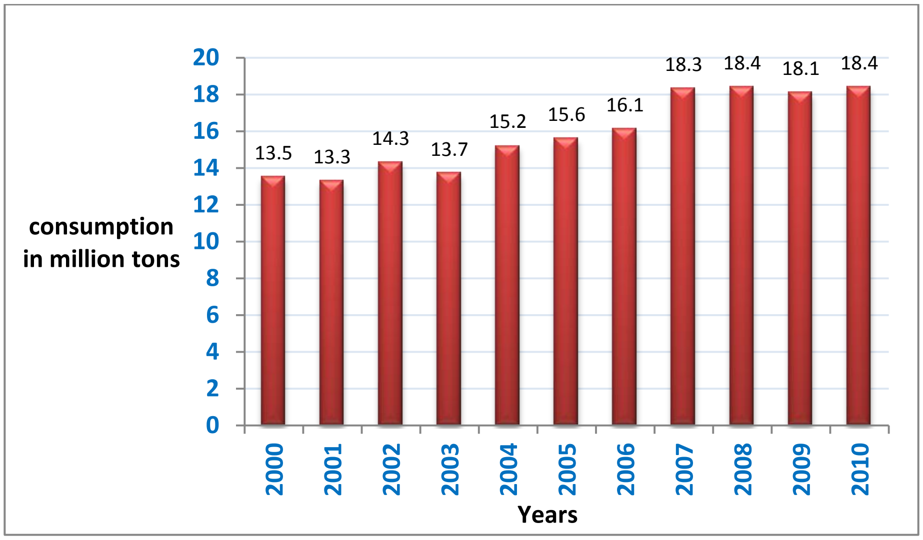


Figure 2.1 Fuel Consumption of white products in Turkey

In 2010 total diesel fuel consumption (including off-road diesel fuel) was 16.3 million m^3 with a 2.4% increase compared to 2009, whereas, total gasoline consumption was approximately 2.7 million m^3 with a 7.7% decrease and auto-gas LPG consumption yield was 2.5 million tons in 2010 with an increase of approximately 8.4%. In parallel to this consumption, fuel transportation industry is also growing every year.

Increasing fuel consumption amounts create high competition among the fuel distribution companies. In Turkey, leading distribution companies are Petrol Ofisi (PO), Shell, Opet, and BP. These companies hold approximately 90% of the total market share (See Figure 2.2). The total number of gas stations is over 12,000 and 15 billion liters of fuel have been sold in these stations in 2010.

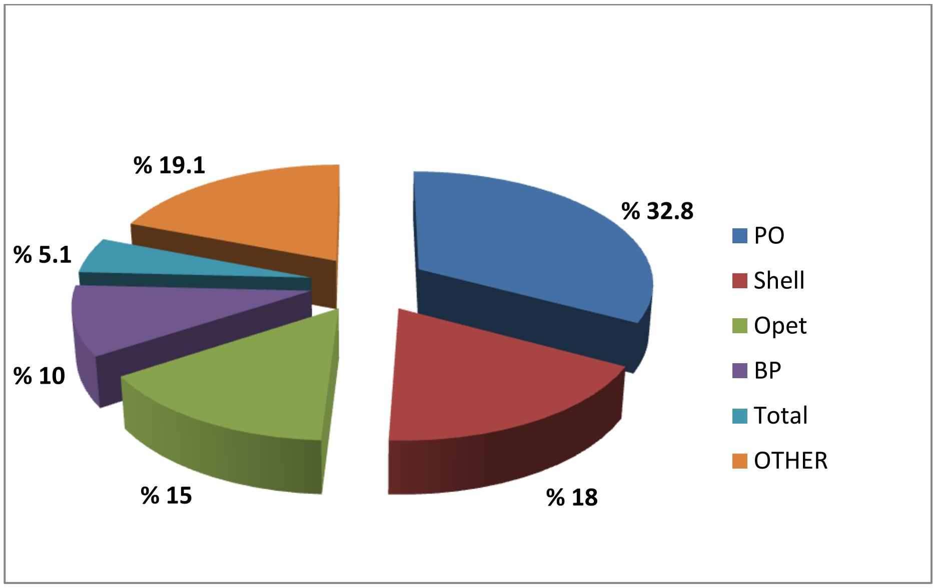


Figure 2.2-Market Shares of Fuel Distribution Companies in Turkey

PO has the largest market share in this sector. It was established in 1941. Their foundation mission is to cover the market according to the needs of public and private customers. Today PO has 2400 fuel stations, 10 fuel terminals, 2 LPG terminals and around 1200 employees.

The Samuel brothers, creators of the SHELL, had achieved a revolution in oil transportation in 1892. They developed bulk transport technique and this type of transport substantially cut the cost of oil and increased the volume that could be carried. At the beginning, they called the company "The Tank Syndicate" but in 1897 renamed it the Shell Transport and Trading Company. Shell Turkey was established in 1923 and today it has 1211 fuel stations and 2 terminals.

OPET was established in 1982 in Mersin where they were operating in the field of mineral oil and fuel oil. 10 years later, they became the owner of 16 fuel-oil stations. In 1992, they established the fuel distribution company named OPET. In 2002, 50% share of the company was owned by Koç Holding Energy Group. Now, OPET has 1258 fuel stations and 6 terminals.

BP is the fourth biggest company in the market. The company was established in 1908 and penetrated into the Turkish market in 1949. First year, sales amount was 40,000 tones and reached to 200,000 tons in 1961. Today, BP has 630 fuel stations and 130 LPG terminals.

Even though Turkey is not an oil producer country, there are four refineries established that process crude oil purchased from different oil producer countries. Refineries are one of the major sources of procurement of fuel products. The other sources of fuel for the distribution companies are oil producer countries from where the fuel is imported via marine transportation.

The fuel distribution system has three main concepts: procurement, storage, and distribution.

The first step is the procurement of fuel products from suppliers. There are two common sources: domestic refineries and overseas suppliers. Generally, the transportation cost is lower if the fuel products are purchased from domestic refineries therefore, supplying from the domestic refineries has priority against supplying from overseas. Sometimes the distribution companies may import fuel products from overseas supply points if domestic suppliers are in deficiency to satisfy the demand or if the fuel product prices are much cheaper than domestic prices. Every company determines its overseas suppliers by considering locations of its terminals in the country and hence distribution companies might have different overseas suppliers. Even though they may use different overseas suppliers, they could procure from only four existing domestic refineries if they prefer to supply the fuel products domestically (See Figure 2.3). The aforementioned refineries have total crude oil processing capacity of 28.1 million tons/year (See Table 2.1). Fuel distribution companies procure large part of their total supply from these refineries. For instance, PO receives 68% of its products from refineries in Turkey, whereas 32% of products are imported from overseas.

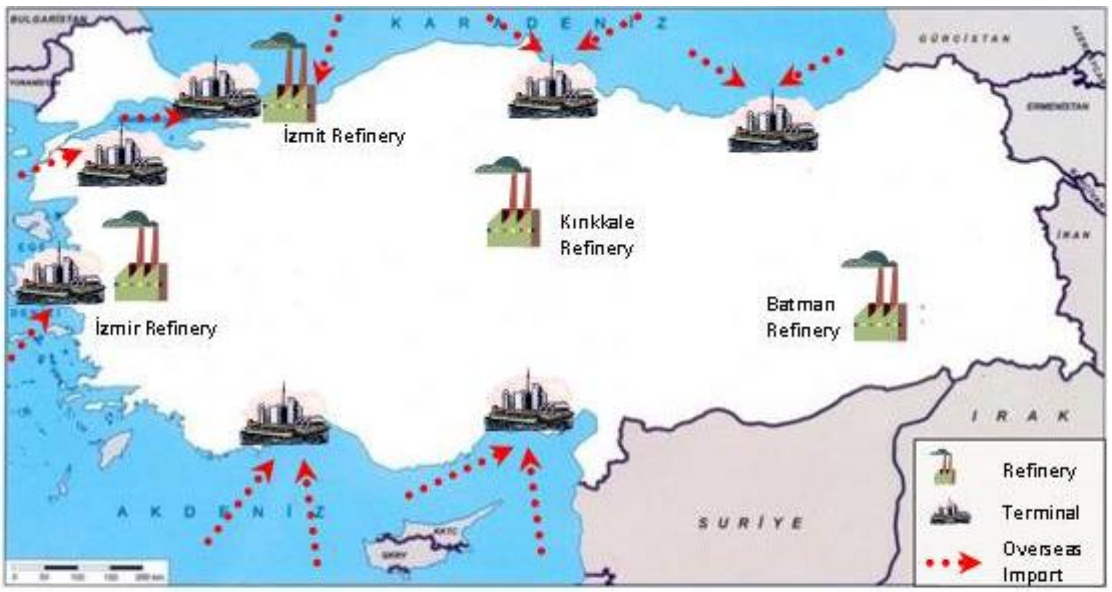


Figure 2.3 Fuel Procurement Ways

Table 2-1 Capacities of Refineries

	Processing Capacity (million tons/year)	Storage capacity (million m^3)
İzmit Refinery	11	2.14
İzmir Refinery	11	1.91
Kırıkkale Refinery	5	1.13
Batman Refinery	1.83	0.228

The İzmit Refinery started production in 1961, with a 1 million tons/year capacity of crude oil processing. The next 20 years, its processing capacity reached to 11 million tons/year through investments. Main products produced in the refinery are LPG, naphtha, gasoline, jet fuel, kerosene, diesel, heating oil, fuel oil, and asphalt. In 2010, İzmit Refinery processed 8.5 million tons of crude oil.

To meet the growing demand of petroleum products, in 1972 the İzmir Refinery has been established and started production. The initial crude oil processing capacity was 3 million tons/year. Up till 1987, with the capacity augmentations, its capacity reached to 10 million tons/year and today it has 11 million tons/year processing capacity. Main products are LPG, naphtha, gasoline, jet fuel, diesel, base oil, heating oil, fuel oil, asphalt, wax, extracts and other products. İzmir Refinery processed 8.5 million tons in 2010.

Kırıkkale Refinery was established to meet the growing demand in the Central Anatolian, Eastern Mediterranean and Eastern Black Sea Regions in 1986. Its processing capacity is 5 million tons/year whereas capacity utilization for crude oil is 53%. Main products are LPG, gasoline, jet fuel, kerosene, diesel, fuel oil, and asphalt. In 2010, this refinery produced 2.7 million tons of petroleum products.

Batman Refinery is the first refinery established in Turkey. It started production in 1955 with a capacity of 330 thousand tons. Up to 1972, its crude oil processing capacity reached to 1.1 million tons/year. Main products produced in refinery are asphalt, naphtha, diesel and semi-finished products. In 2010, the refinery processed 903,000 tons of crude oil.

The second step is to store the fuel products procured from overseas suppliers or refineries. Storage of the petroleum products has a significant importance on the distribution. Companies can establish their own storage terminals as well as they can use other companies' terminals. These terminals provide safe storage of the fuel products on the land. Some of these terminals are nearby the refineries in Turkey. On the other hand, some of them are located in the coastal areas (Aegean, Mediterranean and Black Sea) where there are several active seaports available. No matter where they procure the fuel products, companies store them safely in the depots in the storage terminals.

Fuel terminals of PO are located in Trabzon, Samsun, Kırıkkale, Derince (İzmit), Haramidere, Aliağa, Antalya, Mersin, İskenderun and Batman (See Figure 2.4). The total storage capacity of these terminals is approximately 1 million m^3. Another leader company OPET also has large amount of storage capacity. The terminals are located in Marmara (Tekirdağ), Mersin, Aliağa, Körfez (İzmit), Giresun and Antalya. The total capacity is about 1 million m^3. SHELL has three storage terminals located in Derince, Mersin and Antalya. When their own storage area is inadequate, they prefer to use other companies' terminals located in other cities. The fourth biggest company in this market, BP, has a huge storage terminal in Mersin and for the extra required capacity; they use other companies' terminals. They use this terminal as a hub to distribute fuel products to seaport terminals of other companies by seaway. Then they start distributing the products to the demand points. They use railways to transport the fuel from Mersin to Batman, Kırıkkale and Ankara. In these terminals, railway is available to transfer the fuel by rail tank cars.

Figure 2.4 Terminals of Petrol Ofisi

The third step is to distribute the fuel products to cities. There are two common ways of distributing the fuel.

In the first way, fuel is charged to fuel tankers or trucks in storage terminals in order to distribute the products to customers via highways. In the second way, railroads are used. In railroad shipments, fuel is charged into rail tank cars to ship fuel to the transfer stations composed by “transfer units”. Transfer units are capable of transferring fuel products from railcars to road tankers with the help of intermediary storage tanks eliminating the need to store the products in large capacitated depots. However, storage tanks have limited capacities when compared to depots. Railcars can be filled in refineries or in the storage terminals. After the completion of pouring, fuel is transferred to the road tankers, which carry the fuel to the demand points via highways (See Figure 2.5).

Turkey has a sparse railroad infrastructure compared to the highways and BP is the only company that uses railway and transfer units to distribute fuel products in Turkey. BP delivers the imported fuel products at the Mersin port and loads them to the storage terminal at the port. Railroad infrastructure is available at Mersin storage terminal. Therefore, they use railways in order to distribute the demand of the Central Anatolian Region. They charge the fuel to the rail tank wagons in terminal and after that, they dispatch the wagons to the transfer unit located in Kırıkkale. At that station, as mentioned before, fuel is discharged from wagons to lower capacity tanks. Then, fuel is transferred from these tanks to road tankers or trucks for distributing to the demand points in Central Anatolia.

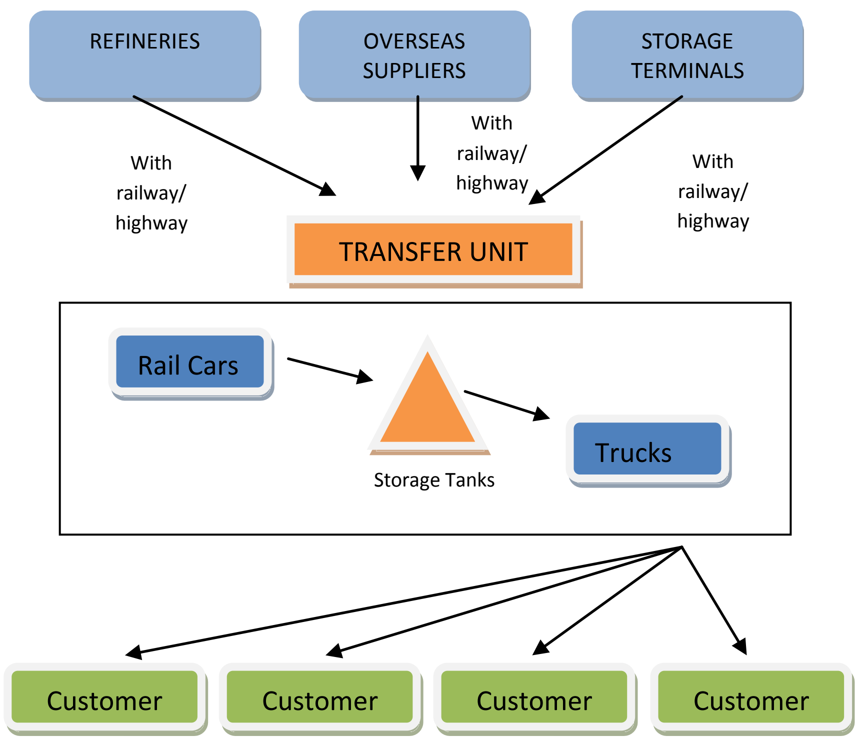


Figure 2.5 Distribution System Using Transfer Units

To sum up, fuel distribution is composed of three main steps. Firstly, fuel is procured from refineries or overseas suppliers. In the second step, fuel is stored at the depots in the storage terminals. At the final step, fuel is distributed to customers by using only highways or using highways together with railways. In this step, from the leader companies of the fuel distribution sector, Petrol Ofisi, Shell and Opet uses only highways whereas BP uses both railways and highways while distributing the fuel products

Chapter 3

Problem Definition

A hazardous material (hazmat) is defined as any substance or material capable of causing harm to people, property and the environment (US Department of Transportation). Basically, there are nine main classes of hazardous materials;

1. Explosive and pyrotechnics
2. Gasses
3. Flammable and combustible liquids
4. Flammable, combustible and dangerous-when-wet solids
5. Oxidizers and organic peroxides
6. Poisonous and infectious materials
7. Radioactive materials
8. Corrosive materials (acidic or basic)
9. Miscellaneous dangerous goods (hazardous wastes)

Among these classes flammable-combustible liquids (48.44%) and corrosive materials (25%) generates the major volume of the hazmat accidents/incidents (U.S. Department of Transportation, 2011) and white/black fuel products belong to this class of hazardous materials. Some possible accidents/incidents that impose risk to people, property and the environment could be an explosion in storage or processing facilities, leak of hazmats from their containers directly to the atmosphere, or an explosion or a leak due to a traffic accident involving hazmat-carrying vehicles. Obviously, such incidents might have catastrophic consequences. Consequently, storing, processing and transportation of hazmats must be handled with extreme care and attention by the authorities so that the risk imposed to the society and environment is minimized as much as possible. In this thesis, we are focusing on the transportation operations of hazmats and the corresponding risk imposed on the society.

Since the transportation of hazardous materials imposes risk to the public and environment, it is essential to measure the risk by appropriate measures. An example is the “traditional risk” measure, which is obtained by multiplying the probability of the occurrence of an undesired event (e.g. a traffic accident) and its corresponding consequence. Another example of a risk measure could be population exposure, which is the total number of people exposed to risk during the transportation of a hazmat carrying vehicle.

Hazardous materials could be transported via five modes: road, rail, water, air, and pipeline. Among these modes, the great majority move by rail and truck. While 94% of all hazmat shipments are done by trucks that many shipments account for 43% of the total transported hazmat tonnage. Carrying hazmat with rail, water, and pipelines account for 57% of the total hazmat tonnage, while they hold only 1% of total hazmat shipments in 2004 in USA (Erkut et al., 2007).

A possible accident, which involves hazmat-carrying vehicles, can have catastrophic consequences. Hazmat transportation accidents could can either at the origin/destination point or at en-route. These accidents can cause fatalities, injuries, evacuation, property damage, environmental harm and traffic disruption. In most of the accidents, the main casue is human error (See Figure 3.1) (Erkut et al., 2007). Due to such risk factors, transportation of hazmat receives close public and governmental attention and should be planned meticulously in order to minimize the risk exposed on the public.

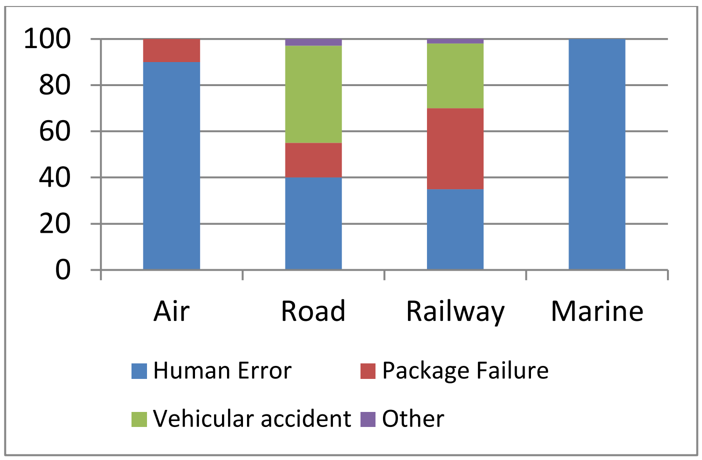


Figure 3.1 Factors Caused to Hazmat Accidents Based on Transportation Modes

Among all hazardous material classes, fuel products, which belong to the class of flammable-combustible liquids, generate a major volume of total transported hazardous materials in Turkey. According to the statistics of General Directorate of Highways, total transported amount of fuel products counted 6.61% of total transported freight by tankers/trucks in 2010 (GDH, 2010). In EU and North American countries, there is a stringent control over transportation operations of hazmat carriers. As a result of this, the rate of accidents involving hazmat-carrying vehicles is very low. For example, in North America such accidents occur one in a million-km. On the other hand, there are no reliable statistics about hazmat accidents in Turkey. Nevertheless, number of accidents occurring on Turkey's highways is significantly higher when compared to the EU and North American countries. To give some statistics, there were 11,119 accidents involving trucks or tankers in Turkey in 2010 whereas number of total accidents was 1,106,201 (TSI, 2010). However, total number of Motor Vehicle Traffic accidents is 30,797 in USA in 2009 according to the NHTSA (2009). In addition, the number of vehicles that carry fuel products counted 4% of total traveled vehicle along the highways in 2010. Therefore, planning for better transportation operations that impose less risk to the society is even more crucial for Turkey.

As explained in Chapter 2, in the current fuel distribution system of Turkey, fuel products are procured from refineries or overseas suppliers by fuel distribution companies. After procurement, fuel is transferred to the transfer units or depots located in storage terminals of companies. At the final step, fuel is charged to road tankers and transported via highways in order to distribute the products to the customers (See Figure 3.2). Currently, market leader companies prefer to transport and distribute the fuel by road tankers in all steps. Transportation using tankers is favorable since Turkey has a dense highway network. For any city, there is at least one highway connection between all of its neighbors. Additionally, highways do not have any availability restrictions while scheduling the transportation even though there are some additional regulations about hazmat carrying trucks. Companies can use their own road tankers or trucks or lease vehicles from transportation companies.

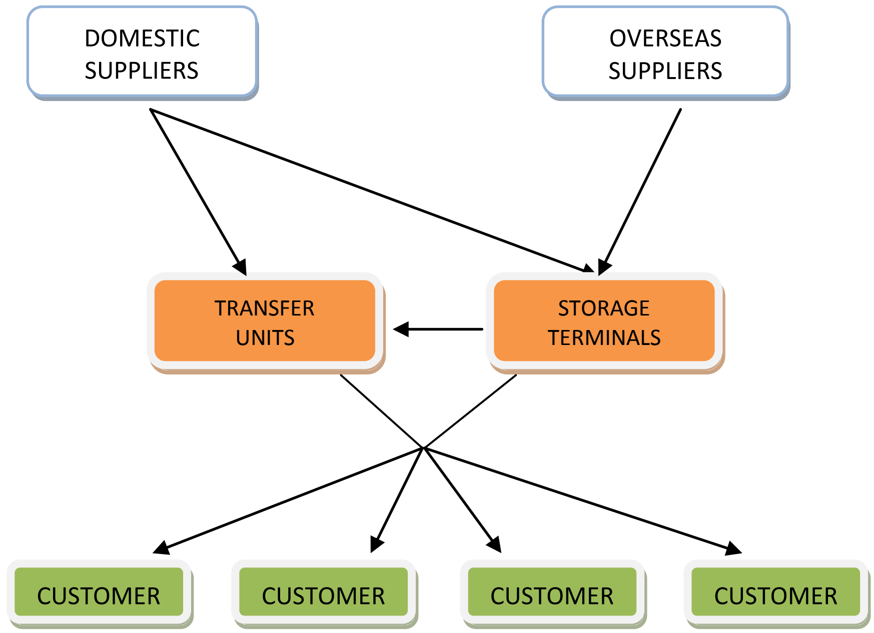


Figure 3.2 Current Fuel Distribution System in Turkey

One of the leader companies BP uses railways to transport fuel as explained in detailed in Chapter 2. Their fuel distribution system starts with the fuel procurement from overseas suppliers or domestic refineries. If fuel is imported from an overseas supplier, they store the fuel at the storage terminal located in Mersin port. Since railroad infrastructure is available at Mersin storage terminal and transportation cost of railway is lower than highway, they use railways in order to distribute the demand of central Anatolia and send the fuel to the transfer unit in Kırıkkale. After shipment, fuel is transferred to tanks by using a transfer unit. Then, they charge the fuel to the road tankers or trucks and distribute to the demand points in central Anatolia by using highways. BP can use railway transportation mode in their distribution system since the infrastructure is already available in the Mersin terminal.

There are several advantages of railway transportation over highway transportation. The first advantage of railways is that road tankers have less capacity than rail tank cars. A tanker can carry at most 27 tons of fuel between an origin and destination point. On the other hand, railway tank wagons have approximately 55-60 tons of capacity. Another advantage of railway transportation is that more than one wagon can move at the same time. Furthermore, Turkish railroads mostly pass through rural areas. Thus, population around the network is less when compared to the highway network. So, if an accident occurs, the number of people exposed to danger will probability be lower than that of highways. Consequently, we expect that including railway transportation into the current distribution system will make the system preferable from both cost and risk perspectives.

The railroad alternative for fuel distribution and risk comparison of railroad and highway options are not extensively studied for Turkey's transportation infrastructure. On the other hand, using only railways to distribute the fuel is not feasible since the railway infrastructure is not available in all cities of Turkey. Therefore, a combination of railway and highway transportation alternatives should be considered together. We refer to such a combination as "intermodal transportation" from now on.

"Transportation of a person or a load from its origin to its destination by a sequence of at least two transportation modes, the transfer from one mode to the next being performed at an intermodal terminal" is one of the definitions of intermodal transportation in the literature (Crainic and Kim, 2007). This definition applies to our approach in this study. However, there are also some other definitions of intermodal transportation in the literature such as "The carriage of goods by at least two different modes of transport in the same loading unit (an Intermodal Transport Unit or ITU) without stuffing or stripping operations when changing modes" (Arnold et al., 2004). In this study, the transported goods are fuel products and they need to be shipped in the special fuel tanks while using both transportation modes. Therefore, a unique transport unit cannot be defined due to complexity of the nature of the fuel transportation nature.

In intermodal transportation, a shipment that needs to be transported through a given network from a supply point (shipper) to a demand point (receiver) is carried by one mode to a terminal and in that terminal freight is transshipped to another transportation mode. After transshipment, freight can reach to the destination with this mode or transshipment between modes can also be made (See Figure 3.3).

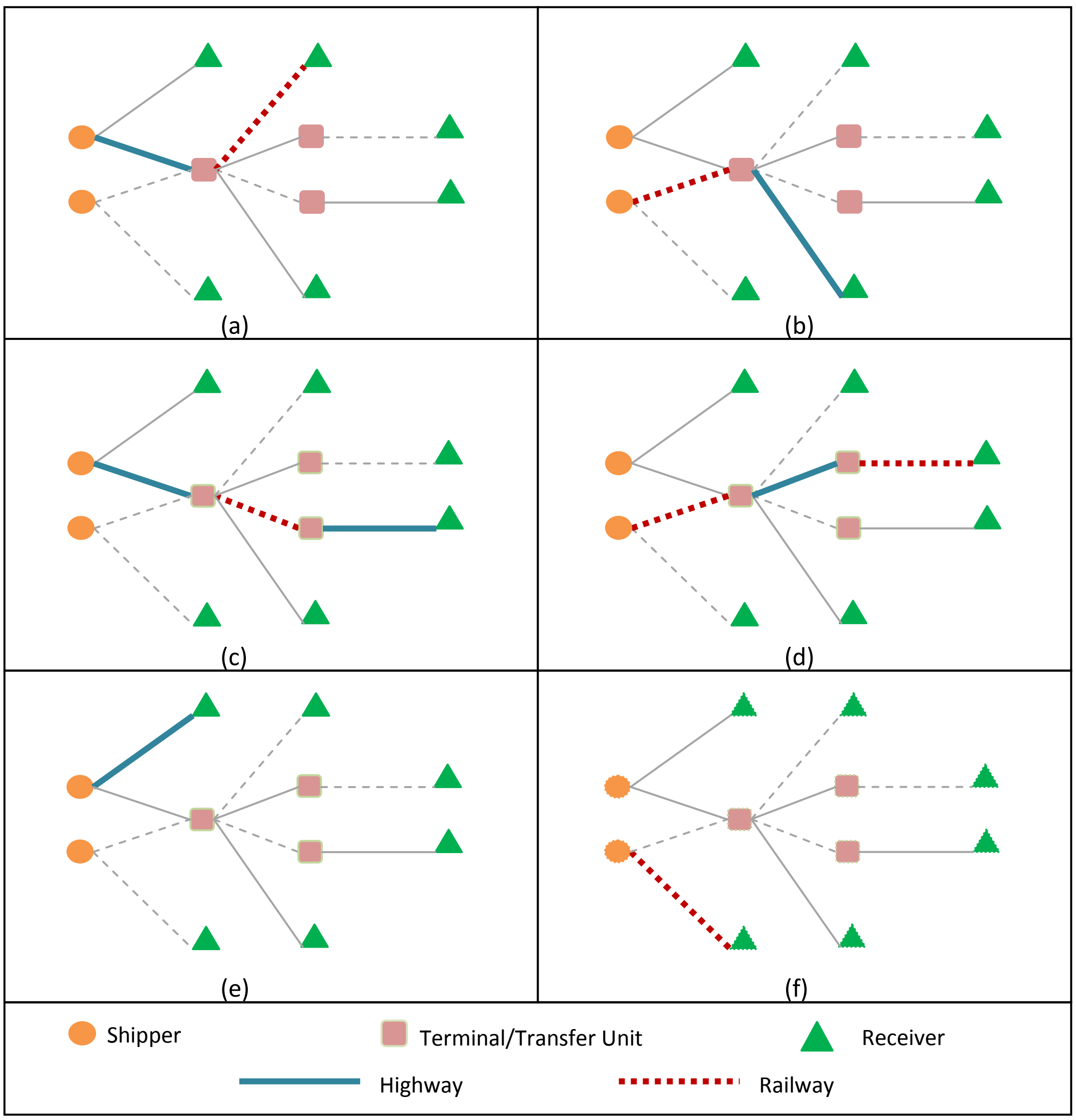


Figure 3.3- a, b, c, d-Intermodal Transportation, e-Highway Transportation, f-Railway Transportation

Figure 3.3 pictures six possible intermodal transportation alternatives considered in this study for fuel distribution. In Figures 3.3-a and b, fuel is transported from a supply point to a terminal/transfer unit via one mode and after changing the mode, fuel carries on its way to a demand point by using the second mode. On the other hand, in Figures 3.3-c and d, two transshipment points are used for the mode changing. One mode is used between the terminals/transfer units and the other mode is used in the remaining parts of the transportation. In addition, Figures 3.3e and f show the single mode transportation between supply and demand points.

One of the major problems that fuel companies face is the routing decisions of the fuel products from suppliers to demand points. As given in Figure 3.3, there are six routing alternatives composed only of trucks, only of trains or of train-truck combinations that fuel companies could select for the given origin-destination pairs. However, as mentioned in Chapter 2 in detail, in this problem supplier points are not designated to demand points as in typical intermodal transportation problems in the literature. Fuel companies can select the supply points among refineries and seaports by considering the railway and network infrastructures availability constraints. Another major problem is the location decisions regarding the storage terminals and transfer units. Locations decisions of these facilities play a crucial role on intermodal fuel transportation since transfer of the fuel between modes is available only at these points. Therefore, it is important to decide on the location of these facilities. Consequently, our problem falls into the category of intermodal transportation with supplier selection, routing and terminal location decisions.

Due to the nature of the fuel products, the objective function used in selecting the routes requires special attention. Consideration of two different performance measures is necessary for hazmat transportation problems: transportation cost and societal risk. Cost minimizing solutions lead to the carriage of the fuel on the minimum cost routes, which are composed of the shortest paths. These shortest paths mostly pass through the population dense areas, therefore these paths may impose high risk to the public and environment nearby. On the other hand, risk minimizing solutions carry the fuel mostly through less populated and less congested areas by using possibly longer and circuitous paths. Thus, these solutions may have high transportation costs compared to the cost minimizing solutions. Consequently, a cost minimizing solution may not be the best solution for the risk minimization objective and vice versa. Therefore, this problem has multiple and conflicting objectives and priority of these performance measures may differ depending on who the decision maker is. For instance, fuel companies may prefer the cost minimizing solutions whereas public authorities may prefer risk minimizing (or at least risk conscious) solutions. Even though cost minimization might be a priority from the perspective of the fuel companies, extra regulations might be imposed on their operations by the governmental institutions so that risk factor is also considered in selecting transportation routes.

To sum up, the problem that we consider in this thesis is named as "Intermodal Transportation of Hazardous Materials with Supplier Selection". In particular, the aim is to find routes between supply points and demand points on a given network composed of highways and railways; and locate transshipment points on that network, so that selected risk and/or cost measures are optimized in an appropriate manner.

Chapter 4

Literature Review

In this chapter, we analyze the intermodal transportation of hazardous materials (hazmat) literature. For this purpose, we examine three different areas of the literature: (1) Hazardous Materials Transportation, (2) Intermodal Transportation, and (3) Intermodal Transportation of Hazardous Materials.

4.1. Hazardous Materials Transportation

Hazardous materials transportation problem has become significantly important for decades due to the consequences of possible incidents/accident of transportation. Thus, the aspects of the hazardous materials transportation attract an increasing attention from researchers in years.

Hazmat incidents are considered as low-probability-high-consequence events. In these types of events, the probability of the occurrence is low, whereas the impacts of consequences are substantial. Due to the danger of hazardous materials, there are some acts to minimize its threat that is exposed by public and environment like Uniform Safety Act (1990) and The Canadian Environmental Protection Act (1988). In the Canadian Act, the purpose is to design and enforce the suitable conditions to control toxic materials transportation. There are some factors that affect the public sensitivity such as inequity in the distribution of risks or the impact created by media (Erkut and Verter, 1995).

In this part, we analyze the risk assessment and location/routing aspects of hazardous materials literature, as they are closely related to our study. For other aspects, we refer the reader to Erkut and Verter (1995).

Risk is the major component that separates hazmat transportation problems from other transportation problems in the literature. Risk is defined as the measure of the probability and severity of harm (Alp, 1995). Risk can be measured by qualitative or quantitative methods. In the qualitative risk assessment, possible accident scenarios are identified to estimate the undesirable consequences. This method is preferred if there is lack of reliable data.

Quantitative methods on the other hand, involve three key steps; (1) hazard and exposed receptor identification, (2) frequency analysis and (3) consequence modeling and risk calculation. While evaluating the risk on the routes by following these steps, one of the crucial decision is to decide on the shape of the impact area. There are different geometric shapes that are used by researchers to model the impact area such as danger circle (e.g., Erkut and Verter, 1998), fixed-bandwidth (e.g., ReVelle et al., 1991), rectangle and Gaussian plume (e.g., Zhang et al., 2000). Figure 4.1 shows four possible shapes of the impact area that have been used in the literature.

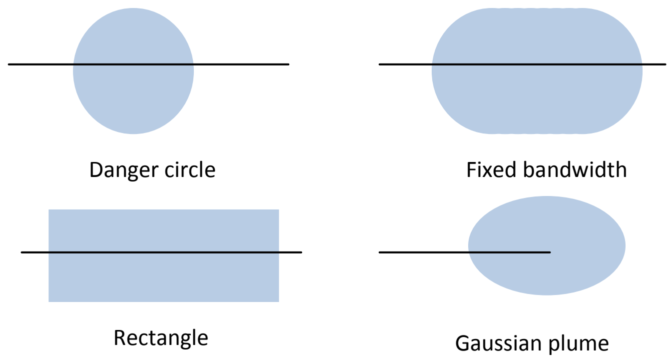


Figure 4.1 Shapes of Impact Area Around the Route Segment

In the literature, there are many risk definitions used in risk assessment. Some of them are clarified briefly and summarized in Figure 4.2.

- *Traditional Risk:* Covello and Merkhofer (1993) define risk as the product of the probability of and the consequence of the undesirable event, denoted as the traditional risk. This definition is sometimes referred to as the "technical risk."
- *Population Exposure:* The total number of people exposed to risk during a transport activity may be another proper definition of risk. ReVelle et al. (1991) use this model in their study conducted for U.S. Department of Energy.
- *Incident Probability:* From another perspective, if it can be assumed that all population densities are equal to some constant (in the danger circle) and hazmat carried has a very small danger radius, then the incident probability can be used as the risk measure. Saccomanno and Chan (1985) use this definition in their study for the first time in the literature.
- *Perceived Risk:* In order to reflect the aversion on the low-probability-high consequence events, Abkowitz et al. (1992) suggest modeling perceived risk (for

a unit road segment), PR, by using a risk preference parameter q as the power of consequence.

- *Conditional Risk:* To consider the importance of accident history on the paths Sivakumar et al. (1993, 1995) propose the definition of conditional risk which is defined as the expected consequence given the occurrence of the first accident.

Approach	Model	Sample References
Traditional Risk	$\text{TR}(P) = \sum_{i \in P} p_i C_i$	Alp 1995, Erkut and Verter 1995b
Population Exposure	$\text{PE}(P) = \sum_{i \in P} T_i$	ReVelle et al. 1991, Batta and Chiu 1988
Incident Probability	$\text{IP}(P) = \sum_{i \in P} p_i$	Saccomanno and Chan 1985, Abkowitz et al. 1992
Perceived Risk	$\text{PR}(P) = \sum_{i \in P} p_i (C_i)^q$	Abkowitz et al. 1992
Conditional Risk	$\text{CR}(P) = \sum_{i \in P} p_i C_i / \sum_{i \in P} p_i$	Sivakumar et al. 1993a, 1993b, 1995

Figure 4.2 Summary of the Five Risk Models Suggested in the Literature for Hazmat Transport Risk, Source: Erkut and Verter (1998)

Apart from these risk models, some recent studies deal with the risk assessment of hazardous materials transportation by highways and/or railways as explained below.

Bonvicini et al. (1998) study the application of fuzzy logic to the risk assessment of the transport of hazardous materials over an intermodal network consisting roads and pipelines. Since fuzzy logic is used for the risk assessment, uncertain parameters are thought as fuzzy numbers. Also, risk calculations are done by using fuzzy arithmetic. This method shows that if there is not enough data, a procedure like fuzzy logic can be a useful alternative approach for calculating uncertainty.

Bubicco et al. (2000) study the comparison of rail and road transportation of LPG. They analyze 130 LPG accidents in Italy in order to identify the accident scenarios and factors that can cause an accident. Authors propose a quantitative risk calculation technique, which is based on individual risk. The parameters they considered are accident rates, number of trips per year, release probability, etc. The results show that for the LPG transportation, the risk for rail transport is more than one order of magnitude lower than that for those on the roads according to the data obtained for Italy.

Milazzo et al. (2002) analyze the of hazmat transportation through Messina town in Sicily. They use a program called TRAT2 and analyze a case study of hazardous materials transportation with different modes. The program has two main steps: (1) analyzing the transport types in order to calculate the effects and vulnerabilities and (2) data input including transport network, population distribution and factories location and calculating the societal and individual risks. According to the output of the program, they offer two different solutions to improve the safety of the territorial area.

Brown and Dunn (2007) present a study on the quantitative risk assessment for evaluating consequence distributions of hazardous materials transportation. Their method has a strong emphasis on consequence modeling and employs considerable statistical data from past incidents. Initially they analyze the key statistical data which includes geographical and temporal incident distributions, discharge fraction distributions and meteorological database. Then they apply two classes of physical models for incident modeling. First one is source emission modeling and second one is atmospheric dispersion modeling. This technique provides analysis of thousands of accident scenarios and application of consequence models in order to estimate the percentage of time a certain protective action distance will be sufficient.

Another quantitative risk assessment study is conducted by Glickman et al. (2007). They present a risk model, which quantifies the rail transport risk. They use the results of this model with a weighted combination of cost to generate alternate routes. Seven factors are used to assess the risk along each link of the network: (1) distances, (2) accident rates, (3) total number of loaded cars per train, (4) number of tank cars per train loaded with the hazardous material of concern, (5) conditional release probability, (6) the size of the critical impact area and (7) population density in the critical impact area. As it is explained further in details, this risk model is used as the basis of our risk assessment in this thesis.

Next, we examine the location-routing category of the hazmat literature. In hazmat transportation problem, there are multiple players such as carriers, shippers, insurers and governments. Governments influence the carriers to prefer the routes with minimum risk in order to minimize the consequences by applying some regulations over highways, whereas carriers generally want to carry hazardous materials on the minimum cost routes. Hence, hazmat transportation problem is a multi-objective problem with multiple stakeholders. From this point of view, selection of the routes and locations of hazardous facilities should satisfy both players in the system to the extent possible (Erkut et al., 2007). Some of the recent studies related to location-routing problems in hazardous materials literature are explained briefly below.

The first related study is conducted by Zografos and Samara (1989). Authors focus on the hazardous wastes, which belong to class of miscellaneous dangerous goods of hazmat categories (See Chapter 3). They consider the transportation of one type of hazardous waste. They have multiple objectives, which are minimizing traveling time, risk of transportation and risk of disposing the wastes. They propose a mixed-integer goal-programming model and analyze the model on hypothetical data.

Later, List and Mirchandani (1991) examines a similar problem with multiple hazardous waste/material types. The proposed model has multiple objectives, which are minimization of risk, minimization of cost, and maximization of equity. Authors apply their model on the real-life data obtained from capital district of Albany, NY.

Giannikos (1998) uses goal-programming technique top tackle with a similar problem. The author develops a multi-objective location-routing model for hazardous waste transportation. He determines four objectives, which are minimization of cost, minimization of total perceived risk, the equitable distribution of risk among population centers, and the equitable distribution of disutility caused by the operation of the treatment facilities.

The most recent study on hazardous waste location routing problem is conducted by Alumur and Kara (2007). Authors study the location and routing of the hazardous wastes considering the compatibility issued among the different treatment technologies. They develop a multi-objective mixed integer programming model, which decides the locations of treatment and disposal centers, and routing of the hazardous wastes. Objectives are minimizing the total cost and minimizing the transportation risk measured by population exposure.

There are also some other location-routing studies which do not focus on only a single class of hazardous materials. An example is by Halender and Melachrioudis (1997). The authors study the integrated location routing problem in order to minimize the expected number of hazardous material transportation accidents. They consider two different routing policies, which are most reliable route planning and multiple routing with random selection. According to these policies, the authors develop two location models.In one of the recent studies, Cappanera et al (2004) use the Lagrangean Relaxation method to separate the location-routing problem, which is NP-Hard, into two sub-problems as location and routing problems.

4.2. Intermodal Transportation

Intermodal transportation is defined by Min (1991) as the movement of products from origin to destination using a mixture of various transportation modes such as air, ocean lines, barge, rail, and truck. Among these transportation modes, rail-truck combination is the most common one researched in the literature.

In the rail-truck intermodal transportation (RTIM) the trucking part of the transport chain is called drayage and the transported part by trains is called rail-haul. Another important component of this system is the transshipment terminals where shipments transferred from one mode to the other mode (See Figure 4.3).

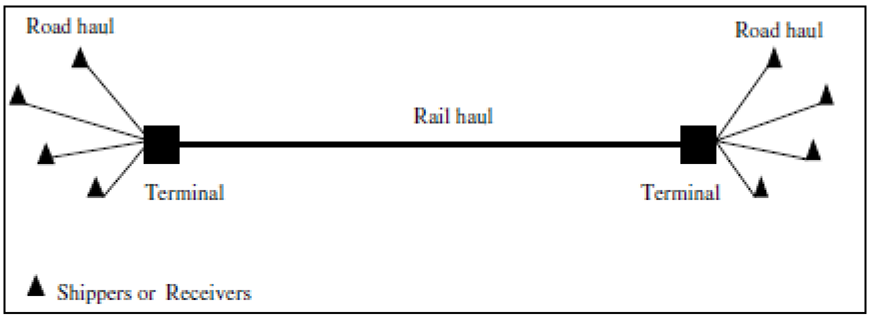


Figure 4.3 Rail-Truck Intermodal Transportation, Source: Macharis and Bontekoning (2004)

There are some characteristics of rail-truck intermodal transportation, which are defined by Bontekoning et al. (2004) (See Figure 4.4).

(a) *Task division between modes with respect to the drayage and rail-haul parts of the chain.*

(b) *Synchronized and seamless schedules between different modes.*

(c) *The use of standardized load units, which increases the efficiency in the transport chain.*

(d) *Transshipment. The transshipment of load units is inherent to the division of tasks between the short-haul and the long-haul. However, intermodal transshipment distinguishes itself from other forms of transshipment for two reasons. First, it involves transshipment from one mode to another; second, transshipment plays a crucial role in a synchronized and often tight schedule.*

(e) *Multi-actor chain management. The level of complexity is higher in intermodal transport chains with various organizations, each of them organizing and controlling a part of the transport chain.*

Figure 4.4 Rail-Truck Intermodal Transportation Characteristics, Source: Bontekoning et al (2004)

In the remaining part of this section, we analyzed the literature in four sub-categories: studies that focus on (1) the whole intermodal network systems, (2) the drayage, (3) rail-haul part, and (4) transshipment part of the intermodal transportation systems.

An example study of the general intermodal network systems is conducted by Chang (2008). The author studies the problem of how to locate best routes for shipments through the entire international intermodal network. He formulates this as a multi-objective multimodal multi-commodity flow problem with time windows and concave costs. The author also proposes a heuristic, which is based on relaxation and decomposition techniques. First sub-problem is a bounded knapsack problem with upper and lower bounds and the second sub-problem is solved by using Lagrangian sub-gradient optimization method. A re-optimization method is used to deal with infeasible solutions.

An application-motivated study is conducted by Caramia and Guerriero (2009). The authors study a vehicle-routing problem, which aims to provide answers at the following two planning levels: design of service network in order to define the best set of transport services, and transportation programming in order to satisfy specific customer requests. The purpose of the study is to minimize the traveling time and operating costs together with the maximization of transportation mode sharing to improve capacity utilization. They develop a heuristic algorithm composed of four steps: (1) computation of all non-dominated paths, (2) removing the paths which are not viable, (3) minimizing road service cost and (4) minimizing rail and maritime service time and costs. The proposed algorithm is applied to a real-life case study in Italy.

The study by Moccia et al. (2010) is another application-oriented study which focuses on the problem faced by a third party logistics company in Italy whose aim is to satisfy customer demand through a minimum cost combination of rail and truck services with different types of departure times. The considered problem is a multimodal transportation problem with flexible time and scheduled service. The authors develop a decomposition-based heuristic, which reflects the problem characteristics. They apply the heuristic on the instances, which are generated from the case study of the logistic company in Italy.

Drayage part of the rail-truck intermodal transportation is defined as the shipment between shipper to terminal or terminal to receiver by using trucks. This part accounts for a large percentage of origin to destination expenses. Major problems in drayage operations are the planning and scheduling of trucks between the terminals and shippers/receivers. These problems can be analyzed in three sub-categories: problems at strategic level, tactical level and operational level.

The main problems at the strategic level deal with the transportation activities between shippers and terminals or terminals and receivers. An example is given by Zhang et al. (2011). The authors study the problem of transporting containers by trucks with the three main movement types; incoming to terminal with loaded trucks, outgoing from terminal with loaded trucks, and incoming to terminal with empty trucks. They consider the resource constraints and time spent at the shippers' and receivers' terminals. They formulate the problem as a directed graph in order to develop a mathematical model. A search algorithm is used to solve the problem.

At the tactical level, most common problems are the assignment problems of shipper locations to terminals or service areas and routing problems. An example study is conducted by Taylor et al. (2002). The authors generate two alternative heuristics and analyze 40 different scenarios for the terminal selection problem.

Lastly, for the operational level, Justice (1996) deals with the problem of planning when, where and how many intermodal truck chassis are redistributed among the terminals. The problem is mathematically formulated as a bi-directional time based (network) transportation problem and applied to eight interconnected terminals in the USA.

Rail-haul part is the terminal-to-terminal phase of the rail-truck intermodal transportation. Rail transport of intermodal transportation distinguishes itself from traditional rail transportation in four areas, which are stated by Bontekoning, et al. (2004) (See Figure 4.5).

1. *In intermodal transport, fixed schedules are used while in traditional rail haul networks, trains run only when full and a lot of classification at intermediate nodes takes place.*

2. *Separating transport unit (rail flatcar) and the load unit (container/trailer) in intermodal transportation is more complicated whereas in traditional rail transportation only box cars are utilized.*

3. *Since the transport unit can be separated from the load unit, intermediate rail yards can be used as the transshipment terminal.*

4. *Since in road-rail terminals two different modes connect to each other, location decisions for these terminals are more complex.*

Figure 4.5 Differences of Rail Transportation, Source: Bontekoning et al. (2004)

For the rail-haul part, most researchers study the problems about decisions of which rail links to use, which origin and destination regions to serve, which terminals to use and where to locate new terminals. One such example is the study of Lei and Church (2011). They study the problem of locating away-from-port storage facilities for empty shipping containers. They present three strategic-level models to establish the facilities to minimize the transport distance.

Transshipment part of the rail-truck transportation deals with the location, layout and transshipment operations at the road–rail terminals and rail–rail terminals.

Arnold et al. (2004) propose a study about developing a model for locating rail/road terminals optimally for freight transport. A 0-1 program is formulated and solved by a heuristic approach, which is applied in Iberian Peninsula. The model used in this study is similar to multi-commodity fixed charge network design problems. The authors consider a terminal as an arc not as a vertex. This approach reduces the number of decision variables. The heuristic procedure use shortest paths and consider three important criterion; (1) total transportation cost, (2) total quantity passing through the transfer arcs and (3) total flow.

Boysen and Pesch (2008) deal with the train scheduling problem at the transshipment yard. They investigate the resolving deadlocks and avoiding multiple crane picks per container move and develop a mathematical model with the exact and heuristic procedures.

Caris and Janssens (2009) study the container hauling at the intermodal transshipment terminal. They model the problem as a full truckload pickup and delivery problem with time windows. The purpose is to find the assignments of delivery and pickup customer pairs in order to minimize the total cost. They develop a two-phase heuristic where the first phase finds the initial assignment combinations and the second phase improves by the local search.

Boysen et al. (2010) focus on the problem of determining yard areas for gantry cranes in order to spread the workload among the cranes. They develop a dynamic programming approach to deal with this problem. The results of a simulation indicate that if optimal crane areas are applied, train processing activities speed-up.

4.3. Intermodal Transportation of Hazardous Materials

Rail–truck intermodal transportation (RTIM) has a very important advantage that it combines the accessibility of road networks and cost effectiveness of railroad shipments. Additionally, rail-truck intermodal transportation attracts attention from shippers since intermodal trains are reliable for on-time deliveries.

Since the transported volume of hazmat has increased over the years, the advantage of rail-truck intermodal transportation became more important in order to minimize the cost and the risk imposed on public. A substantial advantage of rail transportation is that trains can carry non-hazardous and hazardous goods together whereas these two types are almost never mixed in truck shipments. Additionally, a rail tank is three times the capacity of a truck-tanker (Verma and Verter (2007).

Drayage, rail-haul, and transshipment parts are also valid for intermodal transportation of hazardous materials. Drayage is the transportation part between shippers to terminals or terminals to receivers. Rail-haul part is the terminal-to-terminal transportation and transshipment is the transfer activity of hazmat between modes.

Although hazardous materials are transported with rail-truck intermodal systems, particularly in Europe and Canada in past the decades, intermodal transportation od hazmats received less attention from researchers in operational research literature

There are two recent studies that focus on the intermodal transportation of hazmats (Verma (2009), Verma and Verter (2010)). Verma (2009) is the first application oriented study that focuses on the tactical planning problem of a railroad company that regularly transports a predetermined amount of hazardous and non-hazardous cargo across a railroad network, from a set of origin yards to a set of destination yards. He develops a bi-objective optimization model. The cost is determined based on the railroad transportation industry and the risk is determined from the incorporation of the railroad accident rates. The optimization model and the solution framework are used to solve a realistic-size problem instance based in southeast USA.

Later, Verma and Verter (2010) focus on the general version of the intermodal transportation of hazardous materials. The authors study the problem of planning the rail-truck intermodal transportation. Their purpose is to determine the best shipment plan for both hazardous and non-hazardous freight in a rail-truck intermodal network, wherein a set of pre-specified lead times must be satisfied in choosing the truck routes and the intermodal train services to be used. The objectives are; minimizing the total cost of transportation and the total public risk associated with hazmats. They develop a bi-objective optimization model to manage intermodal shipments. Lead-times, which are specified by customers, are considered in intermodal route selection. They develop an iterative decomposition based solution methodology. They decompose the original problem into two sub-problems: rail-haul and drayage. Rail-haul part aims to find the optimal rail travel time for each shipment. These rail travel times are taken into account in drayage part of the problem as parameters of the lead-time constraints. They apply the method on an instance, based on the intermodal service network in eastern USA.

Recall that the main purpose of our problem is to find routes between supply points and demand points on a given network; and to locate the transshipment points on that network so that selected risk and/or cost measures are optimized. The problem considered by Verma and Verter (2010) is the most similar study to our problem since their purpose is to find the optimal routing plan for hazardous materials transportation. However, there are some aspects, which are different in our problem. In their study, origin-destination pairs are given whereas in our case origins are not given. In fact, our problem investigates which demand point is served from which supplier and to what extent. Since supplier selection is an important decision of the problem, we believe that this aspect makes our problem more realistic. Moreover, they consider the lead times specified by customers, which are not considered in our study. Another difference is that, unlike us they decompose the model into two sub problems: drayage and rail-haul, and the locations of the transshipment terminals are given in their study whereas location decisions of these points play a crucial part in our problem. They use only two transshipment terminals and the intermodal connections are materialized only in these terminals, which makes their study restrictive when compared to our model.

Chapter 5

Model Development

In this chapter, firstly, we introduce a transportation risk model for highway and railway transportation. Secondly, we propose a mathematical model, which aims to find the paths that connect supply and demand points so that all demand is satisfied, by deciding on the transportation mode that will be used on the arcs along the paths and locating the transshipment points in a safe and cost effective manner.

5.1. Transportation Risk Model

In this section, highway and railway risk models are explained in details.

5.1.1. Highway Risk Model

There are different transportation risk definitions in the hazardous materials transportation literature as stated in Chapter 4 in details. Some definitions rely on an expected risk measure, which considers probability of incidents and consequence of the events simultaneously. Traditional risk and perceived risk definitions are in this category. Some definitions consider only the probability of incidents on the route or their consequence. Incident probability and conditional risk definitions belong to these categories. Additionally, some other definitions, such as population exposure, consider the number of effected people inside of the impact area (See Figure 4.1 of Chapter 4). Among these different definitions, traditional risk definition is the one that is used as the risk measure in this study.

In this model, risk of traversing a highway arc (i,j) is defined as;

$$R_{ij}^{\mathrm{h}} = \delta^{h} \times D_{ij}^{h} \times q_{ij}^{h} \times p^{r}$$

where

D_{ij}^{h} Distances of arc (i,j) on the highway network

δ^{h} Accident rate over highways

p^{r} Conditional probability of the release of hazardous material when an accident occurs

q_{ij}^{h} Population density in the critical area of exposure along of highway arc (i,j)

The total risk of a path P between an origin and destination is estimated as the summation of the risks of individual arcs along that path. This way of calculating the risk of a path is not an exact method however, the resulting error rate is negligible. For a detailed discussion of this issue, we refer the reader to Erkut and Verter (1995). Consequently, if all (i,j) along P are highway connections, total risk of the path P is calculated as

$$R = \sum_{(i,j)\in P} R_{ij}^{\mathrm{h}}$$

5.1.2. Railway Risk Model

Even though there are different risk definitions to measure the transportation risk of highways, there are just a few studies that focus on railway transportation risk. Some studies based the risk measure on the population exposure (Verma and Verter, 2007) or on the individual risk calculation (Bubicco et al. (2000), Milazzo et al. (2002)) and some of them focused on the quantitative assessment of expected consequence (Glickman et al. (2007), Brown and Dunn (2007)). Details of these studies can be found in Chapter 4. In this study, we basically adapt the risk model of Glickman et al. (2007) and modify the original model slightly to better represent our case. Summary of the notations used in the model is given in the Table 5.1.

Table 5-1 Notations Used in Railway Risk Model

Notations	
$\boldsymbol{D_{ij}^r}$	Distance of arc (i,j) on railway network in kilometers
δ^r	Accident rate over railways
p^r	Conditional probability of the release of hazardous material when an accident occurs
p^d	Derailment probability
$\boldsymbol{q_{ij}^r}$	The population density of arc (i,j) in the critical impact area
X	The number of tank cars per train loaded with the hazardous material of concern
X_D	The number of tank cars loaded with hazmat that are damaged or derailed
X_R	The number of tank cars that experience a major release

Similar to the highway risk definition, risk of traversing a railway arc (*i*,*j*) is defined as,

$$R_{ij}^{r} = f_{ij} \times N_{ij}$$

where

f_{ij} Expected percentage of trains on link (*i*,*j*) that experience an accident involving a major release of the hazardous material of concern

N_{ij} Expected consequence of such an accident measured by the expected number of residents in the critical area of exposure along arc (i, j).

The total risk of a path P between an origin and destination, if all (*i*,*j*) along P are railway connections, is also calculated similar to that of the highway risk model as

$$R = \sum_{(i,j)\in P} R_{ij}^{r}$$

A locomotive can pull railcars loaded with hazardous and non-hazardous materials simultaneously. Amount of fuel that needs to be transported every day is substantial quantity due to very high demand. If railways are used as an alternative transportation mode for fuel distribution, this high demand would result with the requirement of too many railcars and hence trains used for this purpose would pull railcars that are loaded only with fuel.

A railway accident could be a derailment, a head-on collision or a rear collision with a train. In most of these accidents, only a part of the tank cars damage or derail. Sometimes these cars located in the head/end part of train and sometimes located in the middle of the train. Additionally, it is not always the case that all damaged/derailed cars experience a release. In some accidents, even if there are derailed/damaged tank cars, there are might be no release of the hazmat.

Having these in mind, we need to estimate the number of wagons that carry fuel products (X), the number of wagons that are derailed/damaged (X_D) and number of wagons that experience a release (X_R) in order to calculate f_{ij}, which is defined as the expected percentage of trains on link (i, j) that experience an accident involving a major release of the hazardous material of concern. The formula is

$$f_{ij} = \delta^r \times D^{\boldsymbol{r}}_{ij} \times P(X_R > 0)$$

where

δ^r	Accident rate over railways
$D^{\boldsymbol{r}}_{ij}$	Distance of arc (i,j) on the railway network
P(X_R > 0)	Probability of experiencing a major release.

Here, X_R, which is defined as the number of wagons that experience a major release, depends on the number of loaded tank cars that are damaged or derailed (X_{D}). We can estimate the probability of a release for a given number of tank cars that are derailed/damaged as a conditional probability, denoted by P(X_R|X_D). Glickman et al. (2007) assumed that this probability is binomially distributed. This probability distribution assumes that occurrence of a tank car releases is a Bernoulli process, where each of the damaged or derailed tank cars (X_D) has a release probability p. Consequently, probability distribution P(X_R) can be estimated as,

$$P(X_R) = \sum_{X_D} P(X_D) \times P(X_R|X_D)$$

where P(X_D) is defined as the probability of derailment which is dependent on the total number of loaded tank cars (X). In this study, we model P(X_D) with negative binomial distribution, as the details are explained in Chapter-6.

The other component of R^r_{ij} that we need to estimate is N_{ij}, which is the expected consequence of an hazmat incident occurred along arc (i, j). N_{ij} can be estimated by,

$$N_{ij} = q_{ij}^{r} \times \sum_{X_R} [X_R \times P(X_R)]$$

where q_{ij}^{r} is the population density along the railway arc of exposure and the second component is the expected tank cars that experience a release.

To sum up, after calculating the f_{ij} and N_{ij} values, the risk associated with traversing arc (i,j) is computed by the product of these values.

5.2. Mathematical Model

In this section, we propose a mathematical model which aims to find an intermodal network composed of highway and railway infrastructure through which fuel products are carried from sources to destinations in a safe and cost effective manner and to determine the optimal locations of transfer units and depots that makes this distribution possible.

In this study, the highway and railway networks are incomplete networks in which every pair of distinct nodes is not connected with a unique edge. Therefore, we define two new parameters correspond to the availabilities in which the existent edges on the current infrastructure are considered as the available edges for both highway and railway networks. However, we set all of the edges of railway network as available due to the fact that estimated distances are composed of shortest paths for each pair of distinct nodes on the railway network.

The proposed mathematical model for fuel transportation can be stated as follows: Given the railway and highway transportation network and the set of potential nodes for transfer units and depots, find the location of transfer units and the amount of transported fuel products between origin and destination points and find the supplied amounts from suppliers in the given transportation network so as to minimize the transportation risk and/or cost.

The following indices and parameters are used in the mathematical formulation.

Given;

$N=\{1,\ldots,n\}$ Cities

Parameters:

c^h	cost of transporting one unit of fuel oil by highway
c^r	cost of transporting one unit of fuel oil by railway
a_{ij}	1 if link (i, j) is an available highway arc, 0 otherwise
b_{ij}	1 if link (i, j) is an available railway arc, 0 otherwise
D_{ij}^h	distance of link (i,j) on highway
D_{ij}^r	distance of link (i,j) on railway
w_i	demand of city i
o_i	1 if city i is a supply point, 0 otherwise
d_i	1 if city i has a depot, 0 otherwise
k^D	capacity of depots
k^{TU}	capacity of transfer units
p^{TU}	number of transfer units to be opened
R_{ij}^{h}	transportation risk of highway link (i,j)

R^r_{ij} transportation risk of railway link (i,j)

Decision Variables:

x^{h}_{ij} amount of fuel transported through link (i, j) of highway network

x^{r}_{ij} amount of fuel transported through link (i, j) of railway network

z_i 1 if transfer unit is opened at city i, 0 otherwise

s_i supplied amount from supply city i

The model is formulated as follows:

$$Minimize \sum_{i\in N}\sum_{j\in N} x^{\mathrm{h}}_{ij} D^h_{ij} c^h + \sum_{i\in N}\sum_{j\in N} x^{\mathrm{r}}_{ij} D^r_{ij} c^r \qquad (O1)$$

$$Minimize \sum_{i\in N}\sum_{j\in N} x^{\mathrm{h}}_{ij} R^{\mathrm{h}}_{ij} + \sum_{i\in N}\sum_{j\in N} x^{\mathrm{r}}_{ij} R^r_{ij} \qquad (O2)$$

subject to

$$\sum_{i\in N} x^{\mathrm{h}}_{ji} a_{ji} + \sum_{i\in N} x^{\mathrm{r}}_{ji} b_{ji} - \sum_{i\in N} x^{\mathrm{h}}_{ij} a_{ij} - \sum_{i\in N} x^{\mathrm{r}}_{ij} b_{ij} = s_j o_j - w_j \quad \forall\, j \in N \qquad (1)$$

$$\sum_{i\in N} x^{\mathrm{r}}_{ij} b_{ij} \le d_j k^D + z_j k^{TU} \quad \forall\, j \in N \qquad (2)$$

$$\sum_{i\in N} x^{\mathrm{r}}_{ji} b_{ji} \le d_j k^D + z_j k^{TU} \quad \forall\, j \in N \qquad (3)$$

$$\sum_{j\in N} s_j o_j = \sum_{j\in N} w_j \qquad (4)$$

$$\sum_{j\in N} z_j \le p^{TU} \qquad (5)$$

$$x^{\mathrm{h}}_{ij}, x^{\mathrm{r}}_{ij}, s_i \ge 0 \quad \forall i \in N, \forall j \in N \qquad (6)$$

$$z_i \in \{0,1\} \quad \forall i \in N \qquad (7)$$

Objective O1 is the cost objective minimizing the total cost of transporting fuel products through highways and railways. The amount of transported fuel products on a given link multiplied with distance of that link times unit transportation cost is to be minimized.

Objective O2 is the risk objective minimizing the total transportation risk. The assigned risk value of a given link times the amount of transported fuel products on that link is to be minimized. As the risk values of links are different between highways and railways the equation is summed for both modes.

Constraint set (1) is the flow balance constraints for the transportation of fuel products. This constraint set ensures that the demanded amount of fuel is satisfied for all cities by considering the mode availabilities. Also, this constraint set assures that the amount of fuel generated at supply points must be transported from these points to cities.

Constraint sets (2) and (3) correspond to availability constraints for railway transportation by considering the locations of depots and transfer units. This constraint ensures that railway could only be used on a given link if there is a depot or transfer unit located at the origin or destination of that link. Also this constraint guarantees that the shipped amount of fuel to points which has a depot or a transfer unit cannot exceed the capacity of a depot or a transfer unit.

Constraint set (4) is the supplier selection constraint for demand points. By this constraint, model chooses how much of demand is supplied from the available supply points.

Constraint set (5) correspond to the location constraint for transfer units. The constraints assure that the number of opened transfer unit cannot exceed the designated amount.

The other constraint sets that are left are the non-negativity constraints and the constraints defining the binary variables. The model has 11,935 continuous variables (x^h_{ij}, x^r_{ij}, s_i), 77 binary variables (z_i) and 12,245 constraints for a typical problem generated for Turkey.

Observe here that, if the decision maker prefers to allow opening new depots, parameter d_i can be considered as a decision variable.

Next, we create four versions of this base model depending on the prior objective selected. The first two models consider only one of the objectives:

<u>MC:</u>

$Minimize\ \mathrm{O1}$

subject to

$(1) - (7)$

<u>MR:</u>

$Minimize\ \mathrm{O2}$

subject to

$(1) - (7)$

Third model assumes the risk objective function but an upper bound on the total cost of transportation is imposed in the constraints and last model assumes the cost objective function but an upper bound on the total risk of transportation is imposed in the constraints

MR-βCost:

$Minimize\ O2$

subject to

$O1 \leq \beta$

$(1) - (7)$

MC-γRisk:

$Minimize\ O1$

subject to

$O2 \leq \gamma$

$(1) - (7)$

Fuel companies (or the carrier companies that they delegate their transportation operations) are the decision makers of the problem under concern. Since these companies are profit seeking private companies, their first priority would be "cost minimization" and hence MC would be their choice among the above models. If the decision maker were the "public" whose concern is just to minimize the "risk" of transportation then the decision maker's choice would definitely be the MR model. Due to the infrastructure of transportation networks, MR and MC models produce conflicting solutions, meaning that the minimum cost solution yields high risky transportation whereas minimum risk solution yields high cost transportation. Therefore, governments (with an aim of reflecting the public view) try to motivate or force the decision makers to deviate from their MC solution towards less risky paths, by imposing regulations and legislations. If the government asks carrier companies' to choose paths of which risk value is no more than a predefined level then the decision maker solves the MC-γRisk model. On the other hand, if the government motivates the decision maker to operate with a cost figure that is higher than their minimum cost with an acceptable margin (for example, carrier agrees to operate with a total transportation cost 10% higher than the minimum cost possible) then MR-βCost would be the right choice for the decision maker.

Furthermore, we know that railway transportation is cost wise advantageous when compared to highway transportation. Hence, we use MR-βCost model in our numerical analyses in order to observe maximum benefit that can be achieved on the total transportation risk. For preliminary runs, we use both MR-βCost and MC-γRisk models and results indicate that the numerical insights are not very different from each other.

Chapter 6

Data Collection and Computational Results

In this section, our aim is to show the potential benefits of using railways in conjunction with highways in Turkey's fuel distribution system, from both risk and cost perspectives. In order to make our analysis as realistic as possible, we collected all kinds of relevant and realistic data as much as possible. In Section 6.1, we summarize the data collected. In Section 6.2, we present our numerical analysis.

6.1. Data Collection

In order to collect the relevant data, we contacted several institutions such as leader fuel companies (PO, OPET, SHELL, BP, TP) and Turkish State Railways (TSR). Values of some of the required data were readily available and some have been obtained after processing the raw data. Table 6.1 summarizes the required data components.

Table 6-1 Data Components

Data	
Supply Points	Demand Points
Storage Terminals	Transfer Units
Highway Network	Railway Network
Demand Values	Unit Transportation Costs
Distances on the Highway Network	Distances on the Railway Network
Accident Rate Over Highways	Accident Rate Over Railways
Conditional Probability of the Release of Hazardous Material When An Accident Occurs	Derailment probability
Population Densities around the Highway Network	Population Densities around the Railway Network
Size of the Critical Impact Area	

Supply Points

As mentioned in Chapter-2, there are four refineries used as domestic suppliers in Turkey. In addition to that, companies procure fuel products from overseas suppliers and store them in the storage depots located nearby the seaports. There are six common supply points of the leader companies in Turkey. We select those six common points as supply points in this study (See Table 6.2). We ignore unit supply costs of different suppliers and assume that they are approximately same.

Table 6-2- Selected Supply Points

Supply Points	Supplier Type
İzmit	Domestic supplier
İzmir	Domestic supplier
Batman	Domestic supplier
Kırıkkale	Domestic supplier
Mersin	Overseas supplier
Samsun	Overseas supplier

Storage terminals

The storage terminals are located in different cities. Considering the depot locations of market leaders, nine different locations are selected as fixed depots, which are actively used in the current system (See Table 6.3). Moreover, it is assumed that storage terminals have unlimited capacities due to the fact that active storage depots of fuel companies in Turkey have approximately 200,000 tons capacity on the average.

Table 6-3- Fixed Storage Terminals

Fixed Storage Terminals	
İzmir	Mersin
Bursa	Kırıkkale
İzmit	Samsun
Antalya	Trabzon
Batman	

Transfer Units

BP is the only company that uses railroads for distributing fuel products; hence, only BP operates transfer units. In rail transportation, after the fuel is charged into rail tank wagons in storage terminals or in refineries, fuel is transported to the transfer stations. At these stations, fuel is transferred from tank wagons to road tankers by using a storage tank or the transfer unit. In the current system, two transfer units are operating actively (See Table 6.4), therefore these locations are selected as fixed points. Further, opening new transfer units will be analyzed by considering the potential locations. Furthermore, capacity of a transfer unit is estimated based on the maximum discharging time of a fuel tanker whose capacity is 27 tons. It is assumed that transfer units could operate 24 hours a day and 30 days in month. Hence, after calculations, the estimated capacity is set to 97,200 tons/month for one transfer unit.

Table 6-4- Selected Transfer Units

Active Transfer Units
Kırıkkale
Ankara

Demand Points and Values

We have condensed the total demand of all demand sources in a city into a single demand point, which is denoted by the center of the city. Consequently, locations of the final customers in our models correspond to the city centers. Tactical and operational decisions of fuel distribution inside a city are kept out of the scope of this study. In the current infrastructure, railway transportation from Anatolian region to Thrace region is not available and there is only one highway passage from Anatolia to Thrace. Therefore, cities in Thrace region and the city of Istanbul are omitted from demand points set. Consequently, 77 cities are determined as demand points. Demands of the cities are obtained from petroleum sales of Turkey given in the "Petroleum Market Sector Report 2010" which is shown in Figure-6.1 (EMRA, 2010). We have divided annual figures to 12 to obtain monthly sales, assuming that the fuel sales are uniform throughout the year (See Appendix 1).

Figure 6.1 Annual Sales of Cities (EMRA, 2010)

Transportation Cost

Transportation cost is crucial, as it is one of the components of the objective function. We have learned from carrier companies that the unit transportation cost of highways is approximately 0.25 TL per ton per kilometer. However, exact transportations costs of railways could not be obtained from TSR or fuel distribution companies but authorities from these organizations stated that unit transportation cost of fuel is about half of the unit transportation cost of fuel by highways or even cheaper. Consequently, we set the transportation cost by railways as 0.125 TL per ton per kilometer and we assumed this cost value is linearly related with the quantity.

Accident rates

To calculate the accident rate of railways, we need to estimate the total number of accidents involving hazmat carrying tank cars, total number of shipments, and total traveled distance. We obtained that there have been five major train accidents in 2009 in which tank cars were loaded with hazmat (TSR, 2011). It has been reported that there were 126,453 freight shipments in Turkey (TSR, 2011) which have resulted with 17,297 kms of total distance traveled in 2009 (TSR, 2009). We use these numbers in the following formula in order to obtain the accident rate per million kilometers, δ_r:

$$\delta^r = \frac{Number\ of\ Total\ Accidents/Number\ of\ Total\ Shipments}{Total\ Traveled\ Distance\ (km)}$$

For highways, many studies in hazmat literature have adapted the estimates provided by Shortreed et al (1994) for accident probabilities. These estimates are based on the accident frequency per million kilometers. Estimation of the total distance traveled and number of accidents could have been found from authorities however, total number of shipments is not available. Because of the missing data, highway accident rates for Turkey could not be estimated. Rather than making a rough estimate, we decided to analyze the highway accident rate parametrically. Consequently, we obtain the highway accident rate by multiplying the accident rate of railways by a positive parameter k as

$$\delta^{\mathrm{h}} = \delta_r \times k.$$

From the media exposure of highway and railway accidents in Turkey for the past several years, there is a common sense of the public that railway accident rates are much lower than highway accident rates. Therefore, for our initial numerical analysis, we set $k = 10$ but then make a parametric analysis for a wide range of this parameter. Recall that assumption goes along with the findings of Bubicco et al. (2000).

Distances

Highway distances between cities are obtained from "Intercity Distance Chart ", (GDH, 2010). Similarly, railway distances are obtained from "Turkish State Railways Annual Statistics 2005-2009", (TSR, 2009). Distance matrixes are given in the Appendix 2 and 3

Railway and Highway Networks

We have used Arc View 3.1 software to create the network composed of shortest paths between cities for both highway and railway networks. The highway and railway networks are given in Figures 6.2 –4. This network is composed of 232 highway edges, 106 railway edges and 77 nodes. The availability matrixes introduced in Chapter-5 are created based on the arcs of this network.

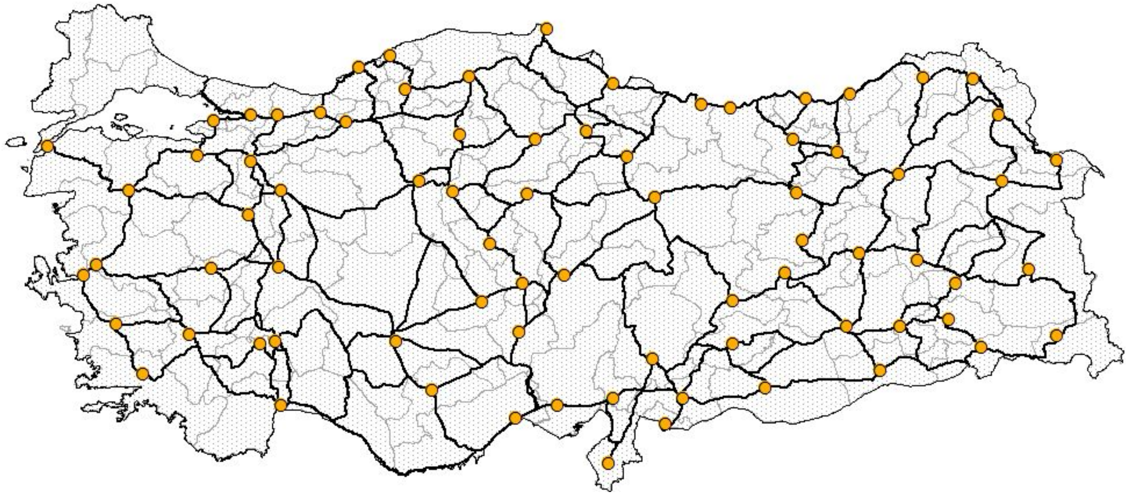


Figure 6.2- Highway Network

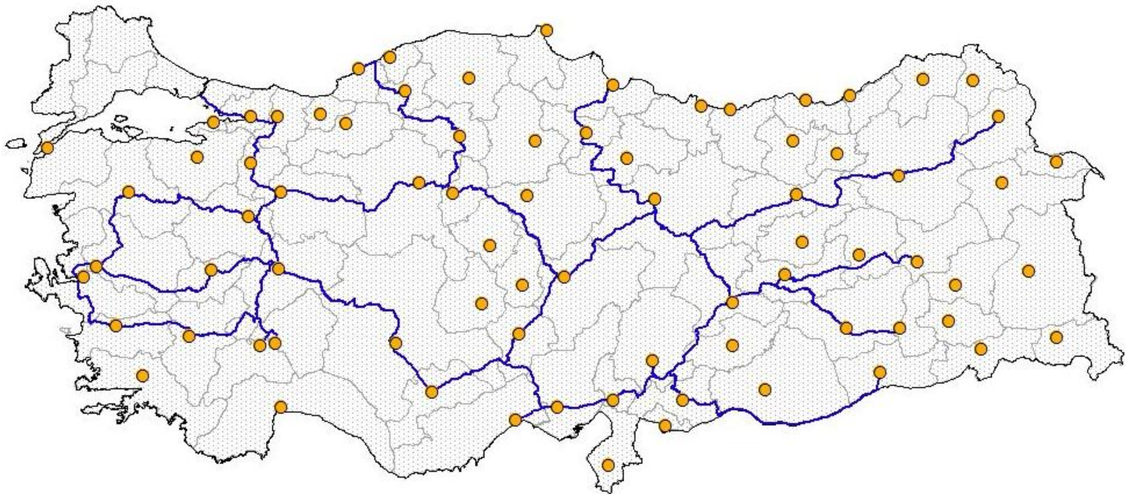


Figure 6.3- Railway Network

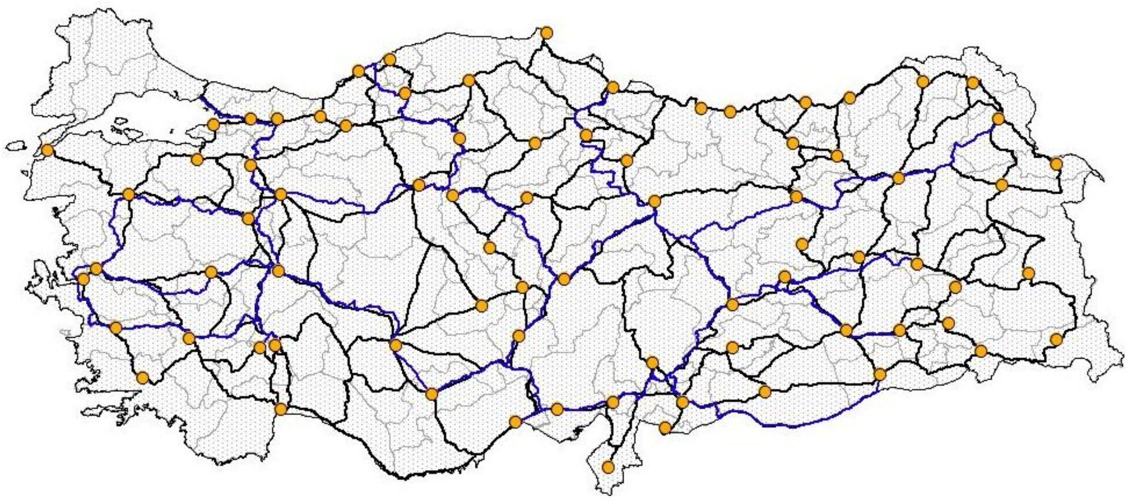


Figure 6.4- Final Railway-Highway Network

Population Densities around Highway and Railway Networks

Population in the impact area around each highway and railway arc is utilized by Arc View 3.1 using an add-on called "Identify Features within Distance" (Jenness, 2003). Impact area is considered as a fixed bandwidth (See Figure 6.5) and population density matrixes are created by aggregating the populations of all districts falling into the bandwidth. The radius of the critical impact area varies depending on the hazardous materials classes according to the Brown et al.. Since we are focusing on the fuel transportation, we use 800 meters as the radius of the bandwidth along the arcs. The resulting population matrixes are given in the Appendix 4 and 5.

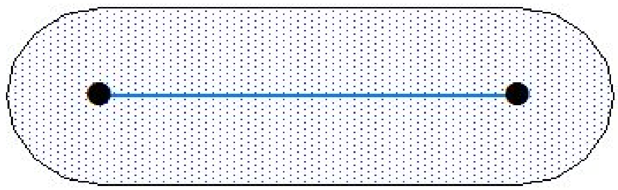


Figure 6.5- Impact Area- Fixed Bandwidth

Derailment probability and conditional probability of the release of hazardous material when an accident occurs

The conditional probability of the release of hazardous material when an accident occurs is adapted from the study of Shortreed et al. (1994) as 0.05. When an accident occurs, number of derailed cars depends on the point of impact. An impact could be in the head, end or middle part of the train and in most cases, only a few of the railcars are derailed. It is also stated by experts in TSR that this is exactly what happened in all train accidents in the past years. Therefore, we assumed that at most 10 cars could derail with one or two cars derailing have the most probability and the rest has diminishing probabilities. Hence, we adapted a negative binomial distribution, which could reflect this behavior. On this account, the probability values are obtained by setting the parameters $p = 0.5$ and $s = 2$ of negative binomial distribution (See Figure 6.6).

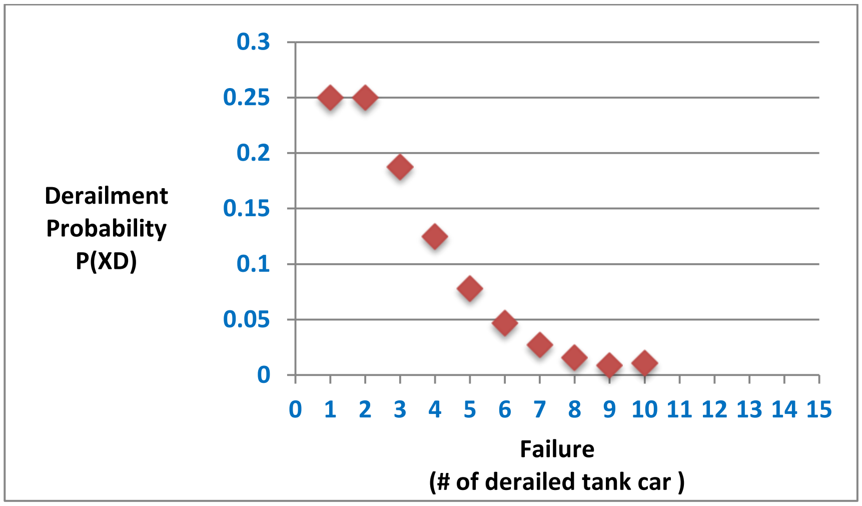


Figure 6.6- Derailment Probability Distribution

All of the above values are used as components for our analyses. Analyses and numerical results are explained in the next section.

6.2. Numerical Analysis

As mentioned in the first part, our primary purpose is to bring out the cost and risk wise benefits (if any) of introducing railway transportation. For this purpose, we first compare the minimum cost and minimum risk solutions of single mode and intermodal transportation alternatives. Then, efficient frontiers are developed for some problem instances. Finally, the impact of the number of operational transfer units together with their operating capacities and the impact of the highway accident rate are analyzed. Note that, in all analyses, the models stated in Chapter 5, found the optimal solutions in less than 10 seconds.

In these analyses, we consider monthly demands of the cities and assume that demand is evenly distributed throughout the whole month. Since the road tankers have small capacities, monthly demand of a city is to be shipped in several trips throughout the month. For the cities in which railway infrastructure is available, the city of Mus has the minimum demand: 1,461 tones. A railway tank wagon accommodates approximately 60 tones of fuel, therefore the total demand of Mus can be shipped with at least 24 wagons. In our numerical studies we set X, the number of tank cars per train loaded with the hazardous material of concern, to a value of 10. So the demand of Mus, if transported with railways, is to be shipped in three trips. We assume that these three trips are evenly distributed in the whole month. Similarly, the city of Ankara has the maximum demand: 103,353.5 tones and if this demand is transported with railways, it is to be shipped in approximately 170 trips which are evenly distributed in the whole month.

Finally, we note that we conducted our numerical analysis by aggregating the demands and operations of the four major fuel distribution companies, assuming that they obey to a central authority. In practice, apparently this is not the case but our aim in our numerical analysis is show the maximum benefit of intermodal transportation in case all companies adapt intermodal transportation for their operations. Hence, some of the insights that we generate in our numerical analysis might not hold if only a subset of the companies adapt intermodal transportation.

6.2.1. Analysis of Single Mode vs. Intermodal Transportation

The main purpose in this sub-section is to observe the estimated benefits of the transportation with railways from cost and risk perspectives. To this end, we compared the Min Cost (Model MC) and Min Risk (Model MR) solutions of preferring single mode or intermodal transportation.

Current fuel distribution system in Turkey is mainly composed of highways. Carriers prefer using highway alternative for distributing the fuel between suppliers and demand points. As it is mentioned in the previous section, we consider 77 demand points and six supply points (Table-6.2) with unlimited capacities. This distribution alternative is denoted as Single Mode Setting (SMS).

As an alternate distribution option to SMS, we consider utilization of railways in addition to highways. In this alternative, there are 77 demand points, six supply points (Table 6.2), nine fixed depots (Table 6.3), and two fixed transfer units (Table 6.4). Similar to SMS, no capacity limitations are imposed on supply points or depots. The number of transfer units that can be opened in addition to the existing two transfer units is set as free and no capacity limitations are imposed on the transfer units. However, we do not include the cost of installing and operating transfer units in this alternative. This alternative is denoted as Intermodal Setting (IMS). Note that in both alternatives, capacities are ignored in order to observe the maximum benefit that could be obtained . However, in further sections we also analyze the effect of capacities.

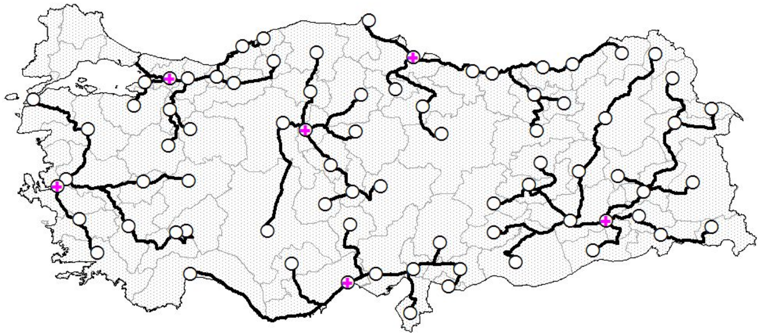
We first solved MC and MR models for both SMS and IMS and obtained four feasible solutions for comparison. These results are given in Table 6.5.

Table 6-5- MC and MR Results of Alternatives

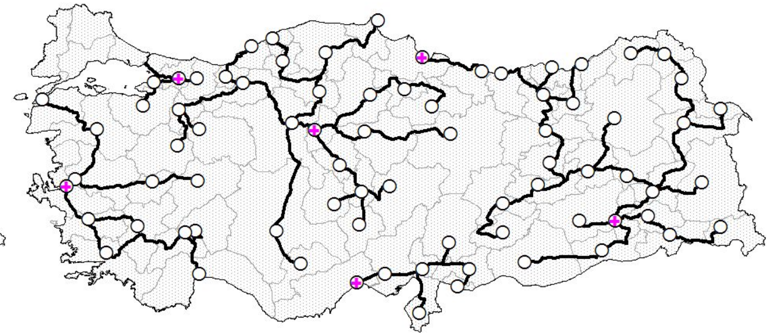
	MC		MR	
	Cost	Risk	Cost	Risk
SMS	**45,325,763 TL**	238,381	60,028,185 TL	**136,708**
IMS	**32,605,145 TL**	63,375	62,142,729 TL	**30,759**

These solutions show that, if the cost objective is adapted as the prior objective then total cost of transportation can be decreased by 37% when intermodal alternative is chosen. Similarly, if risk objective is the preferred objective then total risk of fuel distribution of Turkey can be decreased by 81% by introducing the railroads as an alternative transportation mode.

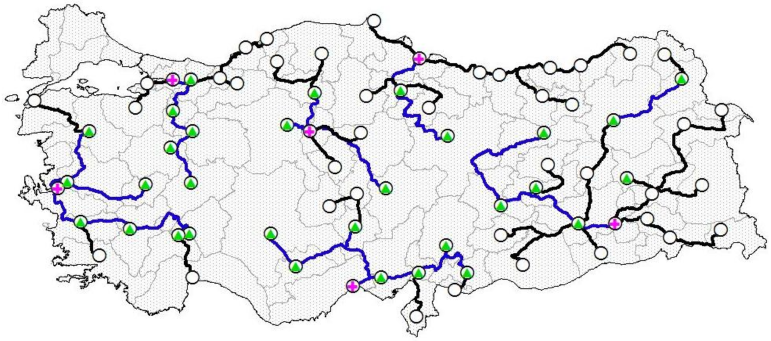
Moreover, when these four solutions are compared to each other, we observe that MC solution of the IMS, which is denoted as MC(IMS), dominates the MR and MC solutions of SMS. This shows that none of the efficient solutions obtained by SMS can be an efficient solution when intermodal transportation is adapted. We found the two extreme solutions for SMS, which are MC(SMS) and MR(SMS) solutions. Since these solutions are dominated by MC(IMS), other possible efficient solutions of SMS that would lie in between these two extreme solutions will also be dominated by MC(IMS), accordingly. The resulting distribution networks of all of the four solutions given in Table 6.5 are depicted in Figure 6.7.



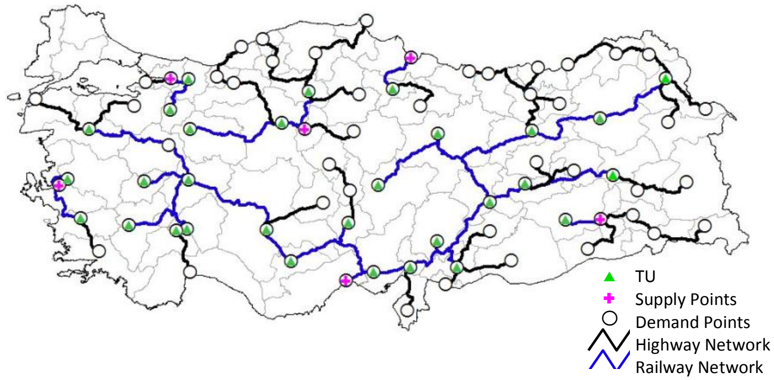
(a) MC of SMS



(b) MR of SMS



(c) MC of IMS



(d) MR of IMS

Figure 6.7- MC and MR Solutions of SMS and IMS

From these highway networks, we observe that in MR(SMS), Central Anatolia and Eastern suppliers cover wider ranges when compared to the MC(SMS). Similarly, in IMS, eastern supplier covers all of the demand of that region in MR solution when compared to MC solution. Additionally, in IMS alternative, the assigned railway network is same in both MC and MR solutions. On the other hand, suppliers cover almost the same regions when MC solutions of the two alternatives are compared. Moreover, it is observed from Figure 6.7c and d that some of the links on the network are both cost wise and risk wise "efficient" when intermodal alternative is introduced. For instance, Mersin-Adana, Adana-Osmaniye, İzmir-Manisa, İzmir-Aydın, Erzurum-Kars, Batman-Diyarbakır, Diyarbakır-Malatya, Malatya-Erzincan links are preferred for rail transportation by all models. Therefore, we can conclude that these links create efficient paths for both cost and risk objectives. The percentage distribution among suppliers for MC and MR solutions of both alternatives are given in Figures 6.8 and 6.9.

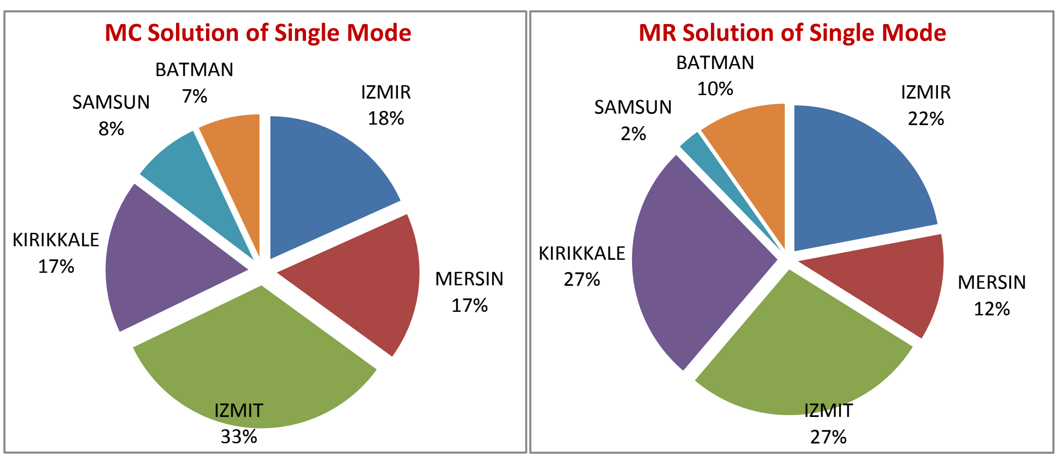


Figure 6.8- Percentage Distributions of MC and MR Solutions of Single Mode Alternative

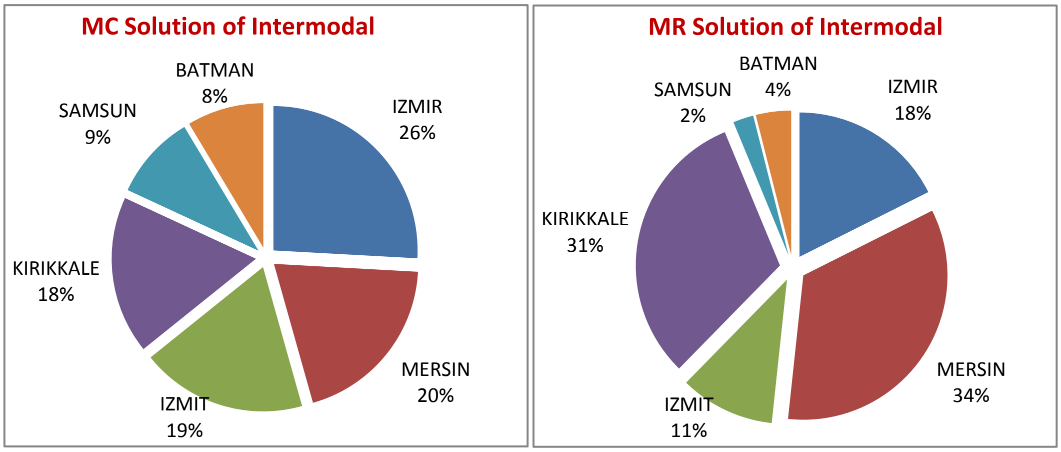


Figure 6.9- Percentage Distributions of MC and MR Solutions of Intermodal Alternative

In MC(SMS), major portion of the total demand is supplied from İzmit whereas in the MR(SMS), Kırıkkale and İzmit cover the major portion together. On the other hand, in MC(IMS), İzmir covers the biggest part of the demand however, in MR(IMS) Mersin and Kırıkkale come forward among six suppliers. Recall that we assume unit supply costs are approximately same among supplier points and 36% of total demand is supplied from overseas and rest of the demand is supplied from domestic suppliers in MR(IMS) solution. In practice, the unit supply costs might be different between domestic and overseas suppliers, these costs may even have a dynamic nature, and the governments might have certain strategies that pose requirements on the percentage use of overseas suppliers.

In IMS, the operating costs of transfer units are ignored. Therefore, the comparison of IMS and SMS might not seem fair. Hence, we create constrained alternatives, which consider limited number of transfer units and impose capacity for each transfer unit. In these alternatives, in addition to the two existing transfer units, we allow a number of additional transfer units to be opened, if preferred by the model, and rest of the parameters are kept the same as in IMS. We denote these alternatives by IMS_{Lx} where x

denotes the total number of TUs that can be opened. We depict MR and MC solutions of IMS_{L5} and IMS_{L7} in Table 6.6.

Table 6-6- MC and MR Results of IMS_{L5} and IMS_{L7} Alternatives

	MC		MR	
	Cost	Risk	Cost	Risk
SMS	**45,325,763 TL**	238,381	60,028,185 TL	**136,708**
IMS_{L5}	**40,096,261 TL**	148,315	62,640,193 TL	**85,671**
IMS_{L7}	**38,307,048 TL**	132,311	73,743,434	**69,271**

As it can be observed from Table 6.6, MC(IMS_{L5}) dominates MC(SMS) but not MR(SMS) since risk value of MC(IMS_{L5}) is slightly higher than the risk value of MR(SMS). On the hand, IMS_{L7} dominates both MC(SMS) and MR(SMS), similar to IMS. Therefore, even if we allow for five more TUs to be opened in addition to the existing two TUs, a feasible solution using only the highway network cannot be an efficient solution, when *k* = 10.

6.2.2. Efficient frontiers for IMS and IMS_{L5}

In this section, we analyze IMS and IMS_{L5} in more detail in order to provide alternative efficient solutions to the decision makers. Recall that our problem has multiple and conflicting objectives, therefore decision makers should be able to choose a solution from non-dominated (efficient) set of solutions. For this purpose, we create 16 solutions for both IMS and IMS_{L5} alternatives in which neither of them is dominated by the other solutions. We started with the MC solution of each of the instances, which provides the minimum cost possible. Based on this solution, we increase the cost gradually until reaching the cost value of MR solution and solve MR-βCost model in each step by setting β to cost value which is increased. The efficient-frontier obtained by these solutions for IMS and IMS_{L5} are given in Figures 6.10 and 6.11, respectively. Additionally, percentage distributions of suppliers of these 16 solutions are given in the Appendix 6 and 7.

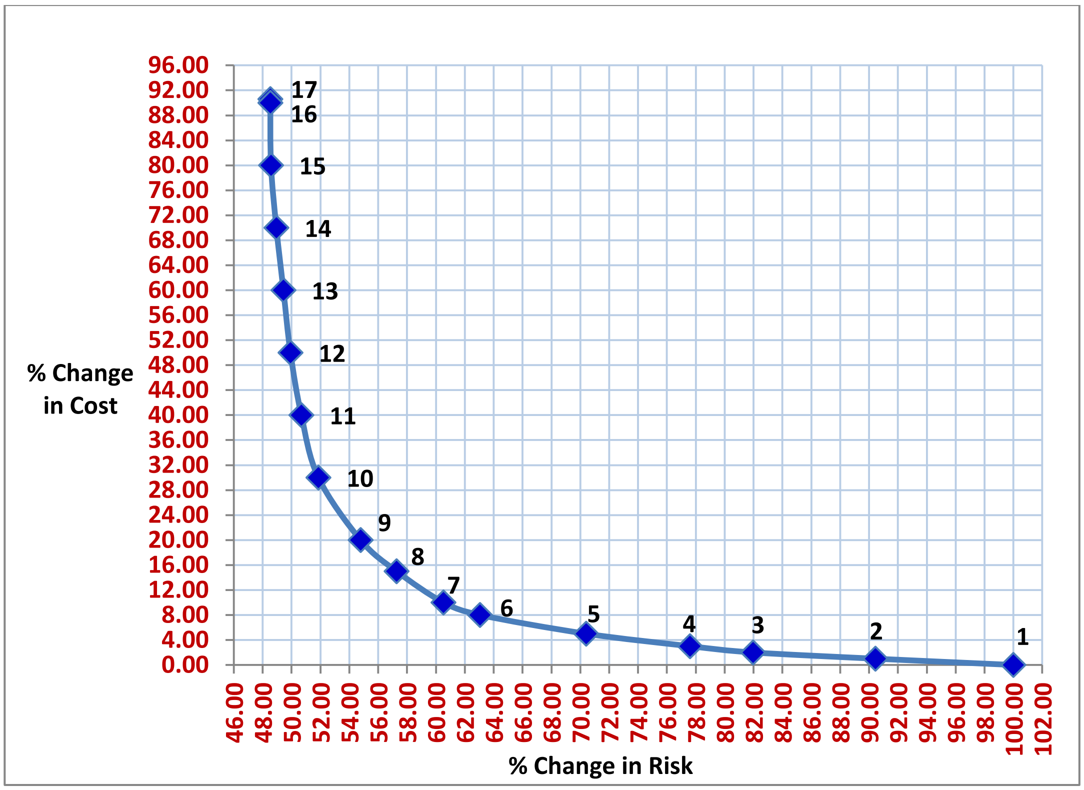


Figure 6.10- Trade-Off Curve for IMS Alternative

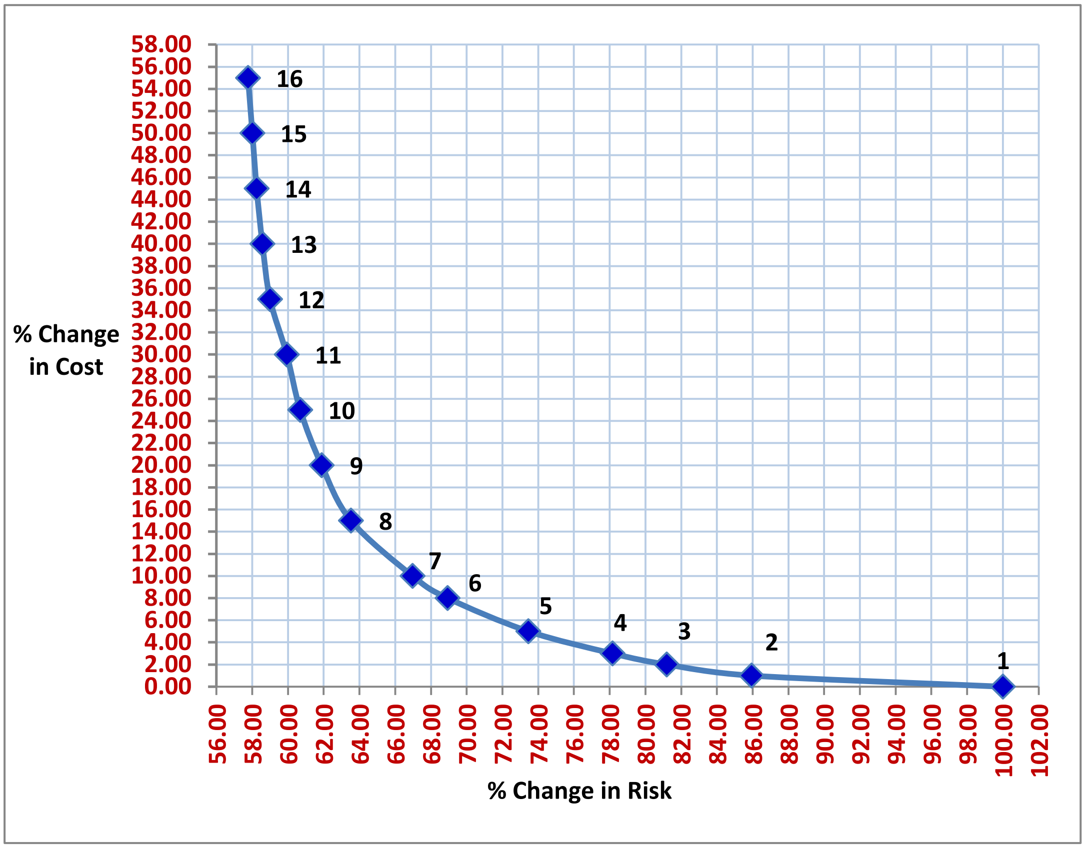


Figure 6.11- Trade-off Curve for IMS_L Alternative

In these graphs, *x*-coordinate corresponds to the percentage reduction in the transportation risk with respect to the transportation risk imposed by the MC solution. Similarly, *y*-coordinate corresponds to the percentage change in the total cost with respect to the minimum cost obtained by the MC model. As an example, consider Point 6 of Figure 6.10. This point is obtained by solving MR-βCost model where β is equal to 8% more of the optimal MC(IMS) solution. The total cost of this solution is 8% higher than the minimum cost obtained by MC model whereas the resulting risk saving is 32% when compared to the total risk of the MC solution.

From the perspective of a decision maker, whose prior objective is cost minimization while regarding also the societal risk, Point 6 could be an acceptable solution since 8% increment on the cost results a significant risk saving. Additionally, from this point forward, increasing cost does not provide satisfactory risk saving with respect to Point 6.

6.2.3. Effects of the number of Transfer Units

In this section, we analyze the effect of opening different number of transfer units by changing the parameter about operating transfer units from perspective of a decision maker described in the previous section. As mentioned before, in the current system, carriers mostly prefer distributing the fuel by using only trucks, which does not require the usage of transfer units. However, when transportation with railways is introduced as an alternative, depots and transfer units become crucial since transfer between modes could only be available via depots or transfer units.

Installation of new depots are both costly and require strategic decisions to be made by carrier companies and the respective governmental authorities. Therefore, we do not allow for opening new depots in our numerical analysis, however we allow for opening new TUs. We note that opening TUs are less costly and require decisions at the tactical level. Nevertheless, we do not explicitly incorporate the installation and operating costs of TUs in our models, but instead, we observe the benefit of opening new TUs in terms of cost and risk and propose that the decision maker should make a decision by resolving the tradeoff between the benefits obtained by opening new TUs and their corresponding installation and operating costs.

For this purpose, by taking a decision maker for whom the solution of MR-βCost problem where β is equal to 8% more of MC(IMS) is the preferred solution as a reference point, we solve this problem by imposing different upper bound values on the numbers of TUs that can be opened and by also considering their operational capacities. We start with the point where there are no active transfer units, and increase the number of transfer units gradually to see the effect of transfer units on the solutions obtained (See Figure 6.12).

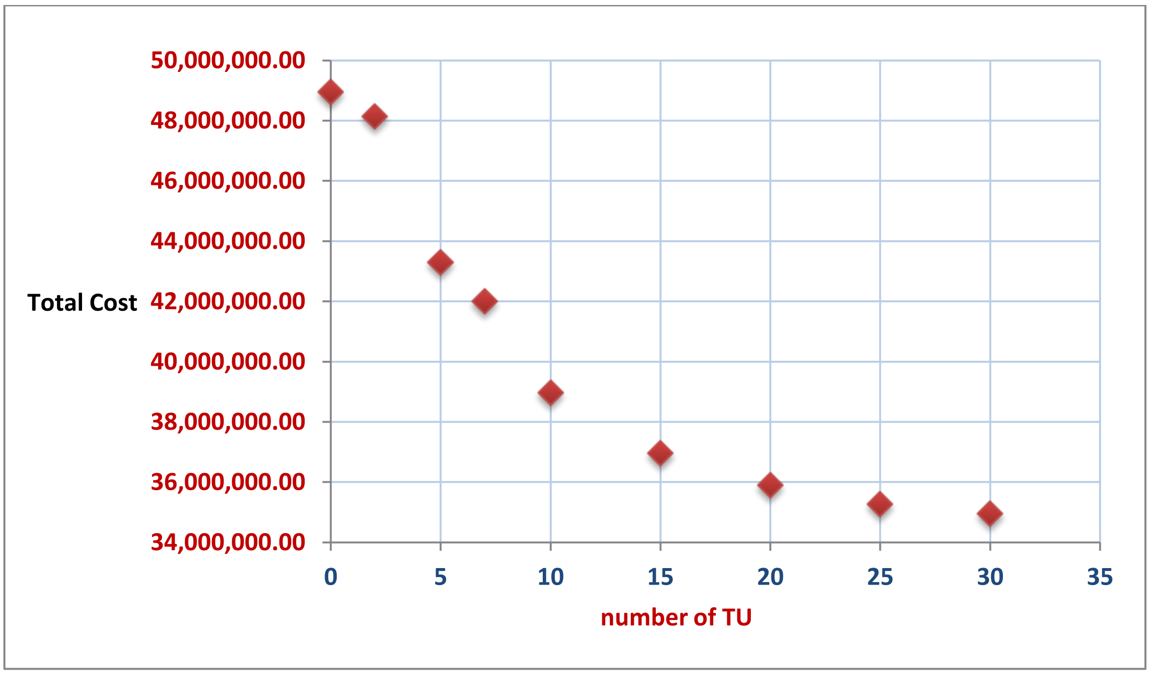


Figure 6.12- Effects of Opening Different Number of Transfer Units

As would be expected, the marginal return of opening every new transfer unit decreases as the number of TUs opened increases. When there is no active TU, total transportation cost is 51,857,835 TL whereas the total cost when 10 TUs are opened is 38,979,435 TL. This change corresponds to a 25% saving per month of the transportation cost. Note that, in return of this saving, there would be an additional cost of installing and operating these transfer units, which we ignore in this analysis. Therefore, by considering the installation and operating costs of transfer units and the time value of money, the decision maker should estimate the total time needed to recoup this investment and select the number of transfer units to operate with, accordingly.

6.2.4. Effects of highway accident rate

As explained in Section 6.1, we are not able to estimate the highway accident rate satisfactorily but set the highway accident rate as 10 times greater than the railway accident rate based on common sense. Nevertheless, setting k = 10 might be an over estimation. Therefore, we analyze the impact of different values of this parameter on the solutions obtained while assessing the benefits of intermodal distribution system over the single mode system.

As stated in the Section 6.2.1, when k = 10, MC(IMS) dominates MR(SMS) and MC(SMS). This implies that, if k = 10, none of the efficient solutions obtained for the design of fuel distribution system of Turkey could consist of only highway mode of transportation. This property is a strong one showing the pure benefit of introducing multi-modal transportation system for Turkey's fuel distribution system.

Considering that that k = 10 might be an overestimation, we reduced k value gradually to observe until which value of k the same property still holds. We observe that even if k is equal to 0.8, meaning that the accident rate of trains is higher than that of trucks, a distribution system composed of only highway transportation cannot be in the efficient set of solutions (See Table 6.7). When k is set to 0.7, this property no longer holds.

Table 6-7- MC and MR Solutions when k=0.8 and k=0.7

		MC		MR	
		Cost	Risk	Cost	Risk
k=0.8	SMS	**45,325,763 TL**	19,071	60,028,185	**10,937**
	IMS	**32,311,643 TL**	10,689	109,706,238	**4,895**
k=0.7	SMS	**45,325,763 TL**	16,687	60,028,185	**9,570**
	IMS	**32,311,643 TL**	10,118	93,399,900	**4,522**

Next, we analyze the impact of *k,* when it is less than 0.8, on the mode selection while designing the fuel distribution network. As stated earlier, MC(SMS) generates the minimum cost value that could be attained in the current distribution system. Therefore, based on this solution, for a decision maker who wants to analyze the effects of *k* without exceeding the minimum cost of the current system, we solve the model MR-βCost by setting the *β* parameter to the optimal cost of MC(SMS). From the results, we examine that even if *k* is very low and is set to 0.05, the decision maker still makes use of the railway alternative to a certain extent. Note that $k = 0.05$ corresponds to very low accident rates for highway transportation relative to railroad transportation. Recall that the risk measure includes not just the accident rates but also the consequences measured as the population exposed to risk while fuel is in transit. There are some portions of the railway network of Turkey, where railroads pass through unpopulated rural areas where the risk exposed to the environment is very low. Due to such regions on the network, railroads are still preferred at least at some parts of the network (See Figure 6.13) even if railroad accident rate is significantly higher than that of highways. For instance in Figure 6.14, bandwidths around railway (green bandwidth) and highway (yellow bandwidth) arcs of Kayseri-Sivas pair is presented. There are three districts that fall into the bandwidth of highway arc whereas there isn't any district that could be counted in bandwidth of railway arc.

As it is seen from the Figure 6.13 that when *k*=10, 83.01% of total transported ton*km is carried with railways and when *k* decrease and set to 0.05, still a significant portion (25.22%) of total transported ton*km is carried with railways since high volumes of fuel is transported over the railway links that are still preferable.

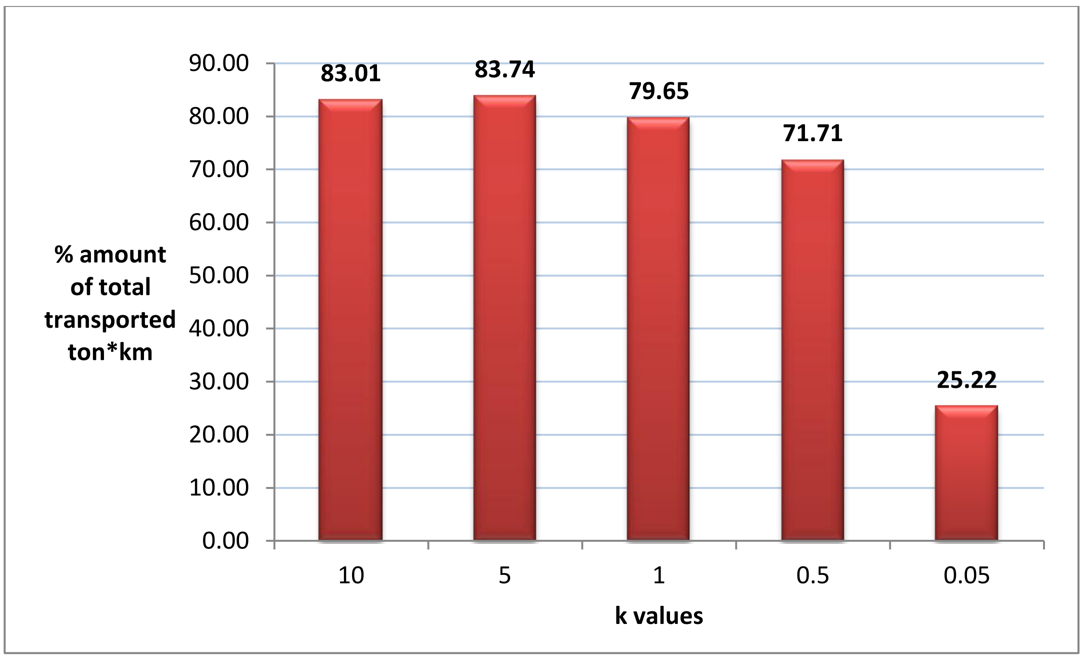


Figure 6.13- Percentage Usage of Railways in Different *k* Values When Solving MR-βCost Model where β equals to MC(SMS) value

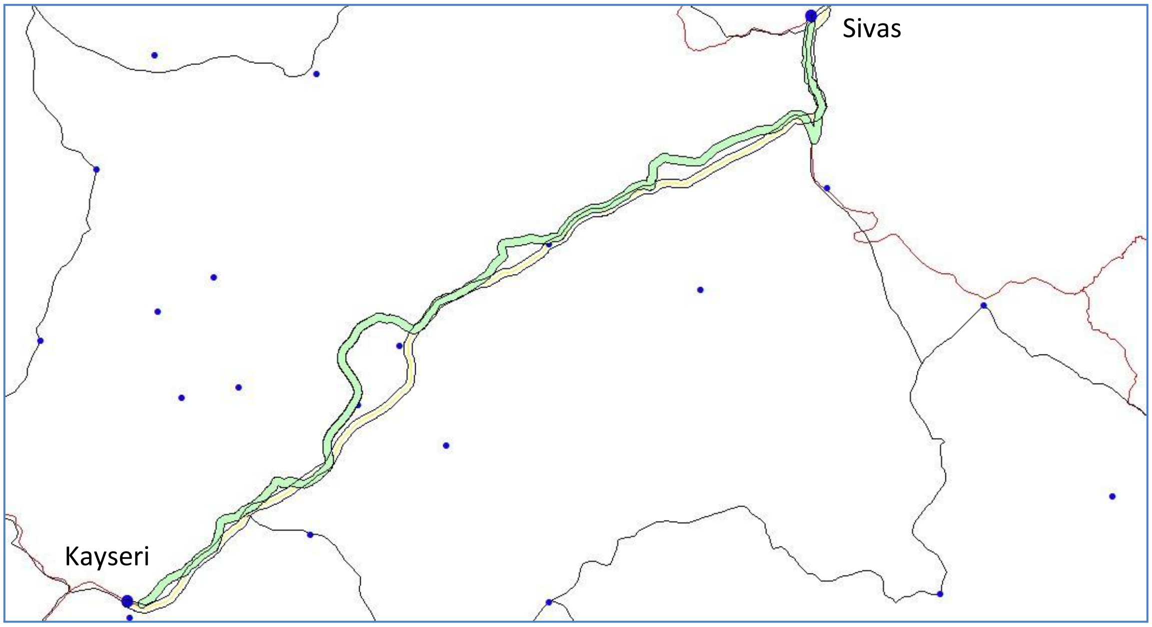
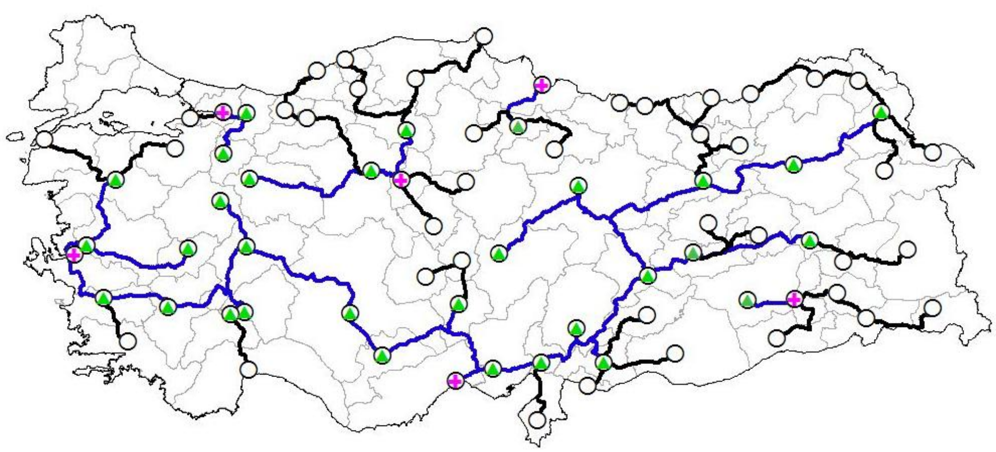
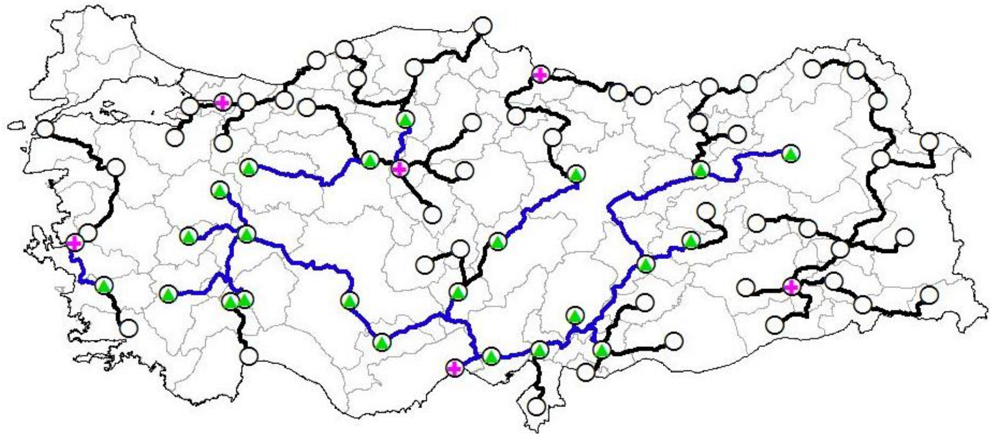


Figure 6.14 Bandwidths Around the Railway and Highway Arcs of Kayseri-Sivas Pair

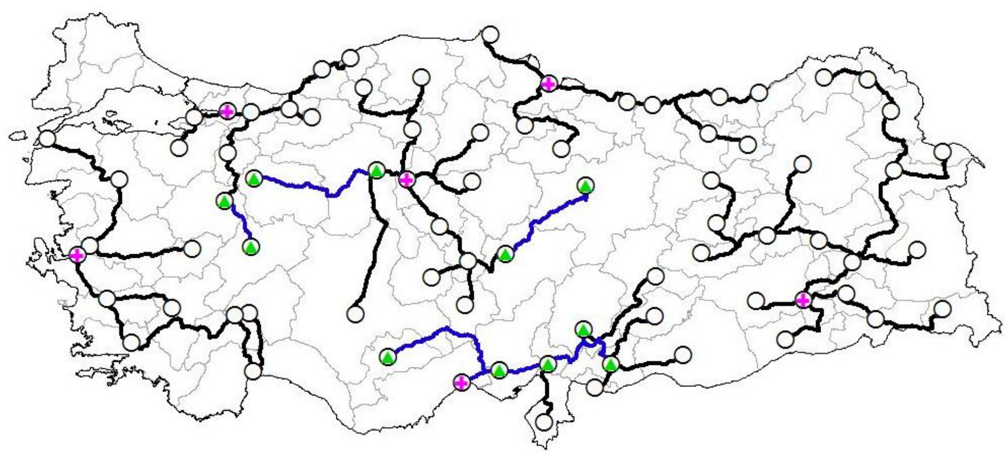
Moreover, Figure 6.15 depicts the distribution networks obtained for k=10, k=0.5 and k=0.05. As it can be seen from the networks that decreasing k value results slight changes on the railway usage.



(a) Distribution network when k=10



(b) Distribution network when k=0.5



(c) Distribution network when k=0.05

Figure 6.15- Solutions Obtained for Different k values

Changing the value of *k* affects the total transportation risk. Therefore, we analyze the MR(IMS) with different *k* values. Results indicate that, if transportation risk is the prior objective, changing *k* results significant changes on the railway usage (See Figure 6.16). As it can be seen from the figure that when *k*=0.01, only 18% of total carried ton*km is transported via railways.

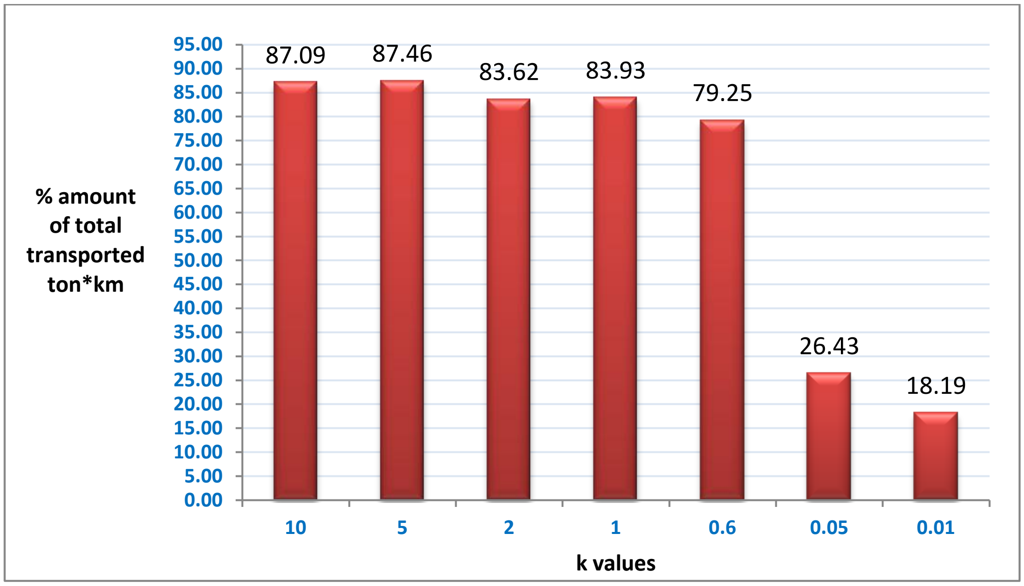


Figure 6.16 Percentage Usage Of Railways in Different *k* Values When Solving MR Model

Chapter 7

Conclusion

Hazardous materials transportation problem is an important problem that should be handled with extreme care since it is different from regular freight transportation as hazardous materials may harm to people, property or environment when an incident occurs. In this study, we focused on the fuel products, which belong to flammable and combustible liquids class of the hazardous materials classes.

As explained in the earlier chapters, fuel products are procured by fuel companies from supplier points in the current fuel distribution system of Turkey. After procurement, fuel is transferred to the transfer units or storage terminals of companies in order to charge the fuel products to road tankers. Finally, charged products are distributed via highways among the customer points. Since Turkey has a dense highway network, most of the leader fuel companies prefer to use road tankers for distribution. However, railway transportation is another favorable alternative with respect to advantages explained in

Chapter-3. We analyze implementing a combination of railway and highway transportation alternatives which is referred as rail-truck intermodal transportation.

“Risk” is considered as a crucial aspect of the hazardous material transportation problem. There are many studies deal with the risk modeling over highways in the literature. However, only a few recent ones focused on railway risk modeling. We adapt the risk model conducted by Glickman et al. (2007) and modify the model to our case by making a few changes. We collected all the needed data specialized on Turkey. Hence, calculating the risk values by the proposed model is one of the contributions of this study.

We propose a mathematical model whose aim is to decide on the following three questions: where to open transfer units, how to route fuel products from suppliers to customer by using which transportation mode, and which supplier covers how much demand. In this model, we define supplied amounts as a decision variable in order to observe the optimal coverage of each supplier. Thus, model provides opportunity to compare the required capacity and actual capacity of the suppliers.

Our model considers two conflicting objectives of intermodal fuel transportation problem, which are total cost and transportation risk. Based on these objectives, we create three variances of the base model. First one is MC model, whose objective is to minimize total cost of transportation. Second one is MR model, whose objective is to minimize total transportation risk and last one is *MR-βCost* model, which considers the risk function as the objective and uses the cost objective as a constraint.

Initially, we compare intermodal transportation alternative with the single mode alternative by using MC and MR models initially. Solutions indicate that intermodal alternative, which uses railways in conjunction with the highways, create significant reductions on both transportation risk and cost. In fact, it is observed that IMS alternative always provides better solutions under the condition that there is no limitation on the transfer units.

As mentioned before, transfer units are important components of the intermodal transportation system. Therefore, we conduct an analysis by changing the number of transfer units to be opened. Results show that under the given settings opening 10 transfer units create 25% monthly reduction on the total transportation cost when compared to the transportation cost of SMS in which there are no active transfer units in service (See Figure 6.12). Moreover, we analyze the effects of highway accident rate by changing the coefficient k. Even if we reduce the k value to 0.05, both MR-0.8Cost and MR solutions still prefer to use railways (See Figure 6.13 and 15).

In this study, we assumed that the fuel distribution system is directed by a centralized management. However, if we make these analyses for each fuel company separately, the results of the numerical analyses might change. In our railway risk model, we justify that the total number of rail wagons that carry fuel products greater or equal to 10. If these analyses make for each company, the railway risk model and these assumptions should be revised accordingly.

Additionally, we make all of these analysis based on the current fuel distribution system in Turkey. As explained in Chapter 3, railway network is very sparse when compared to highways. Therefore, there are limited route alternatives if a fuel company prefers to carry its fuel products by using only railways. Moreover, there are some regulations, which limit the use of the railway network for fuel companies such as leasing limitations for locomotives and scheduling constraints. Nevertheless, by this study we observe that using railways in conjunction with highways results significant reductions on both transportation risk and cost so the distribution system become more efficient in both perspectives. In recent future, if all of the limitations that affect the usage of railways for fuel transportation are relaxed, we show that rail-truck intermodal transportation of fuel products will be an applicable and efficient way for fuel companies.

BIBLIOGRAPHY

Abkowitz, M. D., Lepofsky, M., & Cheng, P. (1992). Selecting Criteria for Designating Hazardous Materials Highway Routes. *Transportation Research Record 1333* , 30-35.

Alp, E. (1995). Risk-based Transportation Planning Practice: Overall Methodology and A Case Example. *INFOR (1)* , 4-19.

Alumur, S., & Kara, B. (2007). A new model for the hazardous waste location-routing problem. *Computers & Operations Research* , 1406–1423.

Arnold, P., Peeters, D., & Thomas, I. (2004). Modelling a rail/road intermodal transportation system. *Transportation Research Part E 40* , 255–270.

Bontekoning, Y., Macharis, C., & Trip, J. ((2004). Is a new applied transportation research field emerging?–A review of intermodal rail–truck freight transport literature. *Transportation Research* , 1–34.

Bonvicini, S., Leonelli, P., & Spadoni, G. (1998). Risk Analysis of Hazardous Materials Transportation: Evaluating Uncertainty by Means of Fuzzy Logic. *Journal of Hazardous Materials 62(1)* , 59-74.

Boysen, N., Fliedner, M., & Kellner, M. (2010). Determining fixed crane areas in rail–rail transshipment yards. *Transportation Research Part E 46* , 1005–1016.

Brown, D., Policastro, A., Dunn, W., Carhard, R., & Lazaro, M. *Development of the initial isolation and protective action distances for the 2000 Emergency Response Guidebook.* Decision and Information Sciences Division, Argonne National Laboratory.

Browna, D. F., & Dunn, W. E. (2007). Application of A Quantitative Risk Assessment Method to Emergency Response Planning. *Computers & Operations Research 34* , 1243-1265.

Bubbico, R., Ferrari, C., & Mazza, B. (2000). Risk analysis of LPG transport by road and rail. *Journal of Loss Prevention in the Process Industries 13* , 27-31.

Cappanera, P., Galloa, G., & Maffioli, F. (2004). Discrete facility location and routing of obnoxious activities. *Discrete Applied Mathematics* , 3 – 28.

Caramia, M., & Guerriero, F. (2009). Aheuristic approach to long-haul freight transportation with multiple objective functions. *Omega 37* , 600 – 614.

Caris, A., & Janssens, G. (2009). A local search heuristic for the pre- and end- haulage of intermodal container terminals. *Computers &Operations Research 36* , 2763-2772.

Chang, T.-S. (2008). Best routes selection in international intermodal networks. *Computers & Operations Research* , 2877 – 2891.

Covello, V. T., & Merkhofer, M. W. (1993). *Risk Assessment Methods: Approaches for Assessing Health and Environmental Risks.* NY: Plenum Press.

(2007). Intermodal Transportation. In T. G. Crainic, & K. H. Kim, *Handbooks in Operations Research and Management Science, Transportation* (Vol. 14, pp. 467-537). North-Holland.

EMRA. (2010). Retrieved from Energy Market Regulatory Authority.

Erkut, E., & Verter, V. (1995). Hazardous Materials Logistics. In Z. Drezner (Ed.), *Facility Location: A Survey of Applications and Methods.* Springer-Verlag.

Erkut, E., & Verter, V. (1998). Modeling Of Transport Risk For Hazardous Materials. *Operations Research 46* , 625-642.

Erkut, E., Tjandra, S. A., & Verter, V. (2007). Hazardous Materials Transportation. In C. Barnhart, & G. Laporte, *Handbooks in Operations Research and Management Science, Transportation* (Vol. 14, pp. 539-611). North-Holland.

GDH. (2010). Retrieved from General Directorate of Highways Statistics: http://www.kgm.gov.tr/Sayfalar/KGM/SiteEng/Root/Statistics.aspx

Giannikos, I. (1998). A multiobjective programming model for locating treatment sites and routing hazardous wastes. *European Journal of Operational Research* , 333-342.

Glickman, T. S., Erkut, E., & Zschocke, M. S. (2007). The Cost and Risk Impacts of Rerouting Railroad Shipments of Hazardous Materials. *Accident Analysis and Prevention 39* , 1015–1025.

Helender, M. E., & Melachrinoudis, E. (1997). Facility location and reliable route planning in hazardous material transportation. *Transportation Science 31* , 216-226.

Jenness, J. (2003). *Jenness Enterprises*. Retrieved from http://www.jennessent.com/arcview/within_distance.htm

Justice, E. (1996). *Optimization of chassis reallocation in doublestack container transportation systems (rail cars, scheduling).* Ph.D. thesis, University of Arkansas.

Lei, T. L., & Church, R. L. (2011). Locating short-term empty-container storage facilities to support port operations: A user optimal approach. *Transportation Research Part E 47* , 738–754.

List, G., & Mirchandani, P. (1991). An integrated network/planar multiobjective model for routing and siting for hazardous materials. *Transportation Science 25 (2)* , 146-156.

Macharis, C., & Bontekoning, Y. (2004). Opportunities for OR in intermodal freight transport research: A review. *European Journal of Operational Research 153* , 400-416.

Milazzo, M., Lisi, R., Maschio, G., & Anto, G. (2002). HazMat Transport Through Messina Town: From Risk Analysis Suggestions for Improving Territorial Safety. *Journal of Loss Prevention in the Process Industries 15* , 347-356.

Min, H. (1991). International intermodal choices via chance-constrained goal programming. *Transportation Research 25 A* , 351–362.

Moccia, L., Cordeau, J.-F., Laporte, G., Ropke, S., & Valentini, M. P. (2011). Modeling and solving a multimodal transportation problem with flexible-time and scheduled services. *Networks 57(1)* , 53–68.

NHTSA. (2009). Retrieved from National Highway Traffic Safety Administration.

PETDER. (2010). *http://www.petder.org.tr.*

ReVelle, C., Cohon, J., & Shobrys, D. (1991). Simultaneous Siting and Routing in the Disposal of Hazardous Hazardous Wastes. *Transportation Science 25* , 138-145.

Sivakumar, R. A., Batta, R., & Karwan, M. H. (1995). A Multiple Route Conditional Risk Model for Transporting. *INFOR 33* , 20-33.

Sivakumar, R. A., Batta, R., & Karwan, M. H. (1993). A Network-based Model for Transporting Extremely Hazardous Materials. *Operations Research Letters 13* , 85-93.

Taylor, G. D., Broadstreet, F., Meinert, T. S., & Usher, J. S. (2002). An analysis of intermodal ramp selection methods. *Transportation Research Part E 38* , 117–134.

TSR. (2009). Retrieved from Turkish State Railways Annual Statistics, 2005-2009.

TSR. (2011). Retrieved from Research Planning & Coordination Department.

TUIK. (2010). Retrieved from Traffic Accident Statistics-Road.

U.S. Department of Transportation. (2011). Retrieved from http://www.dot.gov/

U.S. Department of Transportation. (2011). Retrieved from 2011 Hazmat Summary by Hazardous Materials Class, Pipeline and Hazardous Materials Safety Administration, Office of Hazardous Material Safety.

Verma, M. (2009). A cost and expected consequence approach to planning and managing railroad transportation of hazardous materials. *Transportation Research Part D 14* , 300–308.

Verma, M., & Verter, V. (2010). A lead-time based approach for planning rail–truck intermodal transportation of dangerous goods. *European Journal of Operational Research 202* , 696–706.

Verma, M., & Verter, V. (2007). Railroad transportation of dangerous goods: Population exposure to airborne toxins. *Computers & Operations Research 34* , 1287–1303.

Zhang, J., Hodgson, J., & Erkut, E. (2000). Using GIS to Assess the Risks of Hazardous Materials Transport in Networks. *European Journal of Operational Research 121* , 316-329.

Zhang, R., Yun, W. Y., & Moon, I. K. (2011). Modeling and optimization of acontainer drayag eproblem with resource constraints. *Production Economics 133* , 351–359.

Zografos, K. G., & Samara, S. (1990). Combined location-routing model for hazardous waste transportation and disposal. *Transportation Research Record 1245* , 52-59.

APPENDIX

Appendix 1 Monthly Demand Values in tonnes

Cities	Monthly Demands
ADANA	32,091
ADIYAMAN	5,915
AFYON	12,334
AGRI	3,228
AMASYA	6,429
ANKARA	103,354
ANTALYA	47,067
ARTVIN	2,193
AYDIN	18,070
BALIKESIR	25,800
BILECIK	5,324
BINGOL	1,750
BITLIS	1,630
BOLU	10,321
BURDUR	5,464
BURSA	49,518
CANAKKALE	10,740
CANKIRI	3,826
CORUM	12,281
DENIZLI	20,757
DIYARBAKIR	12,136
ELAZIG	7,730
ERZINCAN	4,338
ERZURUM	9,217
ESKISEHIR	19,537
GAZIANTEP	28,323
GIRESUN	5,568
GUMUSHANE	1,867
HAKKARI	872
HATAY	20,674
ISPARTA	7,083
MERSIN	49,310
IZMIR	76,510
KARS	2,480
KASTAMONU	6,453
KAYSERI	21,279
KIRSEHIR	3,248
IZMIT	35,886
KONYA	38,707

Cities	Monthly Demands
KUTAHYA	9,268
MALATYA	11,175
MANISA	23,034
KMARAS	13,156
MARDIN	3,145
MUGLA	23,646
MUS	1,461
NEVSEHIR	6,105
NIGDE	10,013
ORDU	7,888
RIZE	5,396
SAKARYA	18,679
SAMSUN	23,594
SIIRT	1,530
SINOP	2,770
SIVAS	12,460
TOKAT	9,387
TRABZON	13,885
TUNCELI	981
SANLIURFA	9,291
USAK	7,046
VAN	3,267
YOZGAT	7,653
ZONGULDAK	9,406
AKSARAY	6,610
BAYBURT	1,628
KARAMAN	4,234
KIRIKKALE	10,285
BATMAN	7,749
SIRNAK	2,494
BARTIN	3,189
ARDAHAN	1,542
IGDIR	531
YALOVA	5,039
KARABUK	4,363
KILIS	435
OSMANIYE	5,623
DUZCE	7,922

	ADANA	ADIYAMAN	AFYON	AĞRI	AMASYA	ANKARA	ANTALYA	ARTVİN	AYDIN	BALIKESİR	BİLECİK
ADANA	0	-	642	-	767	674	-	-	1015	999	885
ADIYAMAN	-	0	-	-	-	-	-	-	-	-	-
AFYON	642	-	0	-	1136	415	-	-	374	357	243
AĞRI	-	-	-	0	-	-	-	-	-	-	-
AMASYA	767	-	1136	-	0	824	-	-	1509	1407	1159
ANKARA	674	-	415	-	824	0	-	-	788	584	336
ANTALYA	-	-	-	-	-	-	0	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	0	-	-	-
AYDIN	1015	-	374	-	1509	788	-	-	0	374	616
BALIKESİR	999	-	357	-	1407	584	-	-	374	0	412
BİLECİK	885	-	243	-	1159	336	-	-	616	412	0
BİNGÖL	-	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-	-
BURDUR	811	-	170	-	1305	584	-	-	318	527	412
BURSA	-	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	706	-	588	-	856	173	-	-	961	756	506
ÇORUM	-	-	-	-	-	-	-	-	-	-	-
DENİZLİ	903	-	262	-	1397	677	-	-	131	504	504
DİYARBAKIR	646	-	1287	-	774	1108	-	-	1660	1644	1443
ELAZIĞ	511	-	1153	-	639	973	-	-	1526	1510	1308
ERZİNCAN	752	-	1247	-	601	935	-	-	1620	1518	1270
ERZURUM	967	-	1461	-	816	1150	-	-	1835	1733	1485
ESKİŞEHİR	803	-	162	-	1077	254	-	-	535	330	82
GAZİANTEP	282	-	924	-	786	956	-	-	1297	1281	1167
GİRESUN	-	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-	-
ISPARTA	816	-	175	-	1310	589	-	-	323	531	417
MERSİN	68	-	661	-	786	693	-	-	1035	1010	904
İZMİR	1064	-	422	-	1557	824	-	-	133	241	652
KARS	1183	-	1678	-	1032	1366	-	-	2051	1949	1701
KASTAMONU	-	-	-	-	-	-	-	-	-	-	-
KAYSERİ	324	-	693	-	444	381	-	-	1066	964	716
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-	-
KOCAELİ	1025	-	384	-	1300	476	-	-	757	552	141
KONYA	370	-	272	-	864	687	-	-	645	629	515
KÜTAHYA	747	-	105	-	1154	331	-	-	478	253	159
MALATYA	392	-	1034	-	520	854	-	-	1407	1391	1189
MANİSA	998	-	356	-	1491	758	-	-	199	175	586
K.MARAŞ	219	-	861	-	746	893	-	-	1234	1218	1104
MARDİN	665	-	1307	-	1169	1339	-	-	1680	1664	1550
MUĞLA	-	-	-	-	-	-	-	-	-	-	-
MUŞ	762	-	1404	-	890	1224	-	-	1777	1760	1559
NEVŞEHİR	-	-	-	-	-	-	-	-	-	-	-
NİĞDE	196	-	565	-	571	478	-	-	938	922	808
ORDU	-	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-	-	-
SAKARYA	994	-	352	-	1268	445	-	-	726	521	110
SAMSUN	900	-	1269	-	134	957	-	-	1642	1540	1292
SİİRT	-	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-	-
SİVAS	546	-	915	-	269	603	-	-	1288	1186	938
TOKAT	-	-	-	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-	-
UŞAK	777	-	135	-	1271	550	-	-	420	396	378
VAN	867	-	1509	-	995	1329	-	-	1882	1866	1665
YOZGAT	-	-	-	-	-	-	-	-	-	-	-
ZONGULDAK	1020	-	901	-	1169	486	-	-	1274	1069	820
AKSARAY	-	-	-	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-	-	-	-
KARAMAN	268	-	375	-	762	669	-	-	748	731	617
KIRIKKALE	581	-	508	-	731	93	-	-	881	676	428
BATMAN	736	-	1378	-	864	1198	-	-	1751	1735	1533
ŞIRNAK	-	-	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-	-
OSMANİYE	86	-	728	-	853	760	-	-	1101	1085	971
Düzce	-	-	-	-	-	-	-	-	-	-	-

Appendix 2 Railway Distances (km)

ELAZIĞ	DİYARBAKIR	DENİZLİ	ÇORUM	ÇANKIRI	ÇANAKKALE	BURSA	BURDUR	BOLU	BİTLİS	BİNGÖL	
511	646	903	-	706	-	-	811	-	-	-	ADANA
-	-	-	-	-	-	-	-	-	-	-	ADIYAMAN
1153	1287	262	-	588	-	-	170	-	-	-	AFYON
-	-	-	-	-	-	-	-	-	-	-	AĞRI
639	774	1397	-	856	-	-	1305	-	-	-	AMASYA
973	1108	677	-	173	-	-	584	-	-	-	ANKARA
-	-	-	-	-	-	-	-	-	-	-	ANTALYA
-	-	-	-	-	-	-	-	-	-	-	ARTVİN
1526	1660	131	-	961	-	-	318	-	-	-	AYDIN
1510	1644	504	-	756	-	-	527	-	-	-	BALIKESİR
1308	1443	504	-	506	-	-	412	-	-	-	BİLECİK
-	-	-	-	-	-	-	-	-	-	0	BİNGÖL
-	-	-	-	-	-	-	-	-	0	-	BİTLİS
-	-	-	-	-	-	-	-	0	-	-	BOLU
1322	1457	206	-	757	-	-	0	-	-	-	BURDUR
-	-	-	-	-	-	0	-	-	-	-	BURSA
-	-	-	-	-	0	-	-	-	-	-	ÇANAKKALE
1005	1140	849	-	0	-	-	757	-	-	-	ÇANKIRI
-	-	-	0	-	-	-	-	-	-	-	ÇORUM
1414	1549	0	-	849	-	-	206	-	-	-	DENİZLİ
183	0	1549	-	1140	-	-	1457	-	-	-	DİYARBAKIR
0	183	1414	-	1005	-	-	1322	-	-	-	ELAZIĞ
479	614	1508	-	967	-	-	1416	-	-	-	ERZİNCAN
694	829	1723	-	1182	-	-	1631	-	-	-	ERZURUM
1227	1361	423	-	426	-	-	331	-	-	-	ESKİŞEHİR
385	520	1185	-	988	-	-	1093	-	-	-	GAZİANTEP
-	-	-	-	-	-	-	-	-	-	-	GİRESUN
-	-	-	-	-	-	-	-	-	-	-	GÜMÜŞHANE
-	-	-	-	-	-	-	-	-	-	-	HAKKARİ
-	-	-	-	-	-	-	-	-	-	-	HATAY
1327	1461	211	-	762	-	-	53	-	-	-	ISPARTA
578	713	923	-	725	-	-	831	-	-	-	MERSİN
1574	1709	264	-	997	-	-	450	-	-	-	İZMİR
910	1045	1939	-	1398	-	-	1847	-	-	-	KARS
-	-	-	-	-	-	-	-	-	-	-	KASTAMONU
593	728	954	-	413	-	-	862	-	-	-	KAYSERİ
-	-	-	-	-	-	-	-	-	-	-	KIRŞEHİR
1449	1583	645	-	647	-	-	553	-	-	-	KOCAELİ
881	1016	534	-	803	-	-	441	-	-	-	KONYA
1257	1392	366	-	503	-	-	274	-	-	-	KÜTAHYA
119	254	1295	-	886	-	-	1203	-	-	-	MALATYA
1508	1643	330	-	931	-	-	516	-	-	-	MANİSA
345	480	1122	-	925	-	-	1030	-	-	-	K.MARAŞ
768	902	1568	-	1371	-	-	1476	-	-	-	MARDİN
-	-	-	-	-	-	-	-	-	-	-	MUĞLA
251	434	1665	-	1256	-	-	1573	-	-	-	MUŞ
-	-	-	-	-	-	-	-	-	-	-	NEVŞEHİR
707	841	826	-	511	-	-	734	-	-	-	NİĞDE
-	-	-	-	-	-	-	-	-	-	-	ORDU
-	-	-	-	-	-	-	-	-	-	-	RİZE
1418	1552	614	-	616	-	-	522	-	-	-	SAKARYA
772	907	1530	-	989	-	-	1438	-	-	-	SAMSUN
-	-	-	-	-	-	-	-	-	-	-	SİİRT
-	-	-	-	-	-	-	-	-	-	-	SİNOP
370	505	1176	-	635	-	-	1084	-	-	-	SİVAS
-	-	-	-	-	-	-	-	-	-	-	TOKAT
-	-	-	-	-	-	-	-	-	-	-	TRABZON
-	-	-	-	-	-	-	-	-	-	-	TUNCELİ
-	-	-	-	-	-	-	-	-	-	-	ŞANLIURFA
1288	1422	397	-	722	-	-	305	-	-	-	UŞAK
357	539	1770	-	1362	-	-	1678	-	-	-	VAN
-	-	-	-	-	-	-	-	-	-	-	YOZGAT
1319	1453	1162	-	314	-	-	1070	-	-	-	ZONGULDAK
-	-	-	-	-	-	-	-	-	-	-	AKSARAY
-	-	-	-	-	-	-	-	-	-	-	BAYBURT
779	913	636	-	701	-	-	544	-	-	-	KARAMAN
880	1015	769	-	125	-	-	677	-	-	-	KIRIKKALE
274	91	1639	-	1230	-	-	1547	-	-	-	BATMAN
-	-	-	-	-	-	-	-	-	-	-	ŞIRNAK
-	-	-	-	-	-	-	-	-	-	-	BARTIN
-	-	-	-	-	-	-	-	-	-	-	ARDAHAN
-	-	-	-	-	-	-	-	-	-	-	IĞDIR
-	-	-	-	-	-	-	-	-	-	-	YALOVA
-	-	-	-	-	-	-	-	-	-	-	KARABÜK
-	-	-	-	-	-	-	-	-	-	-	KİLİS
478	613	989	-	792	-	-	897	-	-	-	OSMANİYE
-	-	-	-	-	-	-	-	-	-	-	Düzce

Appendix 1 Railway Distances (km)

	ERZİNCAN	ERZURUM	ESKİŞEHİR	GAZİANTEP	GİRESUN	GÜMÜŞHANE	HAKKARİ	HATAY	ISPARTA
ADANA	752	967	803	282	-	-	-	-	816
ADIYAMAN	-	-	-	-	-	-	-	-	-
AFYON	1247	1461	162	924	-	-	-	-	175
AĞRI	-	-	-	-	-	-	-	-	-
AMASYA	601	816	1077	786	-	-	-	-	1310
ANKARA	935	1150	254	956	-	-	-	-	589
ANTALYA	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-
AYDIN	1620	1835	535	1297	-	-	-	-	323
BALIKESİR	1518	1733	330	1281	-	-	-	-	531
BİLECİK	1270	1485	82	1167	-	-	-	-	417
BİNGÖL	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-
BURDUR	1416	1631	331	1093	-	-	-	-	53
BURSA	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-
ÇANKIRI	967	1182	426	988	-	-	-	-	762
ÇORUM	-	-	-	-	-	-	-	-	-
DENİZLİ	1508	1723	423	1185	-	-	-	-	211
DİYARBAKIR	614	829	1361	520	-	-	-	-	1461
ELAZIĞ	479	694	1227	385	-	-	-	-	1327
ERZİNCAN	0	215	1189	626	-	-	-	-	1421
ERZURUM	215	0	1403	841	-	-	-	-	1635
ESKİŞEHİR	1189	1403	0	1085	-	-	-	-	336
GAZİANTEP	626	841	1085	0	-	-	-	-	1098
GİRESUN	-	-	-	-	0	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	0	-	-	-
HAKKARİ	-	-	-	-	-	-	0	-	-
HATAY	-	-	-	-	-	-	-	0	-
ISPARTA	1421	1635	336	1098	-	-	-	-	0
MERSİN	820	1034	823	350	-	-	-	-	835
İZMİR	1668	1883	571	1346	-	-	-	-	455
KARS	431	217	1619	1057	-	-	-	-	1852
KASTAMONU	-	-	-	-	-	-	-	-	-
KAYSERİ	555	769	634	606	-	-	-	-	867
KIRŞEHİR	-	-	-	-	-	-	-	-	-
KOCAELİ	1411	1625	223	1307	-	-	-	-	558
KONYA	975	1190	433	652	-	-	-	-	446
KÜTAHYA	1266	1480	77	1029	-	-	-	-	279
MALATYA	361	575	1108	266	-	-	-	-	1208
MANİSA	1602	1817	505	1280	-	-	-	-	521
K.MARAŞ	587	801	1022	129	-	-	-	-	1035
MARDİN	1009	1224	1468	383	-	-	-	-	1481
MUĞLA	-	-	-	-	-	-	-	-	-
MUŞ	730	945	1478	636	-	-	-	-	1578
NEVŞEHİR	-	-	-	-	-	-	-	-	-
NİĞDE	682	897	726	478	-	-	-	-	739
ORDU	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-
SAKARYA	1379	1594	191	1276	-	-	-	-	526
SAMSUN	734	949	1210	919	-	-	-	-	1443
SİİRT	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-
SİVAS	332	547	857	517	-	-	-	-	1089
TOKAT	-	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-
UŞAK	1382	1596	297	1059	-	-	-	-	309
VAN	836	1051	1583	741	-	-	-	-	1683
YOZGAT	-	-	-	-	-	-	-	-	-
ZONGULDAK	1280	1495	740	1302	-	-	-	-	1075
AKSARAY	-	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-	-
KARAMAN	873	1087	536	550	-	-	-	-	549
KIRIKKALE	842	1057	347	863	-	-	-	-	682
BATMAN	705	919	1452	610	-	-	-	-	1552
ŞIRNAK	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-
OSMANİYE	720	934	889	196	-	-	-	-	902
Düzce	-	-	-	-	-	-	-	-	-

Appendix 2 Railway Distances (km)

MANİSA	MALATYA	KÜTAHYA	KONYA	KOCAELİ	KIRŞEHİR	KAYSERİ	KASTAMONU	KARS	İZMİR	MERSİN	
998	392	747	370	1025	-	324	-	1183	1064	68	ADANA
-	-	-	-	-	-	-	-	-	-	-	ADIYAMAN
356	1034	105	272	384	-	693	-	1678	422	661	AFYON
-	-	-	-	-	-	-	-	-	-	-	AĞRI
1491	520	1154	864	1300	-	444	-	1032	1557	786	AMASYA
758	854	331	687	476	-	381	-	1366	824	693	ANKARA
-	-	-	-	-	-	-	-	-	-	-	ANTALYA
-	-	-	-	-	-	-	-	-	-	-	ARTVİN
199	1407	478	645	757	-	1066	-	2051	133	1035	AYDIN
175	1391	253	629	552	-	964	-	1949	241	1010	BALIKESİR
586	1189	159	515	141	-	716	-	1701	652	904	BİLECİK
-	-	-	-	-	-	-	-	-	-	-	BİNGÖL
-	-	-	-	-	-	-	-	-	-	-	BİTLİS
-	-	-	-	-	-	-	-	-	-	-	BOLU
516	1203	274	441	553	-	862	-	1847	450	831	BURDUR
-	-	-	-	-	-	-	-	-	-	-	BURSA
-	-	-	-	-	-	-	-	-	-	-	ÇANAKKALE
931	886	503	803	647	-	413	-	1398	997	725	ÇANKIRI
-	-	-	-	-	-	-	-	-	-	-	ÇORUM
330	1295	366	534	645	-	954	-	1939	264	923	DENİZLİ
1643	254	1392	1016	1583	-	728	-	1045	1709	713	DİYARBAKIR
1508	119	1257	881	1449	-	593	-	910	1574	578	ELAZIĞ
1602	361	1266	975	1411	-	555	-	431	1668	820	ERZİNCAN
1817	575	1480	1190	1625	-	769	-	217	1883	1034	ERZURUM
505	1108	77	433	223	-	634	-	1619	571	823	ESKİŞEHİR
1280	266	1029	652	1307	-	606	-	1057	1346	350	GAZİANTEP
-	-	-	-	-	-	-	-	-	-	-	GİRESUN
-	-	-	-	-	-	-	-	-	-	-	GÜMÜŞHANE
-	-	-	-	-	-	-	-	-	-	-	HAKKARİ
-	-	-	-	-	-	-	-	-	-	-	HATAY
521	1208	279	446	558	-	867	-	1852	455	835	ISPARTA
1017	459	766	390	1045	-	343	-	1251	1083	0	MERSİN
67	1456	494	694	793	-	1114	-	2099	0	1083	İZMİR
2033	792	1696	1406	1842	-	986	-	0	2099	1251	KARS
-	-	-	-	-	-	-	0	-	-	-	KASTAMONU
1048	474	711	421	856	-	0	-	986	1114	343	KAYSERİ
-	-	-	-	-	0	-	-	-	-	-	KIRŞEHİR
727	1330	300	655	0	-	856	-	1842	793	1045	KOCAELİ
628	762	377	0	655	-	421	-	1406	694	390	KONYA
428	1138	0	377	300	-	711	-	1696	494	766	KÜTAHYA
1390	0	1138	762	1330	-	474	-	792	1456	459	MALATYA
0	1390	428	628	727	-	1048	-	2033	67	1017	MANİSA
1217	226	966	589	1244	-	543	-	1018	1283	287	K.MARAŞ
1663	649	1412	1035	1690	-	989	-	1440	1729	733	MARDİN
-	-	-	-	-	-	-	-	-	-	-	MUĞLA
1759	370	1508	1132	1700	-	844	-	1161	1825	829	MUŞ
-	-	-	-	-	-	-	-	-	-	-	NEVŞEHİR
921	588	669	293	948	-	128	-	1113	987	215	NİĞDE
-	-	-	-	-	-	-	-	-	-	-	ORDU
-	-	-	-	-	-	-	-	-	-	-	RİZE
696	1299	268	624	49	-	825	-	1810	762	1013	SAKARYA
1624	653	1287	997	1433	-	577	-	1165	1690	919	SAMSUN
-	-	-	-	-	-	-	-	-	-	-	SİİRT
-	-	-	-	-	-	-	-	-	-	-	SİNOP
1271	252	934	643	1079	-	223	-	763	1337	565	SİVAS
-	-	-	-	-	-	-	-	-	-	-	TOKAT
-	-	-	-	-	-	-	-	-	-	-	TRABZON
-	-	-	-	-	-	-	-	-	-	-	TUNCELİ
-	-	-	-	-	-	-	-	-	-	-	ŞANLIURFA
221	1169	240	407	519	-	827	-	1813	287	796	UŞAK
1865	476	1613	1237	1805	-	949	-	1267	1931	935	VAN
-	-	-	-	-	-	-	-	-	-	-	YOZGAT
1244	1200	817	1117	961	-	726	-	1711	1310	1039	ZONGULDAK
-	-	-	-	-	-	-	-	-	-	-	AKSARAY
-	-	-	-	-	-	-	-	-	-	-	BAYBURT
730	660	479	103	758	-	318	-	1304	796	287	KARAMAN
851	762	424	679	569	-	288	-	1273	917	601	KIRIKKALE
1734	345	1482	1106	1674	-	818	-	1136	1800	803	BATMAN
-	-	-	-	-	-	-	-	-	-	-	ŞIRNAK
-	-	-	-	-	-	-	-	-	-	-	BARTIN
-	-	-	-	-	-	-	-	-	-	-	ARDAHAN
-	-	-	-	-	-	-	-	-	-	-	IĞDIR
-	-	-	-	-	-	-	-	-	-	-	YALOVA
-	-	-	-	-	-	-	-	-	-	-	KARABÜK
-	-	-	-	-	-	-	-	-	-	-	KİLİS
1084	359	833	456	1111	-	410	-	1151	1150	154	OSMANİYE
-	-	-	-	-	-	-	-	-	-	-	Düzce

Appendix 2 Railway Distances (km)

	K.MARAŞ	MARDİN	MUĞLA	MUŞ	NEVŞEHİR	NİĞDE	ORDU	RİZE	SAKARYA	SAMSUN	SİİRT	SİNOP	SİVAS
ADANA	219	665	-	762	-	196	-	-	994	900	-	-	546
ADIYAMAN	-	-	-	-	-	-	-	-	-	-	-	-	-
AFYON	861	1307	-	1404	-	565	-	-	352	1269	-	-	915
AĞRI	-	-	-	-	-	-	-	-	-	-	-	-	-
AMASYA	746	1169	-	890	-	571	-	-	1268	134	-	-	269
ANKARA	893	1339	-	1224	-	478	-	-	445	957	-	-	603
ANTALYA	-	-	-	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-	-	-	-
AYDIN	1234	1680	-	1777	-	938	-	-	726	1642	-	-	1288
BALIKESİR	1218	1664	-	1760	-	922	-	-	521	1540	-	-	1186
BİLECİK	1104	1550	-	1559	-	808	-	-	110	1292	-	-	938
BİNGÖL	-	-	-	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-	-	-	-
BURDUR	1030	1476	-	1573	-	734	-	-	522	1438	-	-	1084
BURSA	-	-	-	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	925	1371	-	1256	-	511	-	-	616	989	-	-	635
ÇORUM	-	-	-	-	-	-	-	-	-	-	-	-	-
DENİZLİ	1122	1568	-	1665	-	826	-	-	614	1530	-	-	1176
DİYARBAKIR	480	902	-	434	-	841	-	-	1552	907	-	-	505
ELAZIĞ	345	768	-	251	-	707	-	-	1418	772	-	-	370
ERZİNCAN	587	1009	-	730	-	682	-	-	1379	734	-	-	332
ERZURUM	801	1224	-	945	-	897	-	-	1594	949	-	-	547
ESKİŞEHİR	1022	1468	-	1478	-	726	-	-	191	1210	-	-	857
GAZİANTEP	129	383	-	636	-	478	-	-	1276	919	-	-	517
GİRESUN	-	-	-	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-	-	-	-
ISPARTA	1035	1481	-	1578	-	739	-	-	526	1443	-	-	1089
MERSİN	287	733	-	829	-	215	-	-	1013	919	-	-	565
İZMİR	1283	1729	-	1825	-	987	-	-	762	1690	-	-	1337
KARS	1018	1440	-	1161	-	1113	-	-	1810	1165	-	-	763
KASTAMONU	-	-	-	-	-	-	-	-	-	-	-	-	-
KAYSERİ	543	989	-	844	-	128	-	-	825	577	-	-	223
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-	-	-	-
KOCAELİ	1244	1690	-	1700	-	948	-	-	49	1433	-	-	1079
KONYA	589	1035	-	1132	-	293	-	-	624	997	-	-	643
KÜTAHYA	966	1412	-	1508	-	669	-	-	268	1287	-	-	934
MALATYA	226	649	-	370	-	588	-	-	1299	653	-	-	252
MANİSA	1217	1663	-	1759	-	921	-	-	696	1624	-	-	1271
K.MARAŞ	0	512	-	596	-	415	-	-	1213	879	-	-	478
MARDİN	512	0	-	1019	-	861	-	-	1659	1302	-	-	900
MUĞLA	-	-	0	-	-	-	-	-	-	-	-	-	-
MUŞ	596	1019	-	0	-	957	-	-	1668	1023	-	-	621
NEVŞEHİR	-	-	-	-	0	-	-	-	-	-	-	-	-
NİĞDE	415	861	-	957	-	0	-	-	917	704	-	-	351
ORDU	-	-	-	-	-	-	0	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	0	-	-	-	-	-
SAKARYA	1213	1659	-	1668	-	917	-	-	0	1401	-	-	1048
SAMSUN	879	1302	-	1023	-	704	-	-	1401	0	-	-	402
SİİRT	-	-	-	-	-	-	-	-	-	-	0	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-	-	0	-
SİVAS	478	900	-	621	-	351	-	-	1048	402	-	-	0
TOKAT	-	-	-	-	-	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-	-	-	-
UŞAK	996	1442	-	1539	-	700	-	-	487	1404	-	-	1050
VAN	702	1124	-	608	-	1063	-	-	1774	1129	-	-	727
YOZGAT	-	-	-	-	-	-	-	-	-	-	-	-	-
ZONGULDAK	1239	1685	-	1569	-	824	-	-	930	1302	-	-	949
AKSARAY	-	-	-	-	-	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-	-	-	-	-	-
KARAMAN	487	933	-	1030	-	191	-	-	727	895	-	-	541
KIRIKKALE	800	1246	-	1131	-	386	-	-	538	864	-	-	510
BATMAN	570	993	-	524	-	932	-	-	1643	997	-	-	596
ŞIRNAK	-	-	-	-	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-	-	-	-
OSMANİYE	133	579	-	729	-	282	-	-	1080	986	-	-	611
Düzce	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 2 Railway Distances (km)

	TOKAT	TRABZON	TUNCELİ	ŞANLIURFA	UŞAK	VAN	YOZGAT	ZONGULDAK	AKSARAY	BAYBURT
ADANA	-	-	-	-	777	867	-	1020	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	135	1509	-	901	-	-
AĞRI	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	-	-	1271	995	-	1169	-	-
ANKARA	-	-	-	-	550	1329	-	486	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	420	1882	-	1274	-	-
BALIKESİR	-	-	-	-	396	1866	-	1069	-	-
BİLECİK	-	-	-	-	378	1665	-	820	-	-
BİNGÖL	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-
BURDUR	-	-	-	-	305	1678	-	1070	-	-
BURSA	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	-	-	722	1362	-	314	-	-
ÇORUM	-	-	-	-	-	-	-	-	-	-
DENİZLİ	-	-	-	-	397	1770	-	1162	-	-
DİYARBAKIR	-	-	-	-	1422	539	-	1453	-	-
ELAZIĞ	-	-	-	-	1288	357	-	1319	-	-
ERZİNCAN	-	-	-	-	1382	836	-	1280	-	-
ERZURUM	-	-	-	-	1596	1051	-	1495	-	-
ESKİŞEHİR	-	-	-	-	297	1583	-	740	-	-
GAZİANTEP	-	-	-	-	1059	741	-	1302	-	-
GİRESUN	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-
ISPARTA	-	-	-	-	309	1683	-	1075	-	-
MERSİN	-	-	-	-	796	935	-	1039	-	-
İZMİR	-	-	-	-	287	1931	-	1310	-	-
KARS	-	-	-	-	1813	1267	-	1711	-	-
KASTAMONU	-	-	-	-	-	-	-	-	-	-
KAYSERİ	-	-	-	-	827	949	-	726	-	-
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-
KOCAELİ	-	-	-	-	519	1805	-	961	-	-
KONYA	-	-	-	-	407	1237	-	1117	-	-
KÜTAHYA	-	-	-	-	240	1613	-	817	-	-
MALATYA	-	-	-	-	1169	476	-	1200	-	-
MANİSA	-	-	-	-	221	1865	-	1244	-	-
K.MARAŞ	-	-	-	-	996	702	-	1239	-	-
MARDİN	-	-	-	-	1442	1124	-	1685	-	-
MUĞLA	-	-	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	1539	608	-	1569	-	-
NEVŞEHİR	-	-	-	-	-	-	-	-	-	-
NİĞDE	-	-	-	-	700	1063	-	824	-	-
ORDU	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-	-
SAKARYA	-	-	-	-	487	1774	-	930	-	-
SAMSUN	-	-	-	-	1404	1129	-	1302	-	-
SİİRT	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-
SİVAS	-	-	-	-	1050	727	-	949	-	-
TOKAT	0	-	-	-	-	-	-	-	-	-
TRABZON	-	0	-	-	-	-	-	-	-	-
TUNCELİ	-	-	0	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	0	-	-	-	-	-	-
UŞAK	-	-	-	-	0	1644	-	1036	-	-
VAN	-	-	-	-	1644	0	-	1675	-	-
YOZGAT	-	-	-	-	-	-	0	-	-	-
ZONGULDAK	-	-	-	-	1036	1675	-	0	-	-
AKSARAY	-	-	-	-	-	-	-	-	0	-
BAYBURT	-	-	-	-	-	-	-	-	-	0
KARAMAN	-	-	-	-	509	1135	-	1014	-	-
KIRIKKALE	-	-	-	-	643	1237	-	439	-	-
BATMAN	-	-	-	-	1513	630	-	1544	-	-
ŞIRNAK	-	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-
OSMANİYE	-	-	-	-	863	835	-	1106	-	-
Düzce	-	-	-	-	-	-	-	-	-	-

Appendix 2 Railway Distances (km)

	KARAMAN	KIRIKKALE	BATMAN	ŞIRNAK	BARTIN	ARDAHAN	IĞDIR	YALOVA	KARABÜK	KİLİS
ADANA	268	581	736	-	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-
AFYON	375	508	1378	-	-	-	-	-	-	-
AĞRI	-	-	-	-	-	-	-	-	-	-
AMASYA	762	731	864	-	-	-	-	-	-	-
ANKARA	669	93	1198	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-
AYDIN	748	881	1751	-	-	-	-	-	-	-
BALIKESİR	731	676	1735	-	-	-	-	-	-	-
BİLECİK	617	428	1533	-	-	-	-	-	-	-
BİNGÖL	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-
BURDUR	544	677	1547	-	-	-	-	-	-	-
BURSA	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	701	125	1230	-	-	-	-	-	-	-
ÇORUM	-	-	-	-	-	-	-	-	-	-
DENİZLİ	636	769	1639	-	-	-	-	-	-	-
DİYARBAKIR	913	1015	91	-	-	-	-	-	-	-
ELAZIĞ	779	880	274	-	-	-	-	-	-	-
ERZİNCAN	873	842	705	-	-	-	-	-	-	-
ERZURUM	1087	1057	919	-	-	-	-	-	-	-
ESKİŞEHİR	536	347	1452	-	-	-	-	-	-	-
GAZİANTEP	550	863	610	-	-	-	-	-	-	-
GİRESUN	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-
ISPARTA	549	682	1552	-	-	-	-	-	-	-
MERSİN	287	601	803	-	-	-	-	-	-	-
İZMİR	796	917	1800	-	-	-	-	-	-	-
KARS	1304	1273	1136	-	-	-	-	-	-	-
KASTAMONU	-	-	-	-	-	-	-	-	-	-
KAYSERİ	318	288	818	-	-	-	-	-	-	-
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-
KOCAELİ	758	569	1674	-	-	-	-	-	-	-
KONYA	103	679	1106	-	-	-	-	-	-	-
KÜTAHYA	479	424	1482	-	-	-	-	-	-	-
MALATYA	660	762	345	-	-	-	-	-	-	-
MANİSA	730	851	1734	-	-	-	-	-	-	-
K.MARAŞ	487	800	570	-	-	-	-	-	-	-
MARDİN	933	1246	993	-	-	-	-	-	-	-
MUĞLA	-	-	-	-	-	-	-	-	-	-
MUŞ	1030	1131	524	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	-	-	-	-	-
NİĞDE	191	386	932	-	-	-	-	-	-	-
ORDU	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-	-
SAKARYA	727	538	1643	-	-	-	-	-	-	-
SAMSUN	895	864	997	-	-	-	-	-	-	-
SİİRT	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-
SİVAS	541	510	596	-	-	-	-	-	-	-
TOKAT	-	-	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-
UŞAK	509	643	1513	-	-	-	-	-	-	-
VAN	1135	1237	630	-	-	-	-	-	-	-
YOZGAT	-	-	-	-	-	-	-	-	-	-
ZONGULDAK	1014	439	1544	-	-	-	-	-	-	-
AKSARAY	-	-	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-	-	-
KARAMAN	0	576	1004	-	-	-	-	-	-	-
KIRIKKALE	576	0	1106	-	-	-	-	-	-	-
BATMAN	1004	1106	0	-	-	-	-	-	-	-
ŞIRNAK	-	-	-	0	-	-	-	-	-	-
BARTIN	-	-	-	-	0	-	-	-	-	-
ARDAHAN	-	-	-	-	-	0	-	-	-	-
IĞDIR	-	-	-	-	-	-	0	-	-	-
YALOVA	-	-	-	-	-	-	-	0	-	-
KARABÜK	-	-	-	-	-	-	-	-	0	-
KİLİS	-	-	-	-	-	-	-	-	-	0
OSMANİYE	354	667	703	-	-	-	-	-	-	-
Düzce	-	-	-	-	-	-	-	-	-	-

Appendix 2 Railway Distances (km)

	OSMANİYE	Düzce
ADANA	86	-
ADIYAMAN	-	-
AFYON	728	-
AĞRI	-	-
AMASYA	853	-
ANKARA	760	-
ANTALYA	-	-
ARTVİN	-	-
AYDIN	1101	-
BALIKESİR	1085	-
BİLECİK	971	-
BİNGÖL	-	-
BİTLİS	-	-
BOLU	-	-
BURDUR	897	-
BURSA	-	-
ÇANAKKALE	-	-
ÇANKIRI	792	-
ÇORUM	-	-
DENİZLİ	989	-
DİYARBAKIR	613	-
ELAZIĞ	478	-
ERZİNCAN	720	-
ERZURUM	934	-
ESKİŞEHİR	889	-
GAZİANTEP	196	-
GİRESUN	-	-
GÜMÜŞHANE	-	-
HAKKARİ	-	-
HATAY	-	-
ISPARTA	902	-
MERSİN	154	-
İZMİR	1150	-
KARS	1151	-
KASTAMONU	-	-
KAYSERİ	410	-
KIRŞEHİR	-	-
KOCAELİ	1111	-
KONYA	456	-
KÜTAHYA	833	-
MALATYA	359	-
MANİSA	1084	-
K.MARAŞ	133	-
MARDİN	579	-
MUĞLA	-	-
MUŞ	729	-
NEVŞEHİR	-	-
NİĞDE	282	-
ORDU	-	-
RİZE	-	-
SAKARYA	1080	-
SAMSUN	986	-
SİİRT	-	-
SİNOP	-	-
SİVAS	611	-
TOKAT	-	-
TRABZON	-	-
TUNCELİ	-	-
ŞANLIURFA	-	-
UŞAK	863	-
VAN	835	-
YOZGAT	-	-
ZONGULDAK	1106	-
AKSARAY	-	-
BAYBURT	-	-
KARAMAN	354	-
KIRIKKALE	667	-
BATMAN	703	-
ŞIRNAK	-	-
BARTIN	-	-
ARDAHAN	-	-
IĞDIR	-	-
YALOVA	-	-
KARABÜK	-	-
KİLİS	-	-
OSMANİYE	0	-
Düzce	-	0

Appendix 2 Railway Distances (km)

BİLECİK	BALIKESİR	AYDIN	ARTVİN	ANTALYA	ANKARA	AMASYA	AĞRI	AFYON	ADIYAMAN	ADANA	
768	895	893	1046	558	490	612	966	573	330	0	ADANA
1059	1225	1223	766	888	757	636	648	903	0	330	ADIYAMAN
211	322	352	1256	293	257	593	1314	0	903	573	AFYON
1359	1567	1652	391	1430	1057	734	0	1314	648	966	AĞRI
625	833	939	708	875	336	0	734	593	636	612	AMASYA
313	530	603	999	544	0	336	1057	257	757	490	ANKARA
474	510	344	1468	0	544	875	1430	293	888	558	ANTALYA
1271	1479	1602	0	1468	999	708	391	1256	766	1046	ARTVİN
525	293	0	1602	344	603	939	1652	352	1223	893	AYDIN
246	0	293	1479	510	530	833	1567	322	1225	895	BALIKESİR
0	246	525	1271	474	313	625	1359	211	1059	768	BİLECİK
1207	1424	1426	417	1191	905	640	359	1106	349	633	BİNGÖL
1400	1617	1619	536	1290	1098	833	234	1299	414	732	BİTLİS
216	424	715	1055	690	191	409	1143	424	948	677	BOLU
352	396	272	1421	122	422	758	1430	171	1001	671	BURDUR
95	151	442	1328	537	382	682	1416	274	1128	837	BURSA
366	207	455	1599	717	653	953	1687	529	1399	1102	ÇANAKKALE
444	659	734	911	675	131	248	982	388	785	576	ÇANKIRI
557	774	847	755	783	244	92	826	501	700	575	ÇORUM
399	288	126	1476	222	477	813	1526	226	1097	767	DENİZLİ
1214	1418	1416	561	1081	912	702	443	1096	205	523	DİYARBAKIR
1061	1278	1280	559	1045	759	549	501	960	283	487	ELAZIĞ
990	1198	1283	407	1061	688	365	369	945	548	674	ERZİNCAN
1178	1386	1471	237	1249	876	553	183	1133	529	809	ERZURUM
80	297	483	1232	424	233	569	1290	145	979	688	ESKİŞEHİR
974	1101	1099	878	764	673	609	760	779	150	206	GAZİANTEP
900	1108	1231	371	1112	628	337	545	885	711	725	GİRESUN
1062	1270	1376	334	1172	773	437	383	1030	679	785	GÜMÜŞHANE
1667	1794	1792	770	1457	1366	1145	434	1472	665	899	HAKKARİ
959	1086	1084	1036	749	681	705	956	764	320	191	HATAY
351	395	293	1417	130	421	757	1379	170	950	620	ISPARTA
760	887	833	1115	489	483	639	1035	565	399	69	MERSİN
417	173	130	1578	446	579	915	1636	328	1231	901	İZMİR
1378	1586	1671	210	1449	1076	753	215	1333	731	1011	KARS
462	670	848	890	789	245	253	987	502	889	690	KASTAMONU
622	839	841	849	619	320	348	811	521	437	333	KAYSERİ
488	705	778	966	573	186	308	945	432	571	375	KIRŞEHİR
139	283	574	1206	613	342	560	1294	350	1099	828	KOCAELİ
418	545	541	1153	323	258	560	1115	223	686	356	KONYA
110	221	415	1310	364	311	647	1368	101	1004	674	KÜTAHYA
963	1180	1182	657	947	661	469	599	862	185	389	MALATYA
381	137	156	1560	428	561	897	1618	310	1213	883	MANİSA
895	1081	1079	880	744	593	529	812	759	164	186	K.MARAŞ
1299	1426	1424	656	1089	998	797	518	1104	296	531	MARDİN
544	392	99	1621	313	622	958	1671	371	1201	871	MUĞLA
1317	1534	1536	453	1301	1015	750	245	1216	463	743	MUŞ
579	762	760	930	538	277	363	892	440	518	287	NEVŞEHİR
644	794	792	977	558	346	441	939	472	535	205	NİĞDE
856	1064	1187	415	1109	584	293	589	841	727	730	ORDU
1112	1320	1443	159	1312	840	549	542	1097	854	925	RİZE
102	310	601	1169	576	305	523	1257	313	1062	791	SAKARYA
691	899	1022	580	958	419	131	754	676	753	729	SAMSUN
1401	1601	1599	633	1264	1099	889	331	1279	388	706	SİİRT
651	859	1037	745	978	434	263	919	691	899	875	SİNOP
755	972	1037	653	815	442	222	615	699	414	428	SİVAS
712	929	1002	647	877	399	114	673	656	522	498	TOKAT
1037	1245	1368	234	1237	765	474	483	1022	779	850	TRABZON
1120	1328	1413	461	1180	818	495	423	1075	418	622	TUNCELİ
1111	1238	1236	741	901	810	719	623	916	109	343	ŞANLIURFA
251	224	278	1367	294	368	704	1425	117	1020	690	UŞAK
1540	1757	1759	568	1458	1238	966	232	1439	582	900	VAN
531	748	821	854	685	218	196	839	475	612	473	YOZGAT
285	493	784	1132	759	268	486	1220	496	1025	754	ZONGULDAK
523	687	685	1005	463	225	418	967	365	593	265	AKSARAY
1085	1293	1399	343	1195	796	460	306	1053	653	808	BAYBURT
531	658	647	1166	376	369	629	1128	336	620	290	KARAMAN
390	607	680	922	616	77	259	980	334	684	475	KIRIKKALE
1314	1514	1512	614	1177	1012	802	369	1192	301	619	BATMAN
1477	1604	1602	730	1267	1176	986	428	1282	475	709	ŞIRNAK
374	582	862	1072	803	283	435	1169	516	1040	769	BARTIN
1382	1590	1705	119	1483	1110	787	306	1367	768	1048	ARDAHAN
1469	1677	1762	343	1540	1167	844	143	1424	751	1069	IĞDIR
126	220	511	1271	600	407	625	1359	337	1164	893	YALOVA
350	558	794	1002	735	215	365	1099	448	972	701	KARABÜK
1011	1138	1136	938	801	733	669	820	816	210	243	KİLİS
854	981	979	960	644	576	629	880	659	244	86	OSMANİYE
171	379	670	1100	645	236	454	1188	382	993	722	Düzce

Appendix 3 Highway Distances (km)

ELAZIĞ	DİYARBAKIR	DENİZLİ	ÇORUM	ÇANKIRI	ÇANAKKALE	BURSA	BURDUR	BOLU	BİTLİS	BİNGÖL	
487	523	767	575	576	1102	837	671	677	732	633	ADANA
283	205	1097	700	785	1399	1128	1001	948	414	349	ADIYAMAN
960	1096	226	501	388	529	274	171	424	1299	1106	AFYON
501	443	1526	826	982	1687	1416	1430	1143	234	359	AĞRI
549	702	813	92	248	953	682	758	409	833	640	AMASYA
759	912	477	244	131	653	382	422	191	1098	905	ANKARA
1045	1081	222	783	675	717	537	122	690	1290	1191	ANTALYA
559	561	1476	755	911	1599	1328	1421	1055	536	417	ARTVİN
1280	1416	126	847	734	455	442	272	715	1619	1426	AYDIN
1278	1418	288	774	659	207	151	396	424	1617	1424	BALIKESİR
1061	1214	399	557	444	366	95	352	216	1400	1207	BİLECİK
146	144	1300	732	888	1547	1276	1204	1049	197	0	BİNGÖL
339	209	1493	925	1081	1740	1469	1397	1242	0	197	BİTLİS
950	1103	615	352	235	544	273	568	0	1242	1049	BOLU
1058	1194	150	666	553	603	415	0	568	1397	1204	BURDUR
1130	1283	437	625	508	271	0	415	273	1469	1276	BURSA
1401	1554	495	866	779	0	271	603	544	1740	1547	ÇANAKKALE
769	922	608	156	0	779	508	553	235	1081	888	ÇANKIRI
613	766	721	0	156	866	625	666	352	925	732	ÇORUM
1154	1290	0	721	608	495	437	150	615	1493	1300	DENİZLİ
153	0	1290	766	922	1554	1283	1194	1103	209	144	DİYARBAKIR
0	153	1154	613	769	1401	1130	1058	950	339	146	ELAZIĞ
265	406	1157	457	613	1318	1047	1061	774	468	275	ERZİNCAN
322	324	1345	645	801	1506	1235	1249	962	328	180	ERZURUM
981	1134	357	477	364	420	149	302	296	1320	1127	ESKİŞEHİR
345	317	973	630	701	1308	1043	877	864	526	461	GAZİANTEP
558	688	1105	384	540	1228	957	1050	684	690	544	GİRESUN
396	526	1250	529	685	1390	1119	1172	846	528	382	GÜMÜŞHANE
627	474	1666	1237	1393	2001	1736	1570	1554	340	509	HAKKARİ
477	513	958	726	767	1293	1028	862	868	722	623	HATAY
1007	1143	167	665	552	602	414	51	567	1346	1153	ISPARTA
556	592	711	568	569	1094	829	611	670	801	702	MERSİN
1288	1424	224	823	710	325	322	374	595	1627	1434	İZMİR
524	526	1545	845	1001	1706	1435	1449	1162	410	382	KARS
802	955	722	196	114	790	519	667	246	1086	893	KASTAMONU
439	592	715	277	348	962	691	619	511	778	585	KAYSERİ
573	726	652	216	214	828	557	573	377	912	719	KIRŞEHİR
1101	1254	538	503	386	403	132	491	151	1393	1200	KOCAELİ
743	879	415	468	389	752	487	315	445	1082	889	KONYA
1059	1197	289	555	442	428	173	242	326	1398	1205	KÜTAHYA
98	251	1056	533	689	1303	1032	960	852	437	244	MALATYA
1270	1406	206	805	692	336	286	356	559	1609	1416	MANİSA
321	369	953	550	621	1235	964	857	784	578	467	K.MARAŞ
248	95	1298	861	1017	1633	1368	1202	1189	284	239	MARDİN
1299	1394	145	866	753	554	541	241	760	1603	1445	MUĞLA
256	258	1410	842	998	1657	1386	1314	1159	83	114	MUŞ
520	673	634	292	305	919	648	538	468	859	666	NEVŞEHİR
567	720	666	370	387	984	713	570	533	906	713	NİĞDE
588	729	1061	340	496	1184	913	1006	640	734	588	ORDU
571	701	1317	596	752	1440	1169	1262	896	687	557	RİZE
1064	1217	501	466	349	430	159	454	114	1356	1163	SAKARYA
666	819	896	175	331	1019	748	841	475	899	720	SAMSUN
340	187	1473	953	1109	1741	1470	1377	1290	97	284	SİİRT
812	965	911	307	303	979	708	856	435	1064	875	SİNOP
327	480	911	286	442	1095	824	815	631	666	473	SİVAS
435	588	876	178	334	1052	781	821	523	772	579	TOKAT
496	626	1242	521	677	1365	1094	1187	821	628	482	TRABZON
135	276	1287	587	743	1448	1177	1191	904	338	145	TUNCELİ
333	180	1110	767	838	1445	1180	1014	1001	389	324	ŞANLIURFA
1077	1213	152	612	499	431	310	172	467	1416	1223	UŞAK
479	377	1633	1058	1214	1880	1609	1537	1375	168	337	VAN
551	704	695	104	246	871	600	640	409	890	697	YOZGAT
1027	1180	684	429	312	613	342	637	159	1319	1126	ZONGULDAK
595	748	559	326	311	863	592	463	412	934	741	AKSARAY
395	448	1273	552	708	1413	1142	1195	869	450	304	BAYBURT
756	813	521	537	500	865	600	421	556	1022	902	KARAMAN
686	839	554	167	105	730	459	499	268	1025	832	KIRIKKALE
253	100	1386	866	1022	1654	1383	1290	1203	135	197	BATMAN
437	284	1476	1050	1204	1811	1546	1380	1367	194	381	ŞIRNAK
984	1137	736	378	279	702	431	681	174	1268	1075	BARTIN
561	563	1579	866	1022	1710	1439	1483	1166	467	419	ARDAHAN
615	546	1636	936	1092	1797	1526	1540	1253	337	473	IĞDIR
1166	1319	506	568	451	340	69	478	216	1458	1265	YALOVA
914	1067	668	308	195	678	407	613	134	1198	1005	KARABÜK
405	377	1010	690	761	1345	1080	914	920	586	521	KİLİS
401	437	853	650	662	1188	923	757	763	646	547	OSMANİYE
995	1148	570	397	280	499	228	523	45	1287	1094	Düzce

Appendix 3 Highway Distances (km)

MERSİN	ISPARTA	HATAY	HAKKARİ	GÜMÜŞHANE	GİRESUN	GAZİANTEP	ESKİŞEHİR	ERZURUM	ERZİNCAN	
69	620	191	899	785	725	206	688	809	674	ADANA
399	950	320	665	679	711	150	979	529	548	ADIYAMAN
565	170	764	1472	1030	885	779	145	1133	945	AFYON
1035	1379	956	434	383	545	760	1290	183	369	AĞRI
639	757	705	1145	437	337	609	569	553	365	AMASYA
483	421	681	1366	773	628	673	233	876	688	ANKARA
489	130	749	1457	1172	1112	764	424	1249	1061	ANTALYA
1115	1417	1036	770	334	371	878	1232	237	407	ARTVİN
833	293	1084	1792	1376	1231	1099	483	1471	1283	AYDIN
887	395	1086	1794	1270	1108	1101	297	1386	1198	BALIKESİR
760	351	959	1667	1062	900	974	80	1178	990	BİLECİK
702	1153	623	509	382	544	461	1127	180	275	BİNGÖL
801	1346	722	340	528	690	526	1320	328	468	BİTLİS
670	567	868	1554	846	684	864	296	962	774	BOLU
611	51	862	1570	1172	1050	877	302	1249	1061	BURDUR
829	414	1028	1736	1119	957	1043	149	1235	1047	BURSA
1094	602	1293	2001	1390	1228	1308	420	1506	1318	ÇANAKKALE
569	552	767	1393	685	540	701	364	801	613	ÇANKIRI
568	665	726	1237	529	384	630	477	645	457	ÇORUM
711	167	958	1666	1250	1105	973	357	1345	1157	DENİZLİ
592	1143	513	474	526	688	317	1134	324	406	DİYARBAKIR
556	1007	477	627	396	558	345	981	322	265	ELAZIĞ
743	1010	742	780	131	293	610	921	188	0	ERZİNCAN
878	1198	799	617	202	364	641	1109	0	188	ERZURUM
680	301	879	1588	996	861	894	0	1109	921	ESKİŞEHİR
275	826	196	693	741	722	0	894	641	610	GAZİANTEP
794	1049	818	979	162	0	722	861	364	293	GİRESUN
854	1121	873	817	0	162	741	996	202	131	GÜMÜŞHANE
968	1519	889	0	817	979	693	1588	617	780	HAKKARİ
260	811	0	889	873	818	196	879	799	742	HATAY
587	0	811	1519	1121	1049	826	301	1198	1010	ISPARTA
0	587	260	968	854	794	275	680	878	743	MERSİN
893	382	1092	1800	1352	1207	1107	412	1455	1267	İZMİR
1080	1398	1002	566	402	564	843	1310	202	388	KARS
683	666	881	1398	681	519	815	478	806	618	KASTAMONU
326	568	449	1046	553	493	353	542	630	442	KAYSERİ
368	522	565	1180	687	595	487	408	764	576	KIRŞEHİR
821	490	1019	1705	997	835	1015	219	1113	925	KOCAELİ
348	264	547	1255	857	795	562	338	934	746	KONYA
666	241	865	1573	1084	939	880	78	1187	999	KÜTAHYA
458	909	379	725	494	544	247	883	420	363	MALATYA
875	364	1074	1782	1334	1189	1089	394	1437	1249	MANİSA
255	806	176	773	702	642	80	815	643	586	K.MARAŞ
600	1151	521	391	621	783	325	1219	419	501	MARDİN
802	292	1062	1770	1395	1250	1077	502	1490	1302	MUĞLA
812	1263	733	395	445	607	575	1237	245	385	MUŞ
280	487	478	1127	634	574	434	499	711	523	NEVŞEHİR
198	519	396	1104	681	621	411	564	758	570	NİĞDE
799	1005	823	1023	206	44	727	817	408	323	ORDU
994	1261	1018	921	175	212	916	1073	377	306	RİZE
784	453	982	1668	960	798	978	182	1076	888	SAKARYA
743	840	822	1188	371	209	726	652	573	445	SAMSUN
775	1326	696	287	625	787	500	1321	425	559	SİİRT
872	855	968	1353	536	374	872	667	738	600	SİNOP
497	764	521	954	357	297	425	675	434	246	SİVAS
567	818	591	1062	376	276	495	632	492	304	TOKAT
919	1186	943	917	100	137	841	998	302	231	TRABZON
691	1140	612	650	261	423	480	1051	242	130	TUNCELİ
412	963	333	556	706	794	137	1031	504	586	ŞANLIURFA
682	171	881	1589	1141	996	896	219	1244	1056	UŞAK
969	1486	890	202	615	777	694	1460	415	601	VAN
466	611	624	1178	581	483	528	451	658	470	YOZGAT
747	636	945	1631	923	761	941	365	1039	851	ZONGULDAK
258	412	456	1164	709	649	471	443	786	598	AKSARAY
877	1144	872	739	78	240	740	1029	124	154	BAYBURT
235	370	481	1189	870	810	496	451	947	759	KARAMAN
468	498	666	1293	696	551	600	310	799	611	KIRIKKALE
688	1239	609	374	579	741	413	1234	377	472	BATMAN
778	1329	699	190	722	884	503	1397	522	656	ŞIRNAK
762	680	960	1580	863	701	956	454	988	800	BARTIN
1117	1432	1038	651	436	482	880	1343	239	422	ARDAHAN
1138	1489	1059	427	493	655	863	1401	293	479	IĞDIR
886	477	1084	1770	1062	900	1080	206	1178	990	YALOVA
694	612	892	1510	793	631	888	424	918	730	KARABÜK
312	863	147	753	801	782	64	931	701	670	KİLİS
155	706	128	813	797	742	120	774	723	666	OSMANİYE
715	522	913	1599	891	729	909	251	1007	819	Düzce

Appendix 3 Highway Distances (km)

	İZMİR	KARS	KASTAMONU	KAYSERİ	KIRŞEHİR	KOCAELİ	KONYA	KÜTAHYA	MALATYA	MANİSA	K.MARAŞ
ADANA	901	1011	690	333	375	828	356	674	389	883	186
ADIYAMAN	1231	731	889	437	571	1099	686	1004	185	1213	164
AFYON	328	1333	502	521	432	350	223	101	862	310	759
AĞRI	1636	215	987	811	945	1294	1115	1368	599	1618	812
AMASYA	915	753	253	348	308	560	560	647	469	897	529
ANKARA	579	1076	245	320	186	342	258	311	661	561	593
ANTALYA	446	1449	789	619	573	613	323	364	947	428	744
ARTVİN	1578	210	890	849	966	1206	1153	1310	657	1560	880
AYDIN	130	1671	848	841	778	574	541	415	1182	156	1079
BALIKESİR	173	1586	670	839	705	283	545	221	1180	137	1081
BİLECİK	417	1378	462	622	488	139	418	110	963	381	895
BİNGÖL	1434	382	893	585	719	1200	889	1205	244	1416	467
BİTLİS	1627	410	1086	778	912	1393	1082	1398	437	1609	578
BOLU	595	1162	246	511	377	151	445	326	852	559	784
BURDUR	374	1449	667	619	573	491	315	242	960	356	857
BURSA	322	1435	519	691	557	132	487	173	1032	286	964
ÇANAKKALE	325	1706	790	962	828	403	752	428	1303	336	1235
ÇANKIRI	710	1001	114	348	214	386	389	442	689	692	621
ÇORUM	823	845	196	277	216	503	468	555	533	805	550
DENİZLİ	224	1545	722	715	652	538	415	289	1056	206	953
DİYARBAKIR	1424	526	955	592	726	1254	879	1197	251	1406	369
ELAZIĞ	1288	524	802	439	573	1101	743	1059	98	1270	321
ERZİNCAN	1267	388	618	442	576	925	746	999	363	1249	586
ERZURUM	1455	202	806	630	764	1113	934	1187	420	1437	643
ESKİŞEHİR	412	1310	478	542	408	219	338	78	883	394	815
GAZİANTEP	1107	843	815	353	487	1015	562	880	247	1089	80
GİRESUN	1207	564	519	493	595	835	795	939	544	1189	642
GÜMÜŞHANE	1352	402	681	553	687	997	857	1084	494	1334	702
HAKKARİ	1800	566	1398	1046	1180	1705	1255	1573	725	1782	773
HATAY	1092	1002	881	449	565	1019	547	865	379	1074	176
ISPARTA	382	1398	666	568	522	490	264	241	909	364	806
MERSİN	893	1080	683	326	368	821	348	666	458	875	255
İZMİR	0	1655	824	849	754	454	551	334	1190	36	1087
KARS	1655	0	1006	830	964	1313	1134	1387	622	1637	845
KASTAMONU	824	1006	0	462	328	397	503	556	722	805	735
KAYSERİ	849	830	462	0	134	662	304	620	341	831	273
KIRŞEHİR	754	964	328	134	0	528	258	486	475	736	407
KOCAELİ	454	1313	397	662	528	0	557	249	1003	418	935
KONYA	551	1134	503	304	258	557	0	324	645	533	542
KÜTAHYA	334	1387	556	620	486	249	324	0	961	316	860
MALATYA	1190	622	722	341	475	1003	645	961	0	1172	223
MANİSA	36	1637	805	831	736	418	533	316	1172	0	1069
K.MARAŞ	1087	845	735	273	407	935	542	860	223	1069	0
MARDİN	1432	621	1050	678	812	1340	887	1205	346	1414	405
MUĞLA	229	1690	867	860	797	673	556	434	1201	255	1057
MUŞ	1544	327	1003	695	829	1310	999	1315	354	1526	577
NEVŞEHİR	768	911	419	81	91	619	223	541	422	750	354
NİĞDE	800	958	501	128	173	684	255	573	469	782	391
ORDU	1163	608	475	498	551	791	794	895	560	1145	647
RİZE	1419	361	731	693	807	1047	997	1151	659	1401	842
SAKARYA	481	1276	360	625	491	37	520	212	966	445	898
SAMSUN	998	773	310	452	391	626	643	730	586	980	646
SİİRT	1607	507	1142	779	913	1441	1062	1380	438	1589	552
SİNOP	1013	938	189	584	517	586	692	745	732	994	792
SİVAS	1021	634	475	196	330	782	500	753	247	1003	345
TOKAT	978	692	367	266	319	674	562	710	355	960	415
TRABZON	1344	436	656	618	732	972	922	1076	594	1326	767
TUNCELİ	1397	442	748	572	706	1055	876	1129	233	1379	456
ŞANLIURFA	1244	706	952	490	624	1152	699	1017	268	1226	217
UŞAK	211	1444	613	638	543	390	340	141	979	193	876
VAN	1767	364	1219	918	1052	1526	1222	1538	577	1749	746
YOZGAT	797	858	296	175	112	560	370	529	471	779	448
ZONGULDAK	664	1239	271	588	454	220	522	395	929	628	861
AKSARAY	693	986	425	156	110	563	148	466	497	675	429
BAYBURT	1375	324	713	576	710	1020	880	1107	493	1357	716
KARAMAN	664	1147	614	317	321	670	119	437	658	646	476
KIRIKKALE	656	999	219	247	113	419	301	388	588	638	520
BATMAN	1520	546	1055	692	826	1354	975	1293	351	1502	465
ŞIRNAK	1610	604	1239	856	990	1518	1065	1383	535	1592	583
BARTIN	753	1188	182	603	469	309	537	484	904	717	876
ARDAHAN	1689	91	1001	864	998	1317	1168	1421	659	1671	882
IĞDIR	1746	139	1097	921	1055	1404	1225	1478	713	1728	915
YALOVA	391	1378	462	727	593	65	544	236	1068	355	1000
KARABÜK	729	1118	112	535	401	285	469	460	834	693	808
KİLİS	1144	903	875	413	547	1071	599	917	307	1126	140
OSMANİYE	987	925	776	373	461	914	442	760	303	969	100
Düzce	550	1207	291	556	422	106	490	281	897	514	829

Appendix 3 Highway Distances (km)

TOKAT	SİVAS	SİNOP	SİİRT	SAMSUN	SAKARYA	RİZE	ORDU	NİĞDE	NEVŞEHİR	MUŞ	MUĞLA	MARDİN	
498	428	875	706	729	791	925	730	205	287	743	871	531	ADANA
522	414	899	388	753	1062	854	727	535	518	463	1201	296	ADIYAMAN
656	699	691	1279	676	313	1097	841	472	440	1216	371	1104	AFYON
673	615	919	331	754	1257	542	589	939	892	245	1671	518	AĞRI
114	222	263	889	131	523	549	293	441	363	750	958	797	AMASYA
399	442	434	1099	419	305	840	584	346	277	1015	622	998	ANKARA
877	815	978	1264	958	576	1312	1109	558	538	1301	313	1089	ANTALYA
647	653	745	633	580	1169	159	415	977	930	453	1621	656	ARTVİN
1002	1037	1037	1599	1022	601	1443	1187	792	760	1536	99	1424	AYDIN
929	972	859	1601	899	310	1320	1064	794	762	1534	392	1426	BALIKESİR
712	755	651	1401	691	102	1112	856	644	579	1317	544	1299	BİLECİK
579	473	875	284	720	1163	557	588	713	666	114	1445	239	BİNGÖL
772	666	1064	97	899	1356	687	734	906	859	83	1603	284	BİTLİS
523	631	435	1290	475	114	896	640	533	468	1159	760	1189	BOLU
821	815	856	1377	841	454	1262	1006	570	538	1314	241	1202	BURDUR
781	824	708	1470	748	159	1169	913	713	648	1386	541	1368	BURSA
1052	1095	979	1741	1019	430	1440	1184	984	919	1657	554	1633	ÇANAKKALE
334	442	303	1109	331	349	752	496	387	305	998	753	1017	ÇANKIRI
178	286	307	953	175	466	596	340	370	292	842	866	861	ÇORUM
876	911	911	1473	896	501	1317	1061	666	634	1410	145	1298	DENİZLİ
588	480	965	187	819	1217	701	729	720	673	258	1394	95	DİYARBAKIR
435	327	812	340	666	1064	571	588	567	520	256	1299	248	ELAZIĞ
304	246	600	559	445	888	306	323	570	523	385	1302	501	ERZİNCAN
492	434	738	425	573	1076	377	408	758	711	245	1490	419	ERZURUM
632	675	667	1321	652	182	1073	817	564	499	1237	502	1219	ESKİŞEHİR
495	425	872	500	726	978	916	727	411	434	575	1077	325	GAZİANTEP
276	297	374	787	209	798	212	44	621	574	607	1250	783	GİRESUN
376	357	536	625	371	960	175	206	681	634	445	1395	621	GÜMÜŞHANE
1062	954	1353	287	1188	1668	921	1023	1104	1127	395	1770	391	HAKKARİ
591	521	968	696	822	982	1018	823	396	478	733	1062	521	HATAY
818	764	855	1326	840	453	1261	1005	519	487	1263	292	1151	ISPARTA
567	497	872	775	743	784	994	799	198	280	812	802	600	MERSİN
978	1021	1013	1607	998	481	1419	1163	800	768	1544	229	1432	İZMİR
692	634	938	507	773	1276	361	608	958	911	327	1690	621	KARS
367	475	189	1142	310	360	731	475	501	419	1003	867	1050	KASTAMONU
266	196	584	779	452	625	693	498	128	81	695	860	678	KAYSERİ
319	330	517	913	391	491	807	551	173	91	829	797	812	KIRŞEHİR
674	782	586	1441	626	37	1047	791	684	619	1310	673	1340	KOCAELİ
562	500	692	1062	643	520	997	794	255	223	999	556	887	KONYA
710	753	745	1380	730	212	1151	895	573	541	1315	434	1205	KÜTAHYA
355	247	732	438	586	966	659	560	469	422	354	1201	346	MALATYA
960	1003	994	1589	980	445	1401	1145	782	750	1526	255	1414	MANİSA
415	345	792	552	646	898	842	647	391	354	577	1057	405	K.MARAŞ
683	575	1060	230	914	1303	796	824	736	759	353	1402	0	MARDİN
1021	1056	1056	1577	1041	646	1462	1206	811	779	1555	0	1402	MUĞLA
689	583	981	180	816	1273	604	651	823	776	0	1555	353	MUŞ
339	277	599	860	467	582	774	571	82	0	776	779	759	NEVŞEHİR
394	324	677	907	545	647	821	626	0	82	823	811	736	NİĞDE
232	313	330	831	165	754	256	0	626	571	651	1206	824	ORDU
488	497	586	784	421	1010	0	256	821	774	604	1462	796	RİZE
637	745	549	1404	589	0	1010	754	647	582	1273	646	1303	SAKARYA
231	339	165	996	0	589	421	165	545	467	816	1041	914	SAMSUN
775	667	1152	0	996	1404	784	831	907	860	180	1577	230	SİİRT
377	485	0	1152	165	549	586	330	677	599	981	1056	1060	SİNOP
108	0	485	667	339	745	497	313	324	277	583	1056	575	SİVAS
0	108	377	775	231	637	488	232	394	339	689	1021	683	TOKAT
413	422	511	725	346	935	75	181	746	699	545	1387	721	TRABZON
434	376	730	429	575	1018	436	453	700	653	255	1432	371	TUNCELİ
605	497	982	363	836	1115	881	810	548	571	438	1214	188	ŞANLIURFA
767	810	802	1396	787	353	1208	952	589	557	1333	297	1221	UŞAK
905	806	1151	265	986	1489	719	821	1046	999	223	1771	452	VAN
207	224	411	891	279	523	695	439	268	190	807	840	799	YOZGAT
600	708	460	1367	552	183	973	717	610	545	1236	829	1266	ZONGULDAK
414	352	614	935	501	526	849	646	121	75	851	704	796	AKSARAY
399	380	614	547	449	983	253	284	704	657	367	1418	543	BAYBURT
583	513	803	996	712	633	1010	815	189	271	1012	662	821	KARAMAN
322	365	408	1026	342	382	763	507	286	204	942	699	925	KIRIKKALE
688	580	1065	87	917	1317	754	785	820	773	218	1490	149	BATMAN
872	764	1249	97	1093	1481	881	928	914	937	277	1580	201	ŞIRNAK
549	657	371	1324	492	272	913	657	625	560	1185	881	1232	BARTIN
726	668	856	564	691	1280	270	526	992	945	384	1724	658	ARDAHAN
783	725	1029	434	864	1367	494	699	1049	1002	388	1781	621	IĞDIR
739	847	651	1506	691	102	1112	856	749	684	1375	610	1405	YALOVA
479	587	301	1254	422	248	843	587	557	492	1115	813	1162	KARABÜK
555	485	932	560	786	1034	976	787	448	494	635	1114	385	KİLİS
515	445	892	620	746	877	942	747	291	373	657	957	445	OSMANİYE
568	676	480	1335	520	69	941	685	578	513	1204	715	1234	Düzce

Appendix 3 Highway Distances (km)

KARAMAN	BAYBURT	AKSARAY	ZONGULDAK	YOZGAT	VAN	UŞAK	ŞANLIURFA	TUNCELİ	TRABZON	
290	808	265	754	473	900	690	343	622	850	ADANA
620	653	593	1025	612	582	1020	109	418	779	ADIYAMAN
336	1053	365	496	475	1439	117	916	1075	1022	AFYON
1128	305	967	1220	839	232	1425	623	423	483	AĞRI
629	460	418	486	196	966	704	719	495	474	AMASYA
369	796	225	268	218	1238	368	810	818	765	ANKARA
376	1195	463	759	685	1458	294	901	1180	1237	ANTALYA
1166	343	1005	1132	854	568	1367	741	461	234	ARTVİN
647	1399	685	784	821	1759	278	1236	1413	1368	AYDIN
658	1293	687	493	748	1757	224	1238	1328	1245	BALIKESİR
531	1085	523	285	531	1540	251	1111	1120	1037	BİLECİK
902	304	741	1126	697	337	1223	324	145	482	BİNGÖL
1022	450	934	1319	890	168	1416	389	338	628	BİTLİS
556	869	412	159	409	1375	467	1001	904	821	BOLU
421	1195	463	637	640	1537	172	1014	1191	1187	BURDUR
600	1142	592	342	600	1609	310	1180	1177	1094	BURSA
865	1413	863	613	871	1880	431	1445	1448	1365	ÇANAKKALE
500	708	311	312	246	1214	499	838	743	677	ÇANKIRI
537	552	326	429	104	1058	612	767	587	521	ÇORUM
521	1273	559	684	695	1633	152	1110	1287	1242	DENİZLİ
813	448	748	1180	704	377	1213	180	276	626	DİYARBAKIR
756	395	595	1027	551	479	1077	333	135	496	ELAZIĞ
759	154	598	851	470	601	1056	586	130	231	ERZİNCAN
947	124	786	1039	658	415	1244	504	242	302	ERZURUM
451	1029	443	365	451	1460	219	1031	1051	998	ESKİŞEHİR
496	740	471	941	528	694	896	137	480	841	GAZİANTEP
810	240	649	761	483	777	996	794	423	137	GİRESUN
870	78	709	923	581	615	1141	706	261	100	GÜMÜŞHANE
1189	739	1164	1631	1178	202	1589	556	650	917	HAKKARİ
481	872	456	945	624	890	881	333	612	943	HATAY
370	1144	412	636	611	1486	171	963	1140	1186	ISPARTA
235	877	258	747	466	969	682	412	691	919	MERSİN
664	1375	693	664	797	1767	211	1244	1397	1344	İZMİR
1147	324	986	1239	858	364	1444	706	442	436	KARS
614	713	425	271	296	1219	613	952	748	656	KASTAMONU
317	576	156	588	175	918	638	490	572	618	KAYSERİ
321	710	110	454	112	1052	543	624	706	732	KIRŞEHİR
670	1020	563	220	560	1526	390	1152	1055	972	KOCAELİ
119	880	148	522	370	1222	340	699	876	922	KONYA
437	1107	466	395	529	1538	141	1017	1129	1076	KÜTAHYA
658	493	497	929	471	577	979	268	233	594	MALATYA
646	1357	675	628	779	1749	193	1226	1379	1326	MANİSA
476	716	429	861	448	746	876	217	456	767	K.MARAŞ
821	543	796	1266	799	452	1221	188	371	721	MARDİN
662	1418	704	829	840	1771	297	1214	1432	1387	MUĞLA
1012	367	851	1236	807	223	1333	438	255	545	MUŞ
271	657	75	545	190	999	557	571	653	699	NEVŞEHİR
189	704	121	610	268	1046	589	548	700	746	NİĞDE
815	284	646	717	439	821	952	810	453	181	ORDU
1010	253	849	973	695	719	1208	881	436	75	RİZE
633	983	526	183	523	1489	353	1115	1018	935	SAKARYA
712	449	501	552	279	986	787	836	575	346	SAMSUN
996	547	935	1367	891	265	1396	363	429	725	SİİRT
803	614	614	460	411	1151	802	982	730	511	SİNOP
513	380	352	708	224	806	810	497	376	422	SİVAS
583	399	414	600	207	905	767	605	434	413	TOKAT
935	178	774	898	620	715	1133	806	361	0	TRABZON
889	260	728	981	600	478	1186	456	0	361	TUNCELİ
633	628	608	1078	665	557	1033	0	456	806	ŞANLIURFA
453	1164	482	536	586	1556	0	1033	1186	1133	UŞAK
1190	537	1074	1452	1030	0	1556	557	478	715	VAN
433	604	222	486	0	1030	586	665	600	620	YOZGAT
633	946	489	0	486	1452	536	1078	981	898	ZONGULDAK
211	732	0	489	222	1074	482	608	728	774	AKSARAY
893	0	732	946	604	537	1164	628	260	178	BAYBURT
0	893	211	633	433	1190	453	633	889	935	KARAMAN
412	719	210	345	141	1165	445	737	741	688	KIRIKKALE
909	501	848	1280	804	303	1309	276	342	679	BATMAN
999	644	974	1444	988	362	1399	366	526	822	ŞIRNAK
648	895	504	89	478	1401	625	1093	930	838	BARTIN
1181	358	1020	1243	892	449	1478	743	476	345	ARDAHAN
1238	415	1077	1330	949	225	1535	726	533	569	IĞDIR
657	1085	628	285	625	1591	377	1217	1120	1037	YALOVA
580	825	436	173	408	1331	559	1025	860	768	KARABÜK
533	800	508	997	588	754	933	197	540	901	KİLİS
376	796	351	840	548	814	776	257	536	867	OSMANİYE
601	914	457	114	454	1420	422	1046	949	866	Düzce

Appendix 3 Highway Distances (km)

Düzce	OSMANİYE	KİLİS	KARABÜK	YALOVA	IĞDIR	ARDAHAN	BARTIN	ŞIRNAK	BATMAN	KIRIKKALE	
722	86	243	701	893	1069	1048	769	709	619	475	ADANA
993	244	210	972	1164	751	768	1040	475	301	684	ADIYAMAN
382	659	816	448	337	1424	1367	516	1282	1192	334	AFYON
1188	880	820	1099	1359	143	306	1169	428	369	980	AĞRI
454	629	669	365	625	844	787	435	986	802	259	AMASYA
236	576	733	215	407	1167	1110	283	1176	1012	77	ANKARA
645	644	801	735	600	1540	1483	803	1267	1177	616	ANTALYA
1100	960	938	1002	1271	343	119	1072	730	614	922	ARTVİN
670	979	1136	794	511	1762	1705	862	1602	1512	680	AYDIN
379	981	1138	558	220	1677	1590	582	1604	1514	607	BALIKESİR
171	854	1011	350	126	1469	1382	374	1477	1314	390	BİLECİK
1094	547	521	1005	1265	473	419	1075	381	197	832	BİNGÖL
1287	646	586	1198	1458	337	467	1268	194	135	1025	BİTLİS
45	763	920	134	216	1253	1166	174	1367	1203	268	BOLU
523	757	914	613	478	1540	1483	681	1380	1290	499	BURDUR
228	923	1080	407	69	1526	1439	431	1546	1383	459	BURSA
499	1188	1345	678	340	1797	1710	702	1811	1654	730	ÇANAKKALE
280	662	761	195	451	1092	1022	279	1204	1022	105	ÇANKIRI
397	650	690	308	568	936	866	378	1050	866	167	ÇORUM
570	853	1010	668	506	1636	1579	736	1476	1386	554	DENİZLİ
1148	437	377	1067	1319	546	563	1137	284	100	839	DİYARBAKIR
995	401	405	914	1166	615	561	984	437	253	686	ELAZIĞ
819	666	670	730	990	479	422	800	656	472	611	ERZİNCAN
1007	723	701	918	1178	293	239	988	522	377	799	ERZURUM
251	774	931	424	206	1401	1343	454	1397	1234	310	ESKİŞEHİR
909	120	64	888	1080	863	880	956	503	413	600	GAZİANTEP
729	742	782	631	900	655	482	701	884	741	551	GİRESUN
891	797	801	793	1062	493	436	863	722	579	696	GÜMÜŞHANE
1599	813	753	1510	1770	427	651	1580	190	374	1293	HAKKARİ
913	128	147	892	1084	1059	1038	960	699	609	666	HATAY
522	706	863	612	477	1489	1432	680	1329	1239	498	ISPARTA
715	155	312	694	886	1138	1117	762	778	688	468	MERSİN
550	987	1144	729	391	1746	1689	753	1610	1520	656	İZMİR
1207	925	903	1118	1378	139	91	1188	604	546	999	KARS
291	776	875	112	462	1097	1001	182	1239	1055	219	KASTAMONU
556	373	413	535	727	921	864	603	856	692	247	KAYSERİ
422	461	547	401	593	1055	998	469	990	826	113	KIRŞEHİR
106	914	1071	285	65	1404	1317	309	1518	1354	419	KOCAELİ
490	442	599	469	544	1225	1168	537	1065	975	301	KONYA
281	760	917	460	236	1478	1421	484	1383	1293	388	KÜTAHYA
897	303	307	834	1068	713	659	904	535	351	588	MALATYA
514	969	1126	693	355	1728	1671	717	1592	1502	638	MANİSA
829	100	140	808	1000	915	882	876	583	465	520	K.MARAŞ
1234	445	385	1162	1405	621	658	1232	201	149	925	MARDİN
715	957	1114	813	610	1781	1724	881	1580	1490	699	MUĞLA
1204	657	635	1115	1375	388	384	1185	277	218	942	MUŞ
513	373	494	492	684	1002	945	560	937	773	204	NEVŞEHİR
578	291	448	557	749	1049	992	625	914	820	286	NİĞDE
685	747	787	587	856	699	526	657	928	785	507	ORDU
941	942	976	843	1112	494	270	913	881	754	763	RİZE
69	877	1034	248	102	1367	1280	272	1481	1317	382	SAKARYA
520	746	786	422	691	864	691	492	1093	917	342	SAMSUN
1335	620	560	1254	1506	434	564	1324	97	87	1026	SİİRT
480	892	932	301	651	1029	856	371	1249	1065	408	SİNOP
676	445	485	587	847	725	668	657	764	580	365	SİVAS
568	515	555	479	739	783	726	549	872	688	322	TOKAT
866	867	901	768	1037	569	345	838	822	679	688	TRABZON
949	536	540	860	1120	533	476	930	526	342	741	TUNCELİ
1046	257	197	1025	1217	726	743	1093	366	276	737	ŞANLIURFA
422	776	933	559	377	1535	1478	625	1399	1309	445	UŞAK
1420	814	754	1331	1591	225	449	1401	362	303	1165	VAN
454	548	588	408	625	949	892	478	988	804	141	YOZGAT
114	840	997	173	285	1330	1243	89	1444	1280	345	ZONGULDAK
457	351	508	436	628	1077	1020	504	974	848	210	AKSARAY
914	796	800	825	1085	415	358	895	644	501	719	BAYBURT
601	376	533	580	657	1238	1181	648	999	909	412	KARAMAN
313	561	660	292	484	1090	1033	360	1103	939	0	KIRIKKALE
1248	533	473	1167	1419	472	602	1237	184	0	939	BATMAN
1412	623	563	1351	1583	531	661	1421	0	184	1103	ŞIRNAK
203	855	1012	84	374	1279	1183	0	1421	1237	360	BARTIN
1211	962	940	1113	1382	224	0	1183	661	602	1033	ARDAHAN
1298	983	923	1209	1469	0	224	1279	531	472	1090	IĞDIR
171	979	1136	350	0	1469	1382	374	1583	1419	484	YALOVA
179	787	944	0	350	1209	1113	84	1351	1167	292	KARABÜK
965	157	0	944	1136	923	940	1012	563	473	660	KİLİS
808	0	157	787	979	983	962	855	623	533	561	OSMANİYE
0	808	965	179	171	1298	1211	203	1412	1248	313	Düzce

Appendix 3 Highway Distances (km)

	ADANA	ADIYAMAN	AFYON	AĞRI	AMASYA	ANKARA	ANTALYA	ARTVİN	AYDIN	BALIKESİR	BİLECİK	BİNGÖL	BİTLİS	BOLU	BURDUR	BURSA	ÇANAKKALE	ÇANKIRI	ÇORUM	DENİZLİ
ADANA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	-	-	-	-	-	-	-	-	113180	-	-	-	-	38718
AĞRI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANKARA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	552618	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	470009
BALIKESİR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BİLECİK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	DİYARBAKIR	ELAZIĞ	ERZİNCAN	ERZURUM	ESKİŞEHİR	GAZİANTEP	GİRESUN	GÜMÜŞHANE	HAKKARİ	HATAY	ISPARTA	MERSİN	İZMİR	KARS	KASTAMONU	KAYSERİ	KIRŞEHİR	KOCAELİ	KONYA	KÜTAHYA
ADANA	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	-	-	-	-	23120	-	-	-	-	-	-	-	1	1
AĞRI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANKARA	-	-	-	-	16727	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-	-	-	-	-	328489	-	-	-	-	-	-	-
BALIKESİR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	99775
BİLECİK	-	-	-	-	1063258	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	MALATYA	MANİSA	K.MARAŞ	MARDİN	MUĞLA	MUŞ	NEVŞEHİR	NİĞDE	ORDU	RİZE	SAKARYA	SAMSUN	SİİRT	SİNOP	SİVAS	TOKAT	TRABZON	TUNCELİ	ŞANLIURFA	UŞAK
ADANA	-	-	-	-	-	-	-	117704	-	-	-	-	-	-	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48844
AĞRI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	-	-	987088	-	-	371181	-	-	-	-	-
ANKARA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BALIKESİR	-	531780	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BİLECİK	-	-	-	-	-	-	-	-	-	-	669719	-	-	-	-	-	-	-	-	-

	VAN	YOZGAT	ZONGULDAK	AKSARAY	BAYBURT	KARAMAN	KIRIKKALE	BATMAN	ŞIRNAK	BARTIN	ARDAHAN	IĞDIR	YALOVA	KARABÜK	KİLİS	OSMANİYE	Düzce
ADANA	-	-	-	-	-	54684	-	-	-	-	-	-	-	-	-	14519	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AĞRI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANKARA	-	-	-	-	-	-	488078	-	-	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BALIKESİR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BİLECİK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 4 Population Densities around the Railway Network

	BİNGÖL	BİTLİS	BOLU	BURDUR	BURSA	ÇANAKKALE	ÇANKIRI	ÇORUM	DENİZLİ	DİYARBAKIR	ELAZIĞ
ADANA	-	-	-	-	-		-	-	-	-	-
ADIYAMAN	-	-	-	-	-		-	-	-	-	-
AFYON	-	-	-	113180	-		-	-	38718	-	-
AĞRI	-	-	-	-	-		-	-	-	-	-
AMASYA	-	-	-	-	-		-	-	-	-	-
ANKARA	-	-	-	-	-		552618	-	-	-	-
ANTALYA	-	-	-	-	-		-	-	-	-	-
ARTVİN	-	-	-	-	-		-	-	-	-	-
AYDIN	-	-	-	-	-		-	-	470009	-	-
BALIKESİR	-	-	-	-	-		-	-	-	-	-
BİLECİK	-	-	-	-	-		-	-	-	-	-
BİNGÖL	-	-	-	-	-		-	-	-	-	-
BİTLİS	-	-	-	-	-		-	-	-	-	-
BOLU	-	-	-	-	-		-	-	-	-	-
BURDUR	-	-	-	-	-		-	-	151898	-	-
BURSA	-	-	-	-	-		-	-	-	-	-
ÇANAKKALE	-	-	-	-	-		-	-	-	-	-
ÇANKIRI	-	-	-	-	-		-	-	-	-	-
ÇORUM	-	-	-	-	-		-	-	-	-	-
DENİZLİ	-	-	-	151898	-		-	-	-	-	-
DİYARBAKIR	-	-	-	-	-		-	-	-	-	1303073
ELAZIĞ	-	-	-	-	-		-	-	-	1303073	-
ERZİNCAN	-	-	-	-	-		-	-	-	-	-
ERZURUM	-	-	-	-	-		-	-	-	-	-
ESKİŞEHİR	-	-	-	-	-		-	-	-	-	-
GAZİANTEP	-	-	-	-	-		-	-	-	-	-
GİRESUN	-	-	-	-	-		-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-		-	-	-	-	-
HAKKARİ	-	-	-	-	-		-	-	-	-	-
HATAY	-	-	-	-	-		-	-	-	-	-
ISPARTA	-	-	-	90060	-		-	-	61838	-	-
MERSİN	-	-	-	-	-		-	-	-	-	-
İZMİR	-	-	-	-	-		-	-	-	-	-
KARS	-	-	-	-	-		-	-	-	-	-
KASTAMONU	-	-	-	-	-		-	-	-	-	-
KAYSERİ	-	-	-	-	-		-	-	-	-	-
KIRŞEHİR	-	-	-	-	-		-	-	-	-	-
KOCAELİ	-	-	-	-	-		-	-	-	-	-
KONYA	-	-	-	-	-		-	-	-	-	-
KÜTAHYA	-	-	-	-	-		-	-	-	-	-
MALATYA	-	-	-	-	-		-	-	-	1357969	54896
MANİSA	-	-	-	-	-		-	-	-	-	-
K.MARAŞ	-	-	-	-	-		-	-	-	-	-
MARDİN	-	-	-	-	-		-	-	-	-	-
MUĞLA	-	-	-	-	-		-	-	-	-	-
MUŞ	-	-	-	-	-		-	-	-	-	71544
NEVŞEHİR	-	-	-	-	-		-	-	-	-	-
NİĞDE	-	-	-	-	-		-	-	-	-	-
ORDU	-	-	-	-	-		-	-	-	-	-
RİZE	-	-	-	-	-		-	-	-	-	-
SAKARYA	-	-	-	-	-		-	-	-	-	-
SAMSUN	-	-	-	-	-		-	-	-	-	-
SİİRT	-	-	-	-	-		-	-	-	-	-
SİNOP	-	-	-	-	-		-	-	-	-	-
SİVAS	-	-	-	-	-		-	-	-	-	-
TOKAT	-	-	-	-	-		-	-	-	-	-
TRABZON	-	-	-	-	-		-	-	-	-	-
TUNCELİ	-	-	-	-	-		-	-	-	-	-
ŞANLIURFA	-	-	-	-	-		-	-	-	-	-
UŞAK	-	-	-	-	-		-	-	-	-	-
VAN	-	-	-	-	-		-	-	-	-	-
YOZGAT	-	-	-	-	-		-	-	-	-	-
ZONGULDAK	-	-	-	-	-		-	-	-	-	-
AKSARAY	-	-	-	-	-		-	-	-	-	-
BAYBURT	-	-	-	-	-		-	-	-	-	-
KARAMAN	-	-	-	-	-		-	-	-	-	-
KIRIKKALE	-	-	-	-	-		92736	-	-	-	-
BATMAN	-	-	-	-	-		-	-	-	1667118	-
ŞIRNAK	-	-	-	-	-		-	-	-	-	-
BARTIN	-	-	-	-	-		-	-	-	-	-
ARDAHAN	-	-	-	-	-		-	-	-	-	-
IĞDIR	-	-	-	-	-		-	-	-	-	-
YALOVA	-	-	-	-	-		-	-	-	-	-
KARABÜK	-	-	-	-	-		267644	-	-	-	-
KİLİS	-	-	-	-	-		-	-	-	-	-
OSMANİYE	-	-	-	-	-		-	-	-	-	-
Düzce	-	-	-	-	-		-	-	-	-	-

Appendix 4 Population Densities around the Railway Network

MERSİN	ISPARTA	HATAY	HAKKARİ	GÜMÜŞHANE	GİRESUN	GAZİANTEP	ESKİŞEHİR	ERZURUM	ERZİNCAN	
1	-	-	-	-	-	-	-	-	-	ADANA
-	-	-	-	-	-	-	-	-	-	ADIYAMAN
-	23120	-	-	-	-	-	-	-	-	AFYON
-	-	-	-	-	-	-	-	-	-	AĞRI
-	-	-	-	-	-	-	-	-	-	AMASYA
-	-	-	-	-	-	-	16727	-	-	ANKARA
-	-	-	-	-	-	-	-	-	-	ANTALYA
-	-	-	-	-	-	-	-	-	-	ARTVİN
-	-	-	-	-	-	-	-	-	-	AYDIN
-	-	-	-	-	-	-	-	-	-	BALIKESİR
-	-	-	-	-	-	-	1063258	-	-	BİLECİK
-	-	-	-	-	-	-	-	-	-	BİNGÖL
-	-	-	-	-	-	-	-	-	-	BİTLİS
-	-	-	-	-	-	-	-	-	-	BOLU
-	90060	-	-	-	-	-	-	-	-	BURDUR
-	-	-	-	-	-	-	-	-	-	BURSA
-	-	-	-	-	-	-	-	-	-	ÇANAKKALE
-	-	-	-	-	-	-	-	-	-	ÇANKIRI
-	-	-	-	-	-	-	-	-	-	ÇORUM
-	61838	-	-	-	-	-	-	-	-	DENİZLİ
-	-	-	-	-	-	-	-	-	-	DİYARBAKIR
-	-	-	-	-	-	-	-	-	-	ELAZIĞ
-	-	-	-	-	-	-	-	65806	-	ERZİNCAN
-	-	-	-	-	-	-	-	-	65806	ERZURUM
-	-	-	-	-	-	-	-	-	-	ESKİŞEHİR
-	-	-	-	-	-	-	-	-	-	GAZİANTEP
-	-	-	-	-	-	-	-	-	-	GİRESUN
-	-	-	-	-	-	-	-	-	-	GÜMÜŞHANE
-	-	-	-	-	-	-	-	-	-	HAKKARİ
-	-	-	-	-	-	-	-	-	-	HATAY
-	-	-	-	-	-	-	-	-	-	ISPARTA
-	-	-	-	-	-	-	-	-	-	MERSİN
-	-	-	-	-	-	-	-	-	-	İZMİR
-	-	-	-	-	-	-	-	168586	-	KARS
-	-	-	-	-	-	-	-	-	-	KASTAMONU
-	-	-	-	-	-	-	-	-	-	KAYSERİ
-	-	-	-	-	-	-	-	-	-	KIRŞEHİR
-	-	-	-	-	-	-	-	-	-	KOCAELİ
-	-	-	-	-	-	-	-	-	-	KONYA
-	-	-	-	-	-	-	1002395	-	-	KÜTAHYA
-	-	-	-	-	-	-	-	-	71114	MALATYA
-	-	-	-	-	-	-	-	-	-	MANİSA
-	-	-	-	-	-	1	-	-	-	K.MARAŞ
-	-	-	-	-	-	-	-	-	-	MARDİN
-	-	-	-	-	-	-	-	-	-	MUĞLA
-	-	-	-	-	-	-	-	-	-	MUŞ
-	-	-	-	-	-	-	-	-	-	NEVŞEHİR
117704	-	-	-	-	-	-	-	-	-	NİĞDE
-	-	-	-	-	-	-	-	-	-	ORDU
-	-	-	-	-	-	-	-	-	-	RİZE
-	-	-	-	-	-	-	-	-	-	SAKARYA
-	-	-	-	-	-	-	-	-	-	SAMSUN
-	-	-	-	-	-	-	-	-	-	SİİRT
-	-	-	-	-	-	-	-	-	-	SİNOP
-	-	-	-	-	-	-	-	-	24276	SİVAS
-	-	-	-	-	-	-	-	-	-	TOKAT
-	-	-	-	-	-	-	-	-	-	TRABZON
-	-	-	-	-	-	-	-	-	-	TUNCELİ
-	-	-	-	-	-	-	-	-	-	ŞANLIURFA
-	-	-	-	-	-	-	-	-	-	UŞAK
-	-	-	-	-	-	-	-	-	-	VAN
-	-	-	-	-	-	-	-	-	-	YOZGAT
-	-	-	-	-	-	-	-	-	-	ZONGULDAK
-	-	-	-	-	-	-	-	-	-	AKSARAY
-	-	-	-	-	-	-	-	-	-	BAYBURT
54684	-	-	-	-	-	-	-	-	-	KARAMAN
-	-	-	-	-	-	-	-	-	-	KIRIKKALE
-	-	-	-	-	-	-	-	-	-	BATMAN
-	-	-	-	-	-	-	-	-	-	ŞIRNAK
-	-	-	-	-	-	-	-	-	-	BARTIN
-	-	-	-	-	-	-	-	-	-	ARDAHAN
-	-	-	-	-	-	-	-	-	-	IĞDIR
-	-	-	-	-	-	-	-	-	-	YALOVA
-	-	-	-	-	-	-	-	-	-	KARABÜK
-	-	-	-	-	-	-	-	-	-	KİLİS
-	-	-	-	-	-	26398	-	-	-	OSMANİYE
-	-	-	-	-	-	-	-	-	-	Düzce

Appendix 4 Population Densities around the Railway Network

	İZMİR	KARS	KASTAMONU	KAYSERİ	KIRŞEHİR	KOCAELİ	KONYA	KÜTAHYA	MALATYA	MANİSA
ADANA	-	-	-	-	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	1	1	-	-
AĞRI	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	-
ANKARA	-	-	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-
AYDIN	328489	-	-	-	-	-	-	-	-	1
BALIKESİR	-	-	-	-	-	-	-	99775	-	531780
BİLECİK	-	-	-	-	-	-	-	-	-	-
BİNGÖL	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-
BURDUR	-	-	-	-	-	-	-	-	-	-
BURSA	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	-	-	-	-	-	-	-	-
ÇORUM	-	-	-	-	-	-	-	-	-	-
DENİZLİ	-	-	-	-	-	-	-	-	-	-
DİYARBAKIR	-	-	-	-	-	-	-	-	-	-
ELAZIĞ	-	-	-	-	-	-	-	-	54896	-
ERZİNCAN	-	-	-	-	-	-	-	-	71114	-
ERZURUM	-	168586	-	-	-	-	-	-	-	-
ESKİŞEHİR	-	-	-	-	-	-	-	1002395	-	-
GAZİANTEP	-	-	-	-	-	-	-	-	-	-
GİRESUN	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-
ISPARTA	-	-	-	-	-	-	-	-	-	-
MERSİN	-	-	-	-	-	-	-	-	-	-
İZMİR	-	-	-	-	-	-	-	-	-	831776
KARS	-	-	-	-	-	-	-	-	-	-
KASTAMONU	-	-	-	-	-	-	-	-	-	-
KAYSERİ	-	-	-	-	-	-	-	-	-	-
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-
KOCAELİ	-	-	-	-	-	-	-	-	-	-
KONYA	-	-	-	-	-	-	-	-	-	-
KÜTAHYA	-	-	-	-	-	-	-	-	-	-
MALATYA	-	-	-	-	-	-	-	-	-	-
MANİSA	831776	-	-	-	-	-	-	-	-	-
K.MARAŞ	-	-	-	-	-	-	-	-	186324	-
MARDİN	-	-	-	-	-	-	-	-	-	-
MUĞLA	-	-	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	-	-	-	-	-
NİĞDE	-	-	-	343648	-	-	-	-	-	-
ORDU	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-	-
SAKARYA	-	-	-	-	-	661073	-	-	-	-
SAMSUN	-	-	-	-	-	-	-	-	-	-
SİİRT	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-
SİVAS	-	-	-	1	-	-	-	-	76782	-
TOKAT	-	-	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-
UŞAK	-	-	-	-	-	-	-	-	-	421652
VAN	-	-	-	-	-	-	-	-	-	-
YOZGAT	-	-	-	-	-	-	-	-	-	-
ZONGULDAK	-	-	-	-	-	-	-	-	-	-
AKSARAY	-	-	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-	-	-
KARAMAN	-	-	-	-	-	-	104576	-	-	-
KIRIKKALE	-	-	-	654244	-	-	-	-	-	-
BATMAN	-	-	-	-	-	-	-	-	-	-
ŞIRNAK	-	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-
OSMANİYE	-	-	-	-	-	-	-	-	-	-
Düzce	-	-	-	-	-	-	-	-	-	-

Appendix 4 Population Densities around the Railway Network

	K.MARAŞ	MARDİN	MUĞLA	MUŞ	NEVŞEHİR	NİĞDE	ORDU	RİZE	SAKARYA	SAMSUN	SİİRT	SİNOP
ADANA	-	-	-	-	-	117704	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	-	-	-	-	-	-
AĞRI	-	-	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	987088	-	-
ANKARA	-	-	-	-	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-	-	-	-	-
BALIKESİR	-	-	-	-	-	-	-	-	-	-	-	-
BİLECİK	-	-	-	-	-	-	-	-	669719	-	-	-
BİNGÖL	-	-	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-	-	-
BURDUR	-	-	-	-	-	-	-	-	-	-	-	-
BURSA	-	-	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	-	-	-	-	-	-	-	-	-	-
ÇORUM	-	-	-	-	-	-	-	-	-	-	-	-
DENİZLİ	-	-	-	-	-	-	-	-	-	-	-	-
DİYARBAKIR	-	-	-	-	-	-	-	-	-	-	-	-
ELAZIĞ	-	-	-	######	-	-	-	-	-	-	-	-
ERZİNCAN	-	-	-	-	-	-	-	-	-	-	-	-
ERZURUM	-	-	-	-	-	-	-	-	-	-	-	-
ESKİŞEHİR	-	-	-	-	-	-	-	-	-	-	-	-
GAZİANTEP	1	-	-	-	-	-	-	-	-	-	-	-
GİRESUN	-	-	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-	-	-
ISPARTA	-	-	-	-	-	-	-	-	-	-	-	-
MERSİN	-	-	-	-	-	117704	-	-	-	-	-	-
İZMİR	-	-	-	-	-	-	-	-	-	-	-	-
KARS	-	-	-	-	-	-	-	-	-	-	-	-
KASTAMONU	-	-	-	-	-	-	-	-	-	-	-	-
KAYSERİ	-	-	-	-	-	343648	-	-	-	-	-	-
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-	-	-
KOCAELİ	-	-	-	-	-	-	-	-	661073	-	-	-
KONYA	-	-	-	-	-	-	-	-	-	-	-	-
KÜTAHYA	-	-	-	-	-	-	-	-	-	-	-	-
MALATYA	186324	-	-	-	-	-	-	-	-	-	-	-
MANİSA	-	-	-	-	-	-	-	-	-	-	-	-
K.MARAŞ	-	-	-	-	-	-	-	-	-	-	-	-
MARDİN	-	-	-	-	-	-	-	-	-	-	-	-
MUĞLA	-	-	-	-	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	-	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	-	-	-	-	-	-	-
NİĞDE	-	-	-	-	-	-	-	-	-	-	-	-
ORDU	-	-	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-	-	-	-
SAKARYA	-	-	-	-	-	-	-	-	-	-	-	-
SAMSUN	-	-	-	-	-	-	-	-	-	-	-	-
SİİRT	-	-	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-	-	-
SİVAS	-	-	-	-	-	-	-	-	-	-	-	-
TOKAT	-	-	-	-	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-	-	-
UŞAK	-	-	-	-	-	-	-	-	-	-	-	-
VAN	-	-	-	-	-	-	-	-	-	-	-	-
YOZGAT	-	-	-	-	-	-	-	-	-	-	-	-
ZONGULDAK	-	-	-	-	-	-	-	-	-	-	-	-
AKSARAY	-	-	-	-	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-	-	-	-	-
KARAMAN	-	-	-	-	-	63020	-	-	-	-	-	-
KIRIKKALE	-	-	-	-	-	-	-	-	-	-	-	-
BATMAN	-	-	-	-	-	-	-	-	-	-	-	-
ŞIRNAK	-	-	-	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-	-	-
OSMANİYE	26398	-	-	-	-	-	-	-	-	-	-	-
Düzce	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 4 Population Densities around the Railway Network

AKSARAY	ZONGULDAK	YOZGAT	VAN	UŞAK	ŞANLIURFA	TUNCELİ	TRABZON	TOKAT	SİVAS	
-	-	-	-	-	-	-	-	-	-	ADANA
-	-	-	-	-	-	-	-	-	-	ADIYAMAN
-	-	-	-	48844	-	-	-	-	-	AFYON
-	-	-	-	-	-	-	-	-	-	AĞRI
-	-	-	-	-	-	-	-	-	371181	AMASYA
-	-	-	-	-	-	-	-	-	-	ANKARA
-	-	-	-	-	-	-	-	-	-	ANTALYA
-	-	-	-	-	-	-	-	-	-	ARTVİN
-	-	-	-	-	-	-	-	-	-	AYDIN
-	-	-	-	-	-	-	-	-	-	BALIKESİR
-	-	-	-	-	-	-	-	-	-	BİLECİK
-	-	-	-	-	-	-	-	-	-	BİNGÖL
-	-	-	-	-	-	-	-	-	-	BİTLİS
-	-	-	-	-	-	-	-	-	-	BOLU
-	-	-	-	-	-	-	-	-	-	BURDUR
-	-	-	-	-	-	-	-	-	-	BURSA
-	-	-	-	-	-	-	-	-	-	ÇANAKKALE
-	-	-	-	-	-	-	-	-	-	ÇANKIRI
-	-	-	-	-	-	-	-	-	-	ÇORUM
-	-	-	-	-	-	-	-	-	-	DENİZLİ
-	-	-	-	-	-	-	-	-	-	DİYARBAKIR
-	-	-	-	-	-	-	-	-	-	ELAZIĞ
-	-	-	-	-	-	-	-	-	24276	ERZİNCAN
-	-	-	-	-	-	-	-	-	-	ERZURUM
-	-	-	-	-	-	-	-	-	-	ESKİŞEHİR
-	-	-	-	-	-	-	-	-	-	GAZİANTEP
-	-	-	-	-	-	-	-	-	-	GİRESUN
-	-	-	-	-	-	-	-	-	-	GÜMÜŞHANE
-	-	-	-	-	-	-	-	-	-	HAKKARİ
-	-	-	-	-	-	-	-	-	-	HATAY
-	-	-	-	-	-	-	-	-	-	ISPARTA
-	-	-	-	-	-	-	-	-	-	MERSİN
-	-	-	-	-	-	-	-	-	-	İZMİR
-	-	-	-	-	-	-	-	-	-	KARS
-	-	-	-	-	-	-	-	-	-	KASTAMONU
-	-	-	-	-	-	-	-	-	1	KAYSERİ
-	-	-	-	-	-	-	-	-	-	KIRŞEHİR
-	-	-	-	-	-	-	-	-	-	KOCAELİ
-	-	-	-	-	-	-	-	-	-	KONYA
-	-	-	-	-	-	-	-	-	-	KÜTAHYA
-	-	-	-	-	-	-	-	-	76782	MALATYA
-	-	-	-	421652	-	-	-	-	-	MANİSA
-	-	-	-	-	-	-	-	-	-	K.MARAŞ
-	-	-	-	-	-	-	-	-	-	MARDİN
-	-	-	-	-	-	-	-	-	-	MUĞLA
-	-	-	-	-	-	-	-	-	-	MUŞ
-	-	-	-	-	-	-	-	-	-	NEVŞEHİR
-	-	-	-	-	-	-	-	-	-	NİĞDE
-	-	-	-	-	-	-	-	-	-	ORDU
-	-	-	-	-	-	-	-	-	-	RİZE
-	-	-	-	-	-	-	-	-	-	SAKARYA
-	-	-	-	-	-	-	-	-	-	SAMSUN
-	-	-	-	-	-	-	-	-	-	SİİRT
-	-	-	-	-	-	-	-	-	-	SİNOP
-	-	-	-	-	-	-	-	-	-	SİVAS
-	-	-	-	-	-	-	-	-	-	TOKAT
-	-	-	-	-	-	-	-	-	-	TRABZON
-	-	-	-	-	-	-	-	-	-	TUNCELİ
-	-	-	-	-	-	-	-	-	-	ŞANLIURFA
-	-	-	-	-	-	-	-	-	-	UŞAK
-	-	-	-	-	-	-	-	-	-	VAN
-	-	-	-	-	-	-	-	-	-	YOZGAT
-	-	-	-	-	-	-	-	-	-	ZONGULDAK
-	-	-	-	-	-	-	-	-	-	AKSARAY
-	-	-	-	-	-	-	-	-	-	BAYBURT
-	-	-	-	-	-	-	-	-	-	KARAMAN
-	-	-	-	-	-	-	-	-	-	KIRIKKALE
-	-	-	-	-	-	-	-	-	-	BATMAN
-	-	-	-	-	-	-	-	-	-	ŞIRNAK
-	-	-	-	-	-	-	-	-	-	BARTIN
-	-	-	-	-	-	-	-	-	-	ARDAHAN
-	-	-	-	-	-	-	-	-	-	IĞDIR
-	-	-	-	-	-	-	-	-	-	YALOVA
-	270961	-	-	-	-	-	-	-	-	KARABÜK
-	-	-	-	-	-	-	-	-	-	KİLİS
-	-	-	-	-	-	-	-	-	-	OSMANİYE
-	-	-	-	-	-	-	-	-	-	Düzce

Appendix 4 Population Densities around the Railway Network

	BAYBURT	KARAMAN	KIRIKKALE	BATMAN	ŞIRNAK	BARTIN	ARDAHAN	IĞDIR	YALOVA	KARABÜK
ADANA	.	54684	.	.	.	.	.	.	.	.
ADIYAMAN	.	.	.	.	.	.	.	.	.	.
AFYON	.	.	.	.	.	.	.	.	.	.
AĞRI	.	.	.	.	.	.	.	.	.	.
AMASYA	.	.	.	.	.	.	.	.	.	.
ANKARA	.	.	488078	.	.	.	.	.	.	.
ANTALYA	.	.	.	.	.	.	.	.	.	.
ARTVİN	.	.	.	.	.	.	.	.	.	.
AYDIN	.	.	.	.	.	.	.	.	.	.
BALIKESİR	.	.	.	.	.	.	.	.	.	.
BİLECİK	.	.	.	.	.	.	.	.	.	.
BİNGÖL	.	.	.	.	.	.	.	.	.	.
BİTLİS	.	.	.	.	.	.	.	.	.	.
BOLU	.	.	.	.	.	.	.	.	.	.
BURDUR	.	.	.	.	.	.	.	.	.	.
BURSA	.	.	.	.	.	.	.	.	.	.
ÇANAKKALE	.	.	.	.	.	.	.	.	.	.
ÇANKIRI	.	.	92736	.	.	.	.	.	.	267644
ÇORUM	.	.	.	.	.	.	.	.	.	.
DENİZLİ	.	.	.	.	.	.	.	.	.	.
DİYARBAKIR	.	.	.	1667118	.	.	.	.	.	.
ELAZIĞ	.	.	.	.	.	.	.	.	.	.
ERZİNCAN	.	.	.	.	.	.	.	.	.	.
ERZURUM	.	.	.	.	.	.	.	.	.	.
ESKİŞEHİR	.	.	.	.	.	.	.	.	.	.
GAZİANTEP	.	.	.	.	.	.	.	.	.	.
GİRESUN	.	.	.	.	.	.	.	.	.	.
GÜMÜŞHANE	.	.	.	.	.	.	.	.	.	.
HAKKARİ	.	.	.	.	.	.	.	.	.	.
HATAY	.	.	.	.	.	.	.	.	.	.
ISPARTA	.	.	.	.	.	.	.	.	.	.
MERSİN	.	54684	.	.	.	.	.	.	.	.
İZMİR	.	.	.	.	.	.	.	.	.	.
KARS	.	.	.	.	.	.	.	.	.	.
KASTAMONU	.	.	.	.	.	.	.	.	.	.
KAYSERİ	.	.	654244	.	.	.	.	.	.	.
KIRŞEHİR	.	.	.	.	.	.	.	.	.	.
KOCAELİ	.	.	.	.	.	.	.	.	.	.
KONYA	.	104576	.	.	.	.	.	.	.	.
KÜTAHYA	.	.	.	.	.	.	.	.	.	.
MALATYA	.	.	.	.	.	.	.	.	.	.
MANİSA	.	.	.	.	.	.	.	.	.	.
K.MARAŞ	.	.	.	.	.	.	.	.	.	.
MARDİN	.	.	.	.	.	.	.	.	.	.
MUĞLA	.	.	.	.	.	.	.	.	.	.
MUŞ	.	.	.	.	.	.	.	.	.	.
NEVŞEHİR	.	.	.	.	.	.	.	.	.	.
NİĞDE	.	63020	.	.	.	.	.	.	.	.
ORDU	.	.	.	.	.	.	.	.	.	.
RİZE	.	.	.	.	.	.	.	.	.	.
SAKARYA	.	.	.	.	.	.	.	.	.	.
SAMSUN	.	.	.	.	.	.	.	.	.	.
SİİRT	.	.	.	.	.	.	.	.	.	.
SİNOP	.	.	.	.	.	.	.	.	.	.
SİVAS	.	.	.	.	.	.	.	.	.	.
TOKAT	.	.	.	.	.	.	.	.	.	.
TRABZON	.	.	.	.	.	.	.	.	.	.
TUNCELİ	.	.	.	.	.	.	.	.	.	.
ŞANLIURFA	.	.	.	.	.	.	.	.	.	.
UŞAK	.	.	.	.	.	.	.	.	.	.
VAN	.	.	.	.	.	.	.	.	.	.
YOZGAT	.	.	.	.	.	.	.	.	.	.
ZONGULDAK	.	.	.	.	.	.	.	.	.	270961
AKSARAY	.	.	.	.	.	.	.	.	.	.
BAYBURT	.	.	.	.	.	.	.	.	.	.
KARAMAN	.	.	.	.	.	.	.	.	.	.
KIRIKKALE	.	.	.	.	.	.	.	.	.	.
BATMAN	.	.	.	.	.	.	.	.	.	.
ŞIRNAK	.	.	.	.	.	.	.	.	.	.
BARTIN	.	.	.	.	.	.	.	.	.	.
ARDAHAN	.	.	.	.	.	.	.	.	.	.
IĞDIR	.	.	.	.	.	.	.	.	.	.
YALOVA	.	.	.	.	.	.	.	.	.	.
KARABÜK	.	.	.	.	.	.	.	.	.	.
KİLİS	.	.	.	.	.	.	.	.	.	.
OSMANİYE	.	.	.	.	.	.	.	.	.	.
Düzce	.	.	.	.	.	.	.	.	.	.

Appendix 4 Population Densities around the Railway Network

	KİLİS	OSMANİYE	Düzce
ADANA	.	14519	.
ADIYAMAN	.	.	.
AFYON	.	.	.
AĞRI	.	.	.
AMASYA	.	.	.
ANKARA	.	.	.
ANTALYA	.	.	.
ARTVİN	.	.	.
AYDIN	.	.	.
BALIKESİR	.	.	.
BİLECİK	.	.	.
BİNGÖL	.	.	.
BİTLİS	.	.	.
BOLU	.	.	.
BURDUR	.	.	.
BURSA	.	.	.
ÇANAKKALE	.	.	.
ÇANKIRI	.	.	.
ÇORUM	.	.	.
DENİZLİ	.	.	.
DİYARBAKIR	.	.	.
ELAZIĞ	.	.	.
ERZİNCAN	.	.	.
ERZURUM	.	.	.
ESKİŞEHİR	.	.	.
GAZİANTEP	.	26398	.
GİRESUN	.	.	.
GÜMÜŞHANE	.	.	.
HAKKARİ	.	.	.
HATAY	.	.	.
ISPARTA	.	.	.
MERSİN	.	.	.
İZMİR	.	.	.
KARS	.	.	.
KASTAMONU	.	.	.
KAYSERİ	.	.	.
KIRŞEHİR	.	.	.
KOCAELİ	.	.	.
KONYA	.	.	.
KÜTAHYA	.	.	.
MALATYA	.	.	.
MANİSA	.	.	.
K.MARAŞ	.	26398	.
MARDİN	.	.	.
MUĞLA	.	.	.
MUŞ	.	.	.
NEVŞEHİR	.	.	.
NİĞDE	.	.	.
ORDU	.	.	.
RİZE	.	.	.
SAKARYA	.	.	.
SAMSUN	.	.	.
SİİRT	.	.	.
SİNOP	.	.	.
SİVAS	.	.	.
TOKAT	.	.	.
TRABZON	.	.	.
TUNCELİ	.	.	.
ŞANLIURFA	.	.	.
UŞAK	.	.	.
VAN	.	.	.
YOZGAT	.	.	.
ZONGULDAK	.	.	.
AKSARAY	.	.	.
BAYBURT	.	.	.
KARAMAN	.	.	.
KIRIKKALE	.	.	.
BATMAN	.	.	.
ŞIRNAK	.	.	.
BARTIN	.	.	.
ARDAHAN	.	.	.
IĞDIR	.	.	.
YALOVA	.	.	.
KARABÜK	.	.	.
KİLİS	.	.	.
OSMANİYE	.	.	.
Düzce	.	.	.

Appendix 4 Population Densities around the Railway Network

BALIKESİR	AYDIN	ARTVİN	ANTALYA	ANKARA	AMASYA	AĞRI	AFYON	ADIYAMAN	ADANA	
-	-	-	-	-	-	-	-	-	-	ADANA
-	-	-	-	-	-	-	-	-	-	ADIYAMAN
-	-	-	-	-	-	-	-	-	-	AFYON
-	-	-	-	-	-	-	-	-	-	AĞRI
-	-	-	-	-	-	-	-	-	-	AMASYA
-	-	-	-	-	-	-	-	-	-	ANKARA
-	-	-	-	-	-	-	-	-	-	ANTALYA
-	-	-	-	-	-	-	-	-	-	ARTVİN
-	-	-	-	-	-	-	-	-	-	AYDIN
-	-	-	-	-	-	-	-	-	-	BALIKESİR
-	-	-	-	-	-	-	-	-	-	BİLECİK
-	-	-	-	-	-	-	-	-	-	BİNGÖL
-	-	-	-	-	-	450236	-	-	-	BİTLİS
-	-	-	-	135009	-	-	-	-	-	BOLU
-	-	-	1414137	-	-	-	-	-	-	BURDUR
330816	-	-	-	-	-	-	-	-	-	BURSA
502776	-	-	-	-	-	-	-	-	-	ÇANAKKALE
-	-	-	-	97545	-	-	-	-	-	ÇANKIRI
-	-	-	-	-	409029	-	-	-	-	ÇORUM
-	883712	-	-	-	-	-	805469	-	-	DENİZLİ
-	-	-	-	-	-	-	-	1856072	-	DİYARBAKIR
-	-	-	-	-	-	-	-	-	-	ELAZIĞ
-	-	-	-	-	-	-	-	-	-	ERZİNCAN
-	-	801107	-	-	-	1031049	-	-	-	ERZURUM
-	-	-	-	1118795	-	-	1225206	-	-	ESKİŞEHİR
-	-	-	-	-	-	-	-	414425	-	GAZİANTEP
-	-	-	-	-	-	-	-	-	-	GİRESUN
-	-	-	-	-	-	-	-	-	-	GÜMÜŞHANE
-	-	-	-	-	-	-	-	-	-	HAKKARİ
-	-	-	-	-	-	-	-	-	1510369	HATAY
-	-	-	1488032	-	-	-	471561	-	-	ISPARTA
-	-	-	3284648	-	-	-	-	-	2120785	MERSİN
-	605111	-	-	-	-	-	-	-	-	İZMİR
-	-	-	-	-	-	233814	-	-	-	KARS
-	-	-	-	-	-	-	-	-	-	KASTAMONU
-	-	-	-	-	-	-	-	-	-	KAYSERİ
-	-	-	-	-	-	-	-	-	-	KIRŞEHİR
-	-	-	-	-	-	-	-	-	-	KOCAELİ
-	-	-	2220460	210752	-	-	501372	-	-	KONYA
680857	-	-	-	-	-	-	409015	-	-	KÜTAHYA
-	-	-	-	-	-	-	-	760084	-	MALATYA
786980	-	-	-	-	-	-	-	-	-	MANİSA
-	-	-	-	-	-	-	-	840516	-	K.MARAŞ
-	-	-	-	-	-	-	-	-	-	MARDİN
-	345622	-	1636728	-	-	-	-	-	-	MUĞLA
-	-	-	-	-	-	656642	-	-	-	MUŞ
-	-	-	-	-	-	-	-	-	-	NEVŞEHİR
-	-	-	-	-	-	-	-	-	871039	NİĞDE
-	-	-	-	-	-	-	-	-	-	ORDU
-	-	333591	-	-	-	-	-	-	-	RİZE
-	-	-	-	-	-	-	-	-	-	SAKARYA
-	-	-	-	-	1068582	-	-	-	-	SAMSUN
-	-	-	-	-	-	-	-	-	-	SİİRT
-	-	-	-	-	-	-	-	-	-	SİNOP
-	-	-	-	-	-	-	-	-	-	SİVAS
-	-	-	-	-	465543	-	-	-	-	TOKAT
-	-	-	-	-	-	-	-	-	-	TRABZON
-	-	-	-	-	-	-	-	-	-	TUNCELİ
-	-	-	-	-	-	-	-	850078	-	ŞANLIURFA
-	-	-	-	-	-	-	244460	-	-	UŞAK
-	-	-	-	-	-	633389	-	-	-	VAN
-	-	-	-	-	608207	-	-	-	-	YOZGAT
-	-	-	-	-	-	-	-	-	-	ZONGULDAK
-	-	-	-	358290	-	-	-	-	-	AKSARAY
-	-	-	-	-	-	-	-	-	-	BAYBURT
-	-	-	1991247	-	-	-	-	-	1195746	KARAMAN
-	-	-	-	268379	-	-	-	-	-	KIRIKKALE
-	-	-	-	-	-	-	-	-	-	BATMAN
-	-	-	-	-	-	-	-	-	-	ŞIRNAK
-	-	-	-	-	-	-	-	-	-	BARTIN
-	-	70418	-	-	-	-	-	-	-	ARDAHAN
-	-	-	-	-	-	349984	-	-	-	IĞDIR
-	-	-	-	-	-	-	-	-	-	YALOVA
-	-	-	-	-	-	-	-	-	-	KARABÜK
-	-	-	-	-	-	-	-	-	-	KİLİS
-	-	-	-	-	-	-	-	-	1071664	OSMANİYE
-	-	-	-	-	-	-	-	-	-	Düzce

Appendix 5 Population Densities around the Highway Network

DENİZLİ	ÇORUM	ÇANKIRI	ÇANAKKALE	BURSA	BURDUR	BOLU	BİTLİS	BİNGÖL	BİLECİK	
-	-	-	-	-	-	-	-	-	-	ADANA
-	-	-	-	-	-	-	-	-	-	ADIYAMAN
805469	-	-	-	-	-	-	-	-	-	AFYON
-	-	-	-	-	-	-	450236	-	-	AĞRI
-	409029	-	-	-	-	-	-	-	-	AMASYA
-	-	97545	-	-	-	135009	-	-	-	ANKARA
-	-	-	-	-	1414137	-	-	-	-	ANTALYA
-	-	-	-	-	-	-	-	-	-	ARTVİN
883712	-	-	-	-	-	-	-	-	-	AYDIN
-	-	-	502776	330816	-	-	-	-	-	BALIKESİR
-	-	-	-	632132	-	220144	-	-	-	BİLECİK
-	-	-	-	-	-	-	-	-	-	BİNGÖL
-	-	-	-	-	-	-	-	-	-	BİTLİS
-	-	310224	-	-	-	-	-	-	220144	BOLU
543369	-	-	-	-	-	-	-	-	-	BURDUR
-	-	-	-	-	-	-	-	-	632132	BURSA
-	-	-	-	-	-	-	-	-	-	ÇANAKKALE
-	300337	-	-	-	-	310224	-	-	-	ÇANKIRI
-	-	300337	-	-	-	-	-	-	-	ÇORUM
-	-	-	-	-	543369	-	-	-	-	DENİZLİ
-	-	-	-	-	-	-	-	1429851	-	DİYARBAKIR
-	-	-	-	-	-	-	-	162801	-	ELAZIĞ
-	-	-	-	-	-	-	-	-	-	ERZİNCAN
-	-	-	-	-	-	-	-	925743	-	ERZURUM
-	-	-	-	-	-	-	-	-	1076298	ESKİŞEHİR
-	-	-	-	-	-	-	-	-	-	GAZİANTEP
-	-	-	-	-	-	-	-	-	-	GİRESUN
-	-	-	-	-	-	-	-	-	-	GÜMÜŞHANE
-	-	-	-	-	-	-	-	-	-	HAKKARİ
-	-	-	-	-	-	-	-	-	-	HATAY
610150	-	-	-	-	278924	-	-	-	-	ISPARTA
-	-	-	-	-	-	-	-	-	-	MERSİN
-	-	-	-	-	-	-	-	-	-	İZMİR
-	-	-	-	-	-	-	-	-	-	KARS
-	411080	189608	-	-	-	-	-	-	-	KASTAMONU
-	-	-	-	-	-	-	-	-	-	KAYSERİ
-	-	-	-	-	-	-	-	-	-	KIRŞEHİR
-	-	-	-	-	-	-	-	-	-	KOCAELİ
-	-	-	-	-	-	-	-	-	-	KONYA
-	-	-	-	1038166	-	-	-	-	321697	KÜTAHYA
-	-	-	-	-	-	-	-	-	-	MALATYA
1013153	-	-	-	-	-	-	-	-	-	MANİSA
-	-	-	-	-	-	-	-	-	-	K.MARAŞ
-	-	-	-	-	-	-	-	-	-	MARDİN
566289	-	-	-	-	308220	-	-	-	-	MUĞLA
-	-	-	-	-	-	-	276107	321038	-	MUŞ
-	-	-	-	-	-	-	-	-	-	NEVŞEHİR
-	-	-	-	-	-	-	-	-	-	NİĞDE
-	-	-	-	-	-	-	-	-	-	ORDU
-	-	-	-	-	-	-	-	-	-	RİZE
-	-	-	-	-	-	-	-	-	722648	SAKARYA
-	1102951	-	-	-	-	-	-	-	-	SAMSUN
-	-	-	-	-	-	-	203982	-	-	SİİRT
-	459981	-	-	-	-	-	-	-	-	SİNOP
-	-	-	-	-	-	-	-	-	-	SİVAS
-	-	-	-	-	-	-	-	-	-	TOKAT
-	-	-	-	-	-	-	-	-	-	TRABZON
-	-	-	-	-	-	-	-	116411	-	TUNCELİ
-	-	-	-	-	-	-	-	-	-	ŞANLIURFA
489623	-	-	-	-	-	-	-	-	-	UŞAK
-	-	-	-	-	-	-	523944	-	-	VAN
-	335313	-	-	-	-	-	-	-	-	YOZGAT
-	-	-	-	-	-	446533	-	-	-	ZONGULDAK
-	-	-	-	-	-	-	-	-	-	AKSARAY
-	-	-	-	-	-	-	-	-	-	BAYBURT
-	-	-	-	-	-	-	-	-	-	KARAMAN
-	460406	328381	-	-	-	-	-	-	-	KIRIKKALE
-	-	-	-	-	-	-	369456	-	-	BATMAN
-	-	-	-	-	-	-	-	-	-	ŞIRNAK
-	-	-	-	-	-	-	-	-	-	BARTIN
-	-	-	-	-	-	-	-	-	-	ARDAHAN
-	-	-	-	-	-	-	-	-	-	IĞDIR
-	-	-	-	1277596	-	-	-	-	-	YALOVA
-	-	240548	-	-	-	303284	-	-	-	KARABÜK
-	-	-	-	-	-	-	-	-	-	KİLİS
-	-	-	-	-	-	-	-	-	-	OSMANİYE
-	-	-	-	-	-	156648	-	-	-	Düzce

Appendix 5 Population Densities around the Highway Network

	DİYARBAKIR	ELAZIĞ	ERZİNCAN	ERZURUM	ESKİŞEHİR	GAZİANTEP	GİRESUN	GÜMÜŞHANE	HAKKARİ
ADANA	.	.	.	.	.	.	.	.	.
ADIYAMAN	1856072	.	.	.	.	414425	.	.	.
AFYON	.	.	.	.	1225206	.	.	.	.
AĞRI	.	.	.	1031049	.	.	.	.	.
AMASYA	.	.	.	.	.	.	.	.	.
ANKARA	.	.	.	.	1118795	.	.	.	.
ANTALYA	.	.	.	.	.	.	.	.	.
ARTVİN	.	.	.	801107	.	.	.	.	.
AYDIN	.	.	.	.	.	.	.	.	.
BALIKESİR	.	.	.	.	.	.	.	.	.
BİLECİK	.	.	.	.	1076298	.	.	.	.
BİNGÖL	1429851	162801	.	925743	.	.	.	.	.
BİTLİS	.	.	.	.	.	.	.	.	.
BOLU	.	.	.	.	.	.	.	.	.
BURDUR	.	.	.	.	.	.	.	.	.
BURSA	.	.	.	.	.	.	.	.	.
ÇANAKKALE	.	.	.	.	.	.	.	.	.
ÇANKIRI	.	.	.	.	.	.	.	.	.
ÇORUM	.	.	.	.	.	.	.	.	.
DENİZLİ	.	.	.	.	.	.	.	.	.
DİYARBAKIR	.	1376612	.	.	.	.	.	.	.
ELAZIĞ	1376612	.	.	.	.	.	.	.	.
ERZİNCAN	.	.	.	1021161	.	.	.	300452	.
ERZURUM	.	.	1021161	.	.	.	.	.	.
ESKİŞEHİR	.	.	.	.	.	.	.	.	.
GAZİANTEP	.	.	.	.	.	.	.	.	.
GİRESUN	.	.	.	.	.	.	.	272032	.
GÜMÜŞHANE	.	.	300452	.	.	.	272032	.	.
HAKKARİ	.	.	.	.	.	.	.	.	.
HATAY	.	.	.	.	.	1022513	.	.	.
ISPARTA	.	.	.	.	.	.	.	.	.
MERSİN	.	.	.	.	.	.	.	.	.
İZMİR	.	.	.	.	.	.	.	.	.
KARS	.	.	.	969891	.	.	.	.	.
KASTAMONU	.	.	.	.	.	.	.	.	.
KAYSERİ	.	.	.	.	.	.	.	.	.
KIRŞEHİR	.	.	.	.	.	.	.	.	.
KOCAELİ	.	.	.	.	.	.	.	.	.
KONYA	.	.	.	.	1458618	.	.	.	.
KÜTAHYA	.	.	.	.	1210300	.	.	.	.
MALATYA	.	457566	.	.	.	.	.	.	.
MANİSA	.	.	.	.	.	.	.	.	.
K.MARAŞ	.	.	.	.	.	876556	.	.	.
MARDİN	1326029	.	.	.	.	.	.	.	.
MUĞLA	.	.	.	.	.	.	.	.	.
MUŞ	.	.	.	1079233	.	.	.	.	.
NEVŞEHİR	.	.	.	.	.	.	.	.	.
NİĞDE	.	.	.	.	.	.	.	.	.
ORDU	.	.	.	.	.	.	291554	.	.
RİZE	.	.	.	.	.	.	.	.	.
SAKARYA	.	.	.	.	.	.	.	.	.
SAMSUN	.	.	.	.	.	.	.	.	.
SİİRT	.	.	.	.	.	.	.	.	.
SİNOP	.	.	.	.	.	.	.	.	.
SİVAS	.	.	537314	.	.	.	.	.	.
TOKAT	.	.	.	.	.	.	.	.	.
TRABZON	.	.	.	.	.	.	797953	387862	.
TUNCELİ	.	46390	174921	.	.	.	.	.	.
ŞANLIURFA	2130507	.	.	.	.	609377	.	.	.
UŞAK	.	.	.	.	.	.	.	.	.
VAN	.	.	.	.	.	.	.	.	412057
YOZGAT	.	.	.	.	.	.	.	.	.
ZONGULDAK	.	.	.	.	.	.	.	.	.
AKSARAY	.	.	.	.	.	.	.	.	.
BAYBURT	.	.	325063	887927	.	.	.	117923	.
KARAMAN	.	.	.	.	.	.	.	.	.
KIRIKKALE	.	.	.	.	.	.	.	.	.
BATMAN	1667118	.	.	.	.	.	.	.	.
ŞIRNAK	.	.	.	.	.	.	.	.	69853
BARTIN	.	.	.	.	.	.	.	.	.
ARDAHAN	.	.	.	900614	.	.	.	.	.
IĞDIR	.	.	.	.	.	.	.	.	.
YALOVA	.	.	.	.	.	.	.	.	.
KARABÜK	.	.	.	.	.	.	.	.	.
KİLİS	.	.	.	.	.	87387	.	.	.
OSMANİYE	.	.	.	.	.	657520	.	.	.
Düzce	.	.	.	.	.	.	.	.	.

Appendix 5 Population Densities around the Highway Network

	HATAY	ISPARTA	MERSİN	İZMİR	KARS	KASTAMONU	KAYSERİ	KIRŞEHİR	KOCAELİ	KONYA
ADANA	1510369	-	2120785	-	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-
AFYON	-	471561	-	-	-	-	-	-	-	501372
AĞRI	-	-	-	-	233814	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	-
ANKARA	-	-	-	-	-	-	-	-	-	210752
ANTALYA	-	1488032	3284648	-	-	-	-	-	-	2220460
ARTVİN	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	605111	-	-	-	-	-	-
BALIKESİR	-	-	-	-	-	-	-	-	-	-
BİLECİK	-	-	-	-	-	-	-	-	-	-
BİNGÖL	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-
BURDUR	-	278924	-	-	-	-	-	-	-	-
BURSA	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	-	-	-	189608	-	-	-	-
ÇORUM	-	-	-	-	-	411080	-	-	-	-
DENİZLİ	-	610150	-	-	-	-	-	-	-	-
DİYARBAKIR	-	-	-	-	-	-	-	-	-	-
ELAZIĞ	-	-	-	-	-	-	-	-	-	-
ERZİNCAN	-	-	-	-	-	-	-	-	-	-
ERZURUM	-	-	-	-	969891	-	-	-	-	-
ESKİŞEHİR	-	-	-	-	-	-	-	-	-	1458618
GAZİANTEP	1022513	-	-	-	-	-	-	-	-	-
GİRESUN	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-
ISPARTA	-	-	-	-	-	-	-	-	-	689350
MERSİN	-	-	-	-	-	-	-	-	-	-
İZMİR	-	-	-	-	-	-	-	-	-	-
KARS	-	-	-	-	-	-	-	-	-	-
KASTAMONU	-	-	-	-	-	-	-	-	-	-
KAYSERİ	-	-	-	-	-	-	-	-	-	-
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-
KOCAELİ	-	-	-	-	-	-	-	-	-	-
KONYA	-	689350	-	-	-	-	-	-	-	-
KÜTAHYA	-	-	-	-	-	-	-	-	-	-
MALATYA	-	-	-	-	-	-	-	-	-	-
MANİSA	-	-	-	675325	-	-	-	-	-	-
K.MARAŞ	-	-	-	-	-	-	937365	-	-	-
MARDİN	-	-	-	-	-	-	-	-	-	-
MUĞLA	-	-	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	-	486730	295698	-	-
NİĞDE	-	-	1293258	-	-	-	368478	-	-	88662
ORDU	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-	-
SAKARYA	-	-	-	-	-	-	-	-	1193310	-
SAMSUN	-	-	-	-	-	-	-	-	-	-
SİİRT	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	201243	-	-	-	-
SİVAS	-	-	-	-	-	-	670285	-	-	-
TOKAT	-	-	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-
UŞAK	-	-	-	-	-	-	-	-	-	-
VAN	-	-	-	-	-	-	-	-	-	-
YOZGAT	-	-	-	-	-	-	680118	277581	-	-
ZONGULDAK	-	-	-	-	-	-	-	-	-	-
AKSARAY	-	-	-	-	-	-	-	-	-	236560
BAYBURT	-	-	-	-	-	-	-	-	-	-
KARAMAN	-	-	1797031	-	-	-	-	-	-	157892
KIRIKKALE	-	-	-	-	-	-	-	399233	-	-
BATMAN	-	-	-	-	-	-	-	-	-	-
ŞIRNAK	-	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	158865	-	-	-	-	-
IĞDIR	-	-	-	-	267798	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	810029	-
KARABÜK	-	-	-	-	-	243043	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-
OSMANİYE	883467	-	-	-	-	-	-	-	-	-
Düzce	-	-	-	-	-	-	-	-	-	-

Appendix 5 Population Densities around the Highway Network

	KÜTAHYA	MALATYA	MANİSA	K.MARAŞ	MARDİN	MUĞLA	MUŞ	NEVŞEHİR	NİĞDE	ORDU
ADANA	-	-	-	-	-	-	-	-	871039	-
ADIYAMAN	-	760084	-	840516	-	-	-	-	-	-
AFYON	409015	-	-	-	-	-	-	-	-	-
AĞRI	-	-	-	-	-	-	656642	-	-	-
AMASYA	-	-	-	-	-	-	-	-	-	-
ANKARA	-	-	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	1636728	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	345622	-	-	-	-
BALIKESİR	680857	-	786980	-	-	-	-	-	-	-
BİLECİK	321697	-	-	-	-	-	-	-	-	-
BİNGÖL	-	-	-	-	-	-	321038	-	-	-
BİTLİS	-	-	-	-	-	-	276107	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-
BURDUR	-	-	-	-	-	308220	-	-	-	-
BURSA	1038166	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	-	-	-	-	-	-	-	-
ÇORUM	-	-	-	-	-	-	-	-	-	-
DENİZLİ	-	-	1013153	-	-	566289	-	-	-	-
DİYARBAKIR	-	-	-	-	1326029	-	-	-	-	-
ELAZIĞ	-	457566	-	-	-	-	-	-	-	-
ERZİNCAN	-	-	-	-	-	-	-	-	-	-
ERZURUM	-	-	-	-	-	-	1079233	-	-	-
ESKİŞEHİR	1210300	-	-	-	-	-	-	-	-	-
GAZİANTEP	-	-	-	876556	-	-	-	-	-	-
GİRESUN	-	-	-	-	-	-	-	-	-	291554
GÜMÜŞHANE	-	-	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-
ISPARTA	-	-	-	-	-	-	-	-	-	-
MERSİN	-	-	-	-	-	-	-	-	1293258	-
İZMİR	-	-	675325	-	-	-	-	-	-	-
KARS	-	-	-	-	-	-	-	-	-	-
KASTAMONU	-	-	-	-	-	-	-	-	-	-
KAYSERİ	-	-	-	937365	-	-	-	486730	368478	-
KIRŞEHİR	-	-	-	-	-	-	-	295698	-	-
KOCAELİ	-	-	-	-	-	-	-	-	-	-
KONYA	-	-	-	-	-	-	-	-	88662	-
KÜTAHYA	-	-	-	-	-	-	-	-	-	-
MALATYA	-	-	-	1048552	-	-	-	-	-	-
MANİSA	-	-	-	-	-	-	-	-	-	-
K.MARAŞ	-	1048552	-	-	-	-	-	-	-	-
MARDİN	-	-	-	-	-	-	-	-	-	-
MUĞLA	-	-	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	-	-	-	129709	-
NİĞDE	-	-	-	-	-	-	-	129709	-	-
ORDU	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-	-	-
SAKARYA	-	-	-	-	-	-	-	-	-	-
SAMSUN	-	-	-	-	-	-	-	-	-	1449167
SİİRT	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-
SİVAS	-	852037	-	918440	-	-	-	-	-	-
TOKAT	-	-	-	-	-	-	-	-	-	750167
TRABZON	-	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	905886	-	-	-	-	-
UŞAK	256749	-	499544	-	-	-	-	-	-	-
VAN	-	-	-	-	-	-	-	-	-	-
YOZGAT	-	-	-	-	-	-	-	-	-	-
ZONGULDAK	-	-	-	-	-	-	-	-	-	-
AKSARAY	-	-	-	-	-	-	-	366482	-	-
BAYBURT	-	-	-	-	-	-	-	-	-	-
KARAMAN	-	-	-	-	-	-	-	-	324707	-
KIRIKKALE	-	-	-	-	-	-	-	-	-	-
BATMAN	-	-	-	-	476969	-	-	-	-	-
ŞIRNAK	-	-	-	-	376583	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-
OSMANİYE	-	-	-	735607	-	-	-	-	-	-
Düzce	-	-	-	-	-	-	-	-	-	-

Appendix 5 Population Densities around the Highway Network

	RİZE	SAKARYA	SAMSUN	SİİRT	SİNOP	SİVAS	TOKAT	TRABZON	TUNCELİ	ŞANLIURFA
ADANA	-	-	-	-	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	850078
AFYON	-	-	-	-	-	-	-	-	-	-
AĞRI	-	-	-	-	-	-	-	-	-	-
AMASYA	-	-	1068582	-	-	-	465543	-	-	-
ANKARA	-	-	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-	-	-
ARTVİN	333591	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-	-	-
BALIKESİR	-	-	-	-	-	-	-	-	-	-
BİLECİK	-	722648	-	-	-	-	-	-	-	-
BİNGÖL	-	-	-	-	-	-	-	-	116411	-
BİTLİS	-	-	-	203982	-	-	-	-	-	-
BOLU	-	-	-	-	-	-	-	-	-	-
BURDUR	-	-	-	-	-	-	-	-	-	-
BURSA	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	-	-	-	-	-	-	-	-
ÇORUM	-	-	1102951	-	459981	-	-	-	-	-
DENİZLİ	-	-	-	-	-	-	-	-	-	-
DİYARBAKIR	-	-	-	-	-	-	-	-	-	2130507
ELAZIĞ	-	-	-	-	-	-	-	-	46390	-
ERZİNCAN	-	-	-	-	-	537314	-	-	174921	-
ERZURUM	-	-	-	-	-	-	-	-	-	-
ESKİŞEHİR	-	-	-	-	-	-	-	-	-	-
GAZİANTEP	-	-	-	-	-	-	-	-	-	609377
GİRESUN	-	-	-	-	-	-	-	797953	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	387862	-	-
HAKKARİ	-	-	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	-	-	-	-
ISPARTA	-	-	-	-	-	-	-	-	-	-
MERSİN	-	-	-	-	-	-	-	-	-	-
İZMİR	-	-	-	-	-	-	-	-	-	-
KARS	-	-	-	-	-	-	-	-	-	-
KASTAMONU	-	-	-	-	201243	-	-	-	-	-
KAYSERİ	-	-	-	-	-	670285	-	-	-	-
KIRŞEHİR	-	-	-	-	-	-	-	-	-	-
KOCAELİ	-	1193310	-	-	-	-	-	-	-	-
KONYA	-	-	-	-	-	-	-	-	-	-
KÜTAHYA	-	-	-	-	-	-	-	-	-	-
MALATYA	-	-	-	-	-	852037	-	-	-	-
MANİSA	-	-	-	-	-	-	-	-	-	-
K.MARAŞ	-	-	-	-	-	918440	-	-	-	-
MARDİN	-	-	-	-	-	-	-	-	-	905886
MUĞLA	-	-	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	-	-	-	-	-
NİĞDE	-	-	-	-	-	-	-	-	-	-
ORDU	-	-	1449167	-	-	-	750167	-	-	-
RİZE	-	-	-	-	-	-	-	689420	-	-
SAKARYA	-	-	-	-	-	-	-	-	-	-
SAMSUN	-	-	-	-	1066965	-	1182117	-	-	-
SİİRT	-	-	-	-	-	-	-	-	-	-
SİNOP	-	-	1066965	-	-	-	-	-	-	-
SİVAS	-	-	-	-	-	-	550867	-	-	-
TOKAT	-	-	1182117	-	-	550867	-	-	-	-
TRABZON	689420	-	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-
UŞAK	-	-	-	-	-	-	-	-	-	-
VAN	-	-	-	-	-	-	-	-	-	-
YOZGAT	-	-	-	-	-	610043	649700	-	-	-
ZONGULDAK	-	-	-	-	-	-	-	-	-	-
AKSARAY	-	-	-	-	-	-	-	-	-	-
BAYBURT	297460	-	-	-	-	-	-	613054	-	-
KARAMAN	-	-	-	-	-	-	-	-	-	-
KIRIKKALE	-	-	-	-	-	-	-	-	-	-
BATMAN	-	-	-	466727	-	-	-	-	-	-
ŞIRNAK	-	-	-	192621	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	-	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-
OSMANİYE	-	-	-	-	-	-	-	-	-	-
Düzce	-	706323	-	-	-	-	-	-	-	-

Appendix 5 Population Densities around the Highway Network

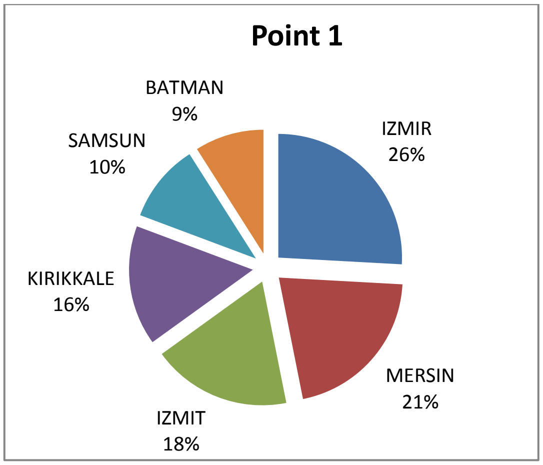
	ŞIRNAK	BATMAN	KIRIKKALE	KARAMAN	BAYBURT	AKSARAY	ZONGULDAK	YOZGAT	VAN	UŞAK
ADANA	-	-	-	1195746	-	-	-	-	-	-
ADIYAMAN	-	-	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	-	-	-	244460
AĞRI	-	-	-	-	-	-	-	-	633389	-
AMASYA	-	-	-	-	-	-	-	608207	-	-
ANKARA	-	-	268379	-	-	358290	-	-	-	-
ANTALYA	-	-	-	1991247	-	-	-	-	-	-
ARTVİN	-	-	-	-	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-	-	-
BALIKESİR	-	-	-	-	-	-	-	-	-	-
BİLECİK	-	-	-	-	-	-	-	-	-	-
BİNGÖL	-	-	-	-	-	-	-	-	-	-
BİTLİS	-	369456	-	-	-	-	-	-	523944	-
BOLU	-	-	-	-	-	-	446533	-	-	-
BURDUR	-	-	-	-	-	-	-	-	-	-
BURSA	-	-	-	-	-	-	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	328381	-	-	-	-	-	-	-
ÇORUM	-	-	460406	-	-	-	-	335313	-	-
DENİZLİ	-	-	-	-	-	-	-	-	-	489623
DİYARBAKIR	-	1667118	-	-	-	-	-	-	-	-
ELAZIĞ	-	-	-	-	-	-	-	-	-	-
ERZİNCAN	-	-	-	-	325063	-	-	-	-	-
ERZURUM	-	-	-	-	887927	-	-	-	-	-
ESKİŞEHİR	-	-	-	-	-	-	-	-	-	-
GAZİANTEP	-	-	-	-	-	-	-	-	-	-
GİRESUN	-	-	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	117923	-	-	-	-	-
HAKKARİ	69853	-	-	-	-	-	-	-	412057	-
HATAY	-	-	-	-	-	-	-	-	-	-
ISPARTA	-	-	-	-	-	-	-	-	-	-
MERSİN	-	-	-	1797031	-	-	-	-	-	-
İZMİR	-	-	-	-	-	-	-	-	-	-
KARS	-	-	-	-	-	-	-	-	-	-
KASTAMONU	-	-	-	-	-	-	-	-	-	-
KAYSERİ	-	-	-	-	-	-	-	680118	-	-
KIRŞEHİR	-	-	399233	-	-	-	-	277581	-	-
KOCAELİ	-	-	-	-	-	-	-	-	-	-
KONYA	-	-	-	157892	-	236560	-	-	-	-
KÜTAHYA	-	-	-	-	-	-	-	-	-	256749
MALATYA	-	-	-	-	-	-	-	-	-	-
MANİSA	-	-	-	-	-	-	-	-	-	499544
K.MARAŞ	-	-	-	-	-	-	-	-	-	-
MARDİN	376583	476969	-	-	-	-	-	-	-	-
MUĞLA	-	-	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	366482	-	-	-	-
NİĞDE	-	-	-	324707	-	-	-	-	-	-
ORDU	-	-	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	297460	-	-	-	-	-
SAKARYA	-	-	-	-	-	-	-	-	-	-
SAMSUN	-	-	-	-	-	-	-	-	-	-
SİİRT	192621	466727	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-	-	-
SİVAS	-	-	-	-	-	-	-	610043	-	-
TOKAT	-	-	-	-	-	-	-	649700	-	-
TRABZON	-	-	-	-	613054	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-	-	-
UŞAK	-	-	-	-	-	-	-	-	-	-
VAN	-	-	-	-	-	-	-	-	-	-
YOZGAT	-	-	352321	-	-	-	-	-	-	-
ZONGULDAK	-	-	-	-	-	-	-	-	-	-
AKSARAY	-	-	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-	-	-
KARAMAN	-	-	-	-	-	-	-	-	-	-
KIRIKKALE	-	-	-	-	-	-	-	352321	-	-
BATMAN	-	-	-	-	-	-	-	-	-	-
ŞIRNAK	-	-	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	-	-	348914	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-	-	-
KARABÜK	-	-	-	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-	-	-
OSMANİYE	-	-	-	-	-	-	-	-	-	-
Düzce	-	-	-	-	-	-	263000	-	-	-

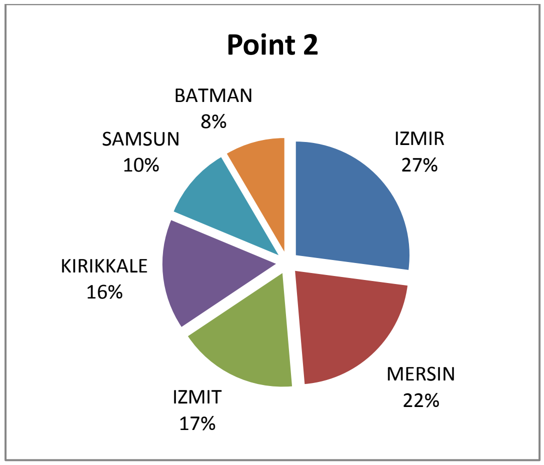
Appendix 5 Population Densities around the Highway Network

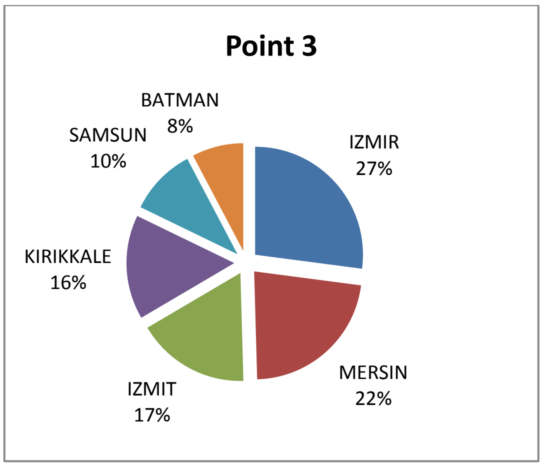
	BARTIN	ARDAHAN	IĞDIR	YALOVA	KARABÜK	KİLİS	OSMANİYE	Düzce
ADANA	-	-	-	-	-	-	1071664	-
ADIYAMAN	-	-	-	-	-	-	-	-
AFYON	-	-	-	-	-	-	-	-
AĞRI	-	-	349984	-	-	-	-	-
AMASYA	-	-	-	-	-	-	-	-
ANKARA	-	-	-	-	-	-	-	-
ANTALYA	-	-	-	-	-	-	-	-
ARTVİN	-	70418	-	-	-	-	-	-
AYDIN	-	-	-	-	-	-	-	-
BALIKESİR	-	-	-	-	-	-	-	-
BİLECİK	-	-	-	-	-	-	-	-
BİNGÖL	-	-	-	-	-	-	-	-
BİTLİS	-	-	-	-	-	-	-	-
BOLU	-	-	-	-	303284	-	-	156648
BURDUR	-	-	-	-	-	-	-	-
BURSA	-	-	-	1277596	-	-	-	-
ÇANAKKALE	-	-	-	-	-	-	-	-
ÇANKIRI	-	-	-	-	240548	-	-	-
ÇORUM	-	-	-	-	-	-	-	-
DENİZLİ	-	-	-	-	-	-	-	-
DİYARBAKIR	-	-	-	-	-	-	-	-
ELAZIĞ	-	-	-	-	-	-	-	-
ERZİNCAN	-	-	-	-	-	-	-	-
ERZURUM	-	900614	-	-	-	-	-	-
ESKİŞEHİR	-	-	-	-	-	-	-	-
GAZİANTEP	-	-	-	-	-	87387	657520	-
GİRESUN	-	-	-	-	-	-	-	-
GÜMÜŞHANE	-	-	-	-	-	-	-	-
HAKKARİ	-	-	-	-	-	-	-	-
HATAY	-	-	-	-	-	-	883467	-
ISPARTA	-	-	-	-	-	-	-	-
MERSİN	-	-	-	-	-	-	-	-
İZMİR	-	-	-	-	-	-	-	-
KARS	-	158865	267798	-	-	-	-	-
KASTAMONU	-	-	-	-	243043	-	-	-
KAYSERİ	-	-	-	-	-	-	-	-
KIRŞEHİR	-	-	-	-	-	-	-	-
KOCAELİ	-	-	-	810029	-	-	-	-
KONYA	-	-	-	-	-	-	-	-
KÜTAHYA	-	-	-	-	-	-	-	-
MALATYA	-	-	-	-	-	-	-	-
MANİSA	-	-	-	-	-	-	-	-
K.MARAŞ	-	-	-	-	-	-	735607	-
MARDİN	-	-	-	-	-	-	-	-
MUĞLA	-	-	-	-	-	-	-	-
MUŞ	-	-	-	-	-	-	-	-
NEVŞEHİR	-	-	-	-	-	-	-	-
NİĞDE	-	-	-	-	-	-	-	-
ORDU	-	-	-	-	-	-	-	-
RİZE	-	-	-	-	-	-	-	-
SAKARYA	-	-	-	-	-	-	-	706323
SAMSUN	-	-	-	-	-	-	-	-
SİİRT	-	-	-	-	-	-	-	-
SİNOP	-	-	-	-	-	-	-	-
SİVAS	-	-	-	-	-	-	-	-
TOKAT	-	-	-	-	-	-	-	-
TRABZON	-	-	-	-	-	-	-	-
TUNCELİ	-	-	-	-	-	-	-	-
ŞANLIURFA	-	-	-	-	-	-	-	-
UŞAK	-	-	-	-	-	-	-	-
VAN	-	-	-	-	-	-	-	-
YOZGAT	-	-	-	-	-	-	-	-
ZONGULDAK	348914	-	-	-	-	-	-	263000
AKSARAY	-	-	-	-	-	-	-	-
BAYBURT	-	-	-	-	-	-	-	-
KARAMAN	-	-	-	-	-	-	-	-
KIRIKKALE	-	-	-	-	-	-	-	-
BATMAN	-	-	-	-	-	-	-	-
ŞIRNAK	-	-	-	-	-	-	-	-
BARTIN	-	-	-	-	247296	-	-	-
ARDAHAN	-	-	-	-	-	-	-	-
IĞDIR	-	-	-	-	-	-	-	-
YALOVA	-	-	-	-	-	-	-	-
KARABÜK	247296	-	-	-	-	-	-	-
KİLİS	-	-	-	-	-	-	-	-
OSMANİYE	-	-	-	-	-	-	-	-
Düzce	-	-	-	-	-	-	-	-

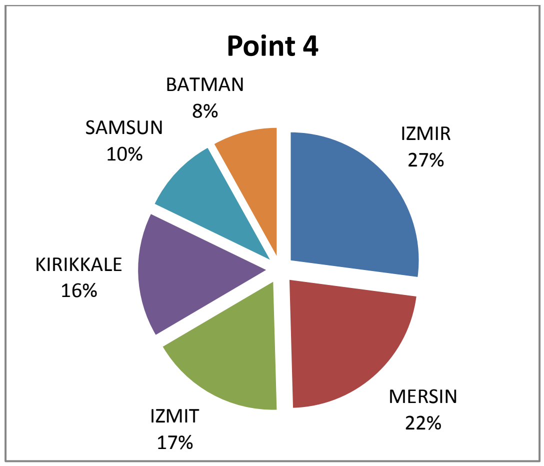
Appendix 5 Population Densities around the Highway Network

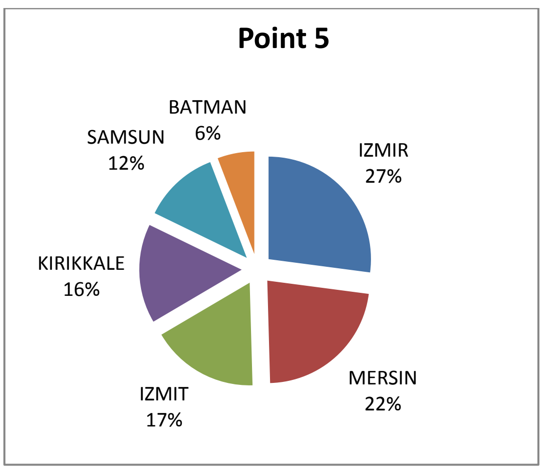
Appendix 6 Percentage Distributions of Suppliers of 16 Solutions of IMS

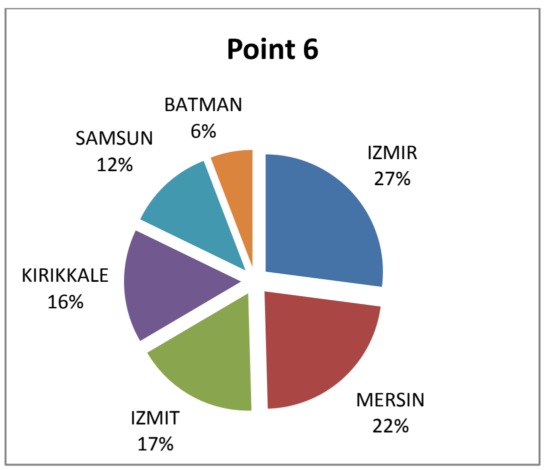


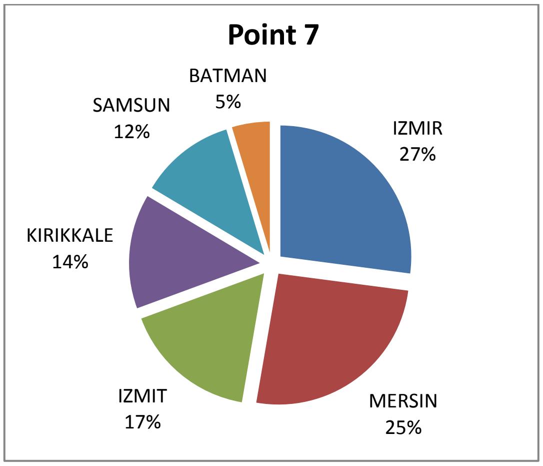


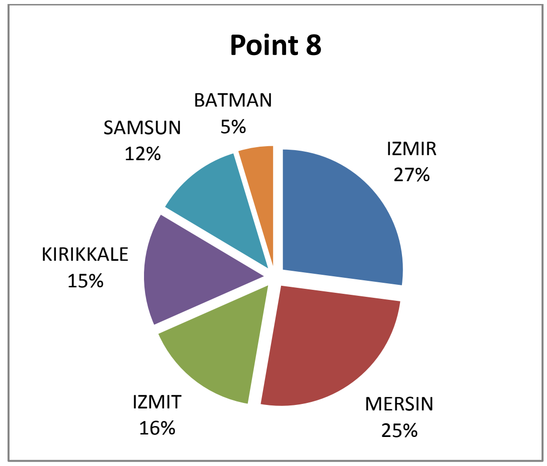


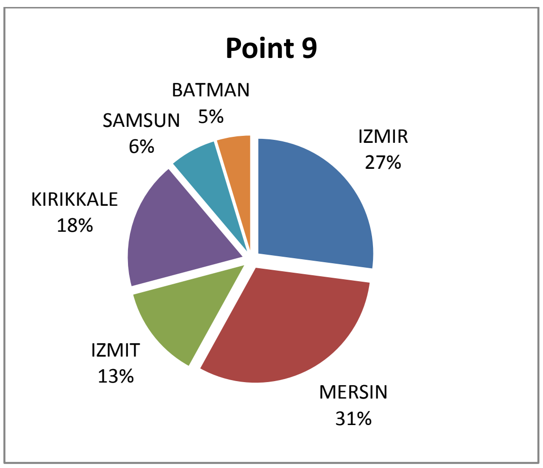


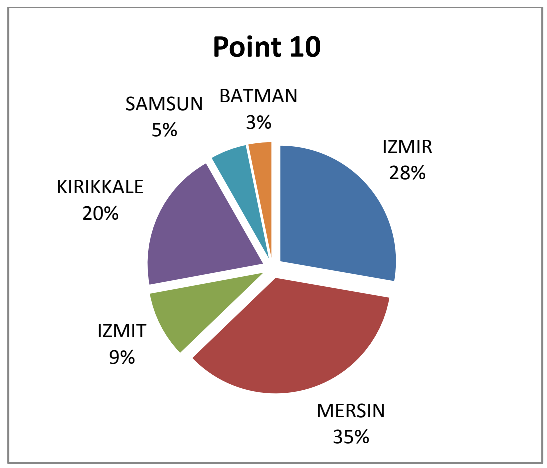


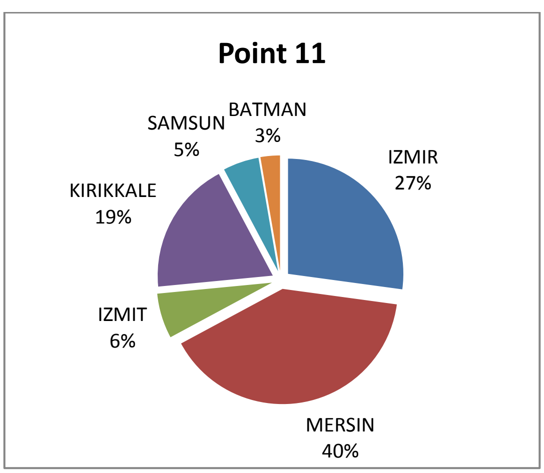


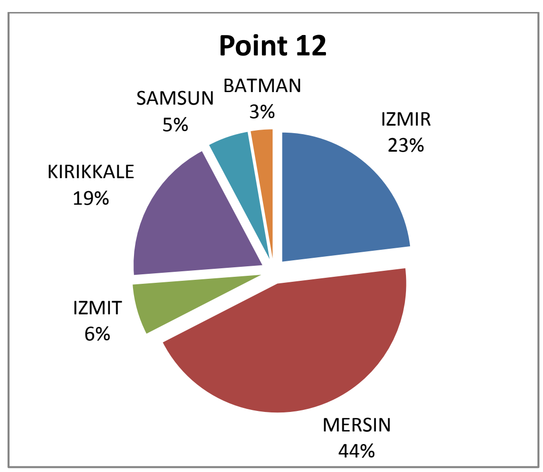

Point 7
BATMAN 5%
IZMIR 27%
MERSIN 25%
IZMIT 17%
KIRIKKALE 14%
SAMSUN 12%

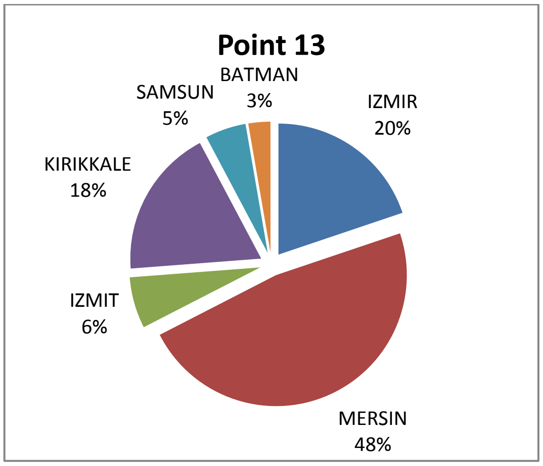

Point 8
BATMAN 5%
IZMIR 27%
MERSIN 25%
IZMIT 16%
KIRIKKALE 15%
SAMSUN 12%

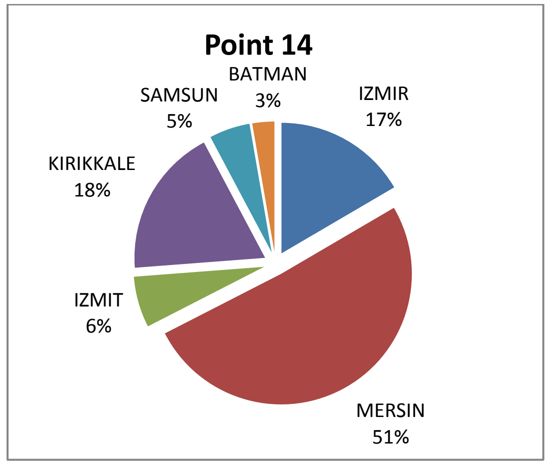

Point 9
BATMAN 5%
IZMIR 27%
MERSIN 31%
IZMIT 13%
KIRIKKALE 18%
SAMSUN 6%

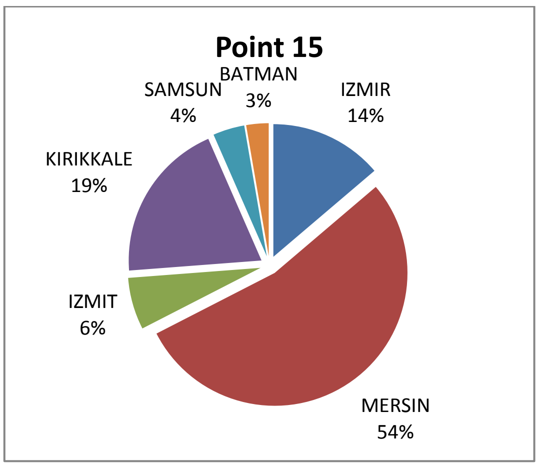

Point 10
BATMAN 3%
IZMIR 28%
MERSIN 35%
IZMIT 9%
KIRIKKALE 20%
SAMSUN 5%

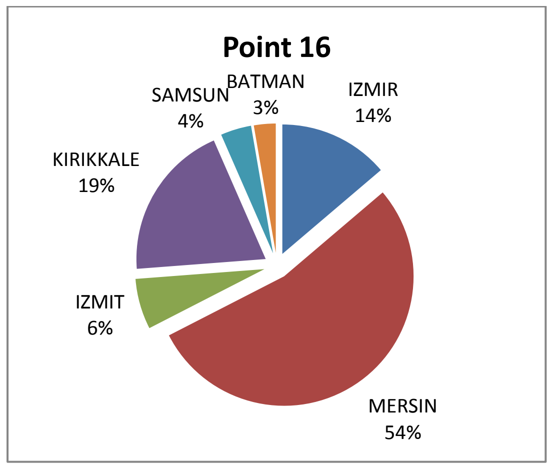

Point 11
BATMAN 3%
IZMIR 27%
MERSIN 40%
IZMIT 6%
KIRIKKALE 19%
SAMSUN 5%


Point 12
BATMAN 3%
IZMIR 23%
MERSIN 44%
IZMIT 6%
KIRIKKALE 19%
SAMSUN 5%

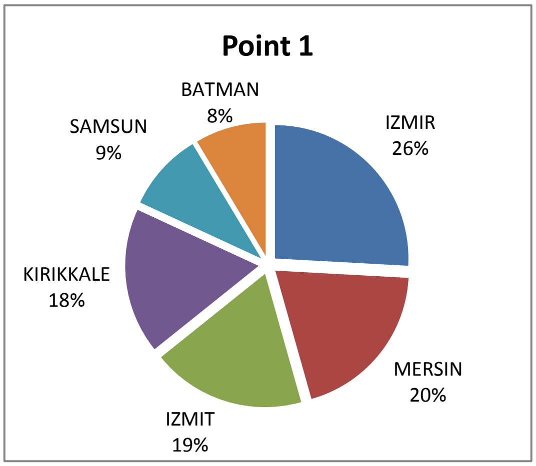

Point 13
BATMAN 3%
SAMSUN 5%
IZMIR 20%
KIRIKKALE 18%
IZMIT 6%
MERSIN 48%

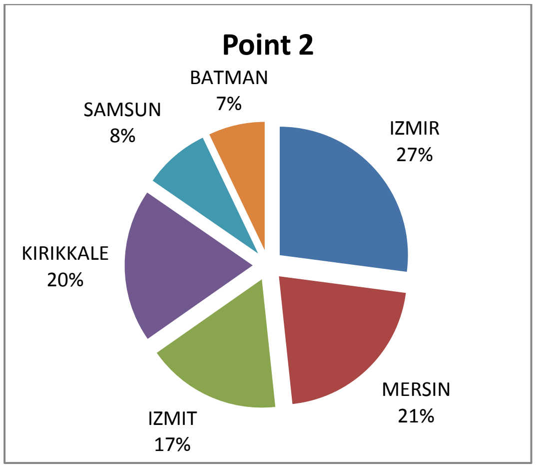

Point 14
BATMAN 3%
SAMSUN 5%
IZMIR 17%
KIRIKKALE 18%
IZMIT 6%
MERSIN 51%

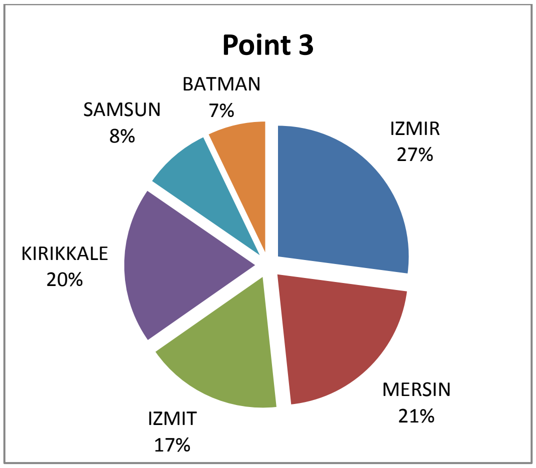

Point 15
BATMAN 3%
SAMSUN 4%
IZMIR 14%
KIRIKKALE 19%
IZMIT 6%
MERSIN 54%

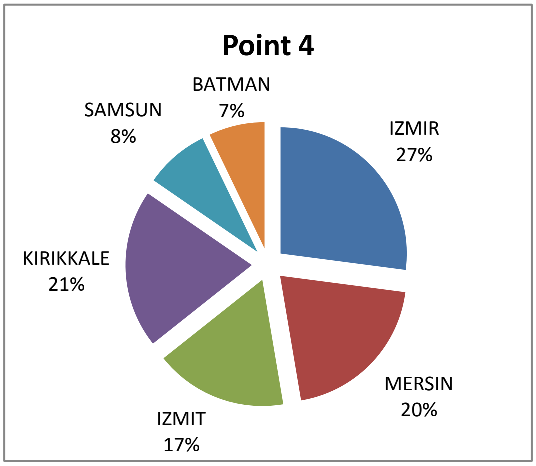

Point 16
BATMAN 3%
SAMSUN 4%
IZMIR 14%
KIRIKKALE 19%
IZMIT 6%
MERSIN 54%

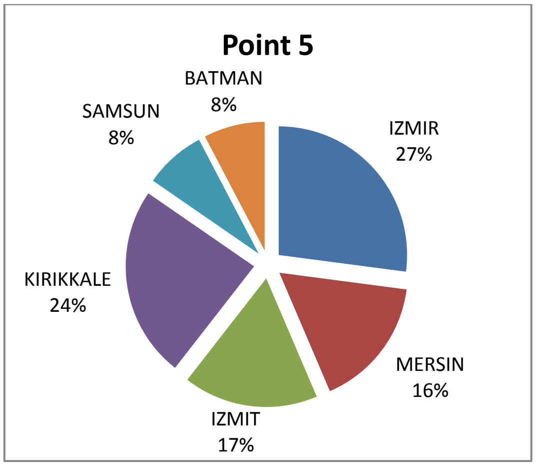
Appendix 7 Percentage Distributions of Suppliers of 16 Solutions of IMS_L

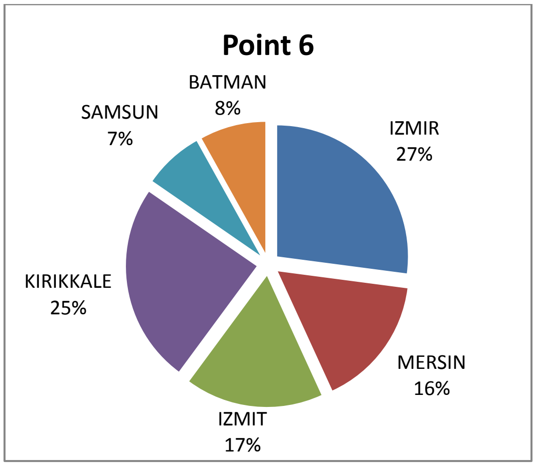


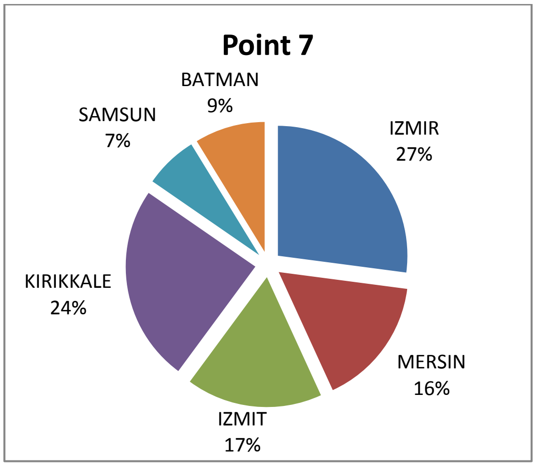


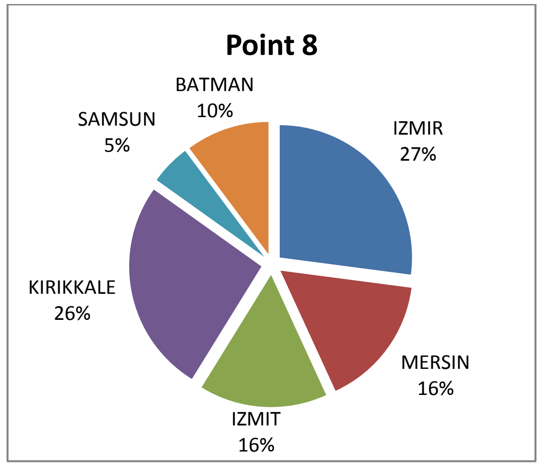


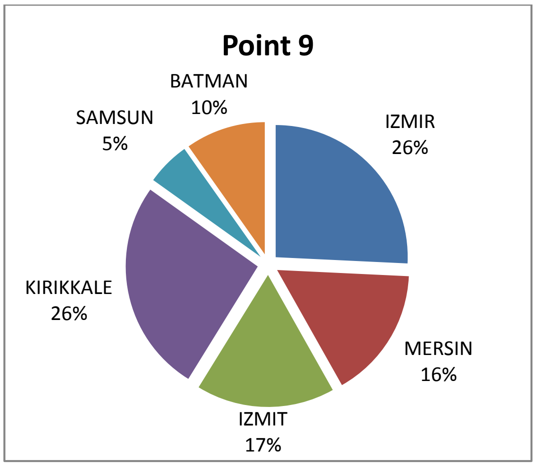


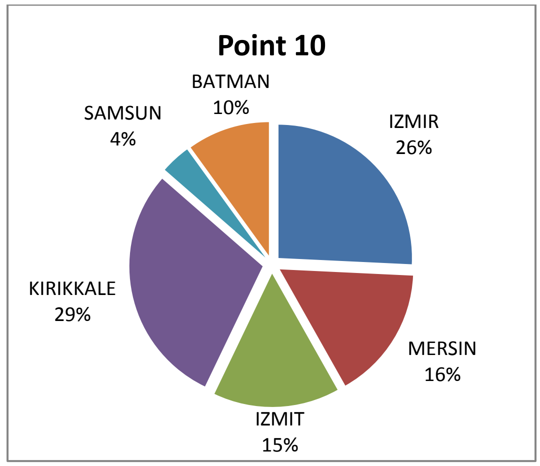


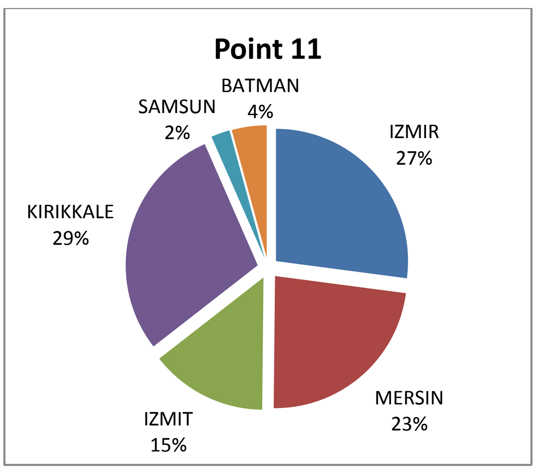


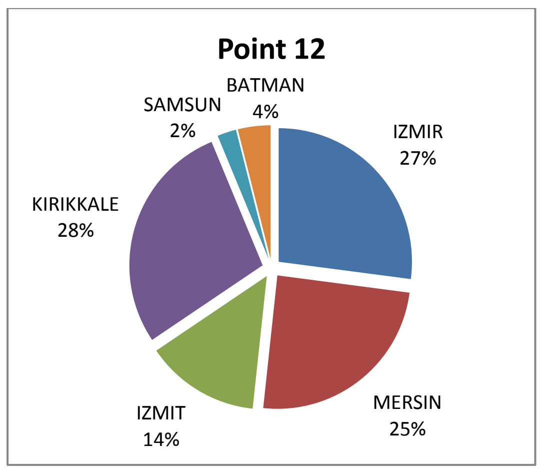

Point 7
BATMAN 9%
SAMSUN 7%
IZMIR 27%
KIRIKKALE 24%
MERSIN 16%
IZMIT 17%

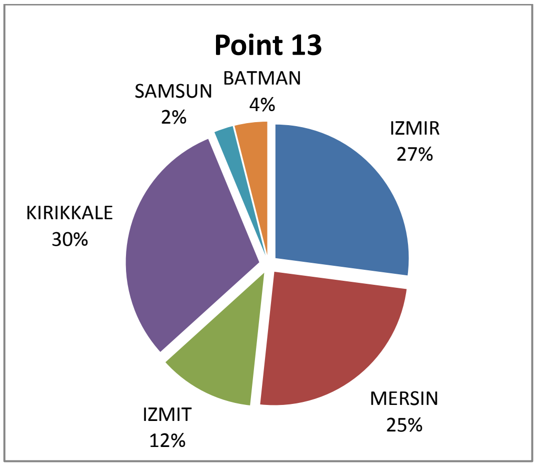

Point 8
BATMAN 10%
SAMSUN 5%
IZMIR 27%
KIRIKKALE 26%
MERSIN 16%
IZMIT 16%

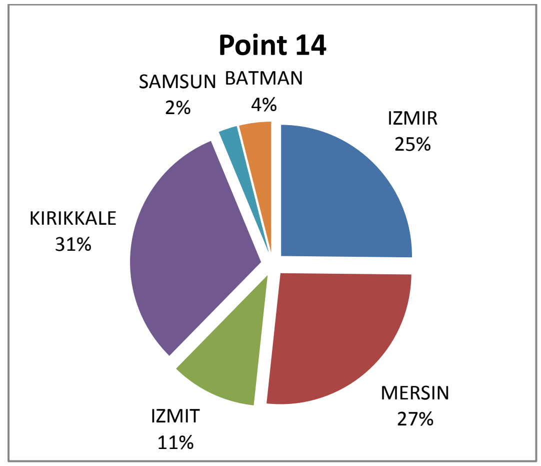

Point 9
BATMAN 10%
SAMSUN 5%
IZMIR 26%
KIRIKKALE 26%
MERSIN 16%
IZMIT 17%

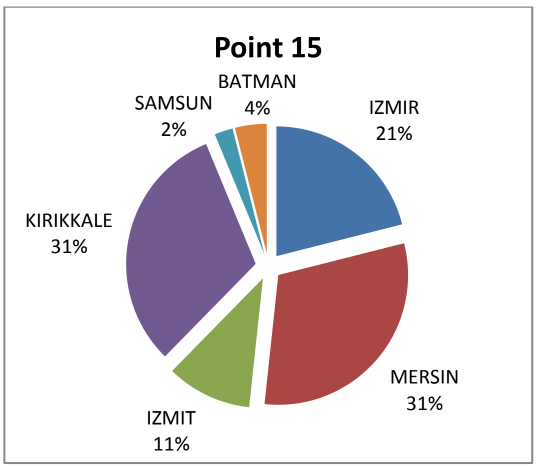

Point 10
BATMAN 10%
SAMSUN 4%
IZMIR 26%
KIRIKKALE 29%
MERSIN 16%
IZMIT 15%

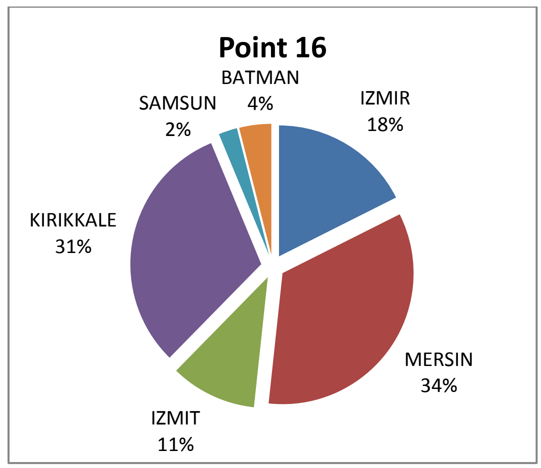

Point 11
BATMAN 4%
SAMSUN 2%
IZMIR 27%
KIRIKKALE 29%
MERSIN 23%
IZMIT 15%


Point 12
BATMAN 4%
SAMSUN 2%
IZMIR 27%
KIRIKKALE 28%
MERSIN 25%
IZMIT 14%


Point 13
SAMSUN 2%
BATMAN 4%
IZMIR 27%
KIRIKKALE 30%
MERSIN 25%
IZMIT 12%


Point 14
SAMSUN 2%
BATMAN 4%
IZMIR 25%
KIRIKKALE 31%
MERSIN 27%
IZMIT 11%


Point 15
SAMSUN 2%
BATMAN 4%
IZMIR 21%
KIRIKKALE 31%
MERSIN 31%
IZMIT 11%


Point 16
SAMSUN 2%
BATMAN 4%
IZMIR 18%
KIRIKKALE 31%
MERSIN 34%
IZMIT 11%