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MASTER THESIS

FREIGHT TRANSPORTATION IN TURKISH STATE RAILWAYS (TCDD) HIGH-SPEED TRAIN SYSTEM

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Title of the Thesis : FREIGHT TRANSPORTATION IN TURKISH STATE RAILWAYS (TCDD) HIGH-SPEED TRAIN SYSTEM

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ABSTRACT

FREIGHT TRANSPORTATION IN
TURKISH STATE RAILWAYS (TCDD)
HIGH-SPEED TRAIN SYSTEM

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The aim of this thesis is to improve the freight transportation system of Turkish State Railways (TCDD) by using high speed trains (HSTs) on high speed lines as a new concept. The development of railway and HST systems in the world and in Turkey is discussed and comparison of these systems with other transportation modes is investigated. Since HST is faster than trucks and cheaper than airlines for freight transportation and increases the utilization of railway system substantially, it is very advantageous. While HSTs are used for freight transportation in some countries such as France, Germany etc., they are not used currently for freight transportation in Turkey. Therefore, in this thesis, freight is added to the existing high speed rail system which is currently used for only passengers. A HST scheduling model is constructed to observe the effects of freight when it is included in the system. The aim of the model is to complete daily travel as early as possible within a day to increase utilization of the system. Daily travel of each train consists of sequence of cities and links between these cities. In experimental study, two types of sequence of cities are used: trips using one sequence of cities and trips using two sequences of cities. In the first type, all available trains are used to perform daily travels in one sequence of cities. Then for the second type, the linkage is divided into two and available trains are allocated to these separate two linkages. Freight transportation is also analyzed in two cases which are adding separate freight trains to the system and using the same trains with passengers for freight transportation. It can be concluded that dividing the sequence of cities into two provides the completion of the train services earlier in a day and using the same trains with passengers for freight transportation provides more time savings for the system. Freight transportation in HSTs is a complex task to achieve and requires many factors to be taken into account. This thesis is a first attempt to address this complex task.

Keywords: Freight Transportation, High Speed Rail, Scheduling, Mixed Traffic

ÖZ

TCDD YÜKSEK HIZLI TREN SİSTEMİNDE YÜK TAŞIMACILIĞI

KESKİN, Merve

Yüksek lisans, Endüstri Mühendisliği Anabilim Dalı

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Bu tezin amacı, Türkiye Cumhuriyeti Devlet Demiryolları'nın (TCDD) yük taşımacılığı sistemini yeni bir konsept olan yüksek hızlı hat üzerinde yüksek hızlı tren (YHT) kullanarak iyileştirmektir. Demiryolları ve YHT sistemlerinin dünyadaki ve Türkiye'deki gelişimi ele alındı ve bu sistemlerin diğer taşıma modları ile kıyaslaması yapıldı. Yük taşımacılığı perspektifinden bakıldığında, YHT kamyondan daha hızlı ve uçaktan daha ucuz olduğundan ve demiryolu sisteminin kapasite kullanımını artırdığı için oldukça avantajlı olduğu söylenebilir. YHT'ler yük taşımacılığı için Fransa, Almanya gibi bazı ülkelerde kullanıldığı halde, Türkiye'de günümüzde yük taşımacılığı için kullanılmamaktadır. Dolayısıyla, bu tezde, sadece yolcu taşımacılığı için kullanılan mevcut yüksek hızlı demiryolu sistemine yük dahil edilmiştir. Yükün sisteme dahil edildiğindeki etkisini gözlemlemek üzere bir YHT çizelgeleme modeli kurulmuştur. Modelin amacı, sistemin kapasite kullanımını artırmak amacıyla seferleri gün içinde mümkün olduğu kadar erken tamamlamaktır.

Trenlerin günlük seferi, bir dizi şehirden ve bu şehirlerarasındaki ayrıtlardan oluşmaktadır. Deneysel çalışmalarda, iki çeşit şehir dizisi kullanılmaktadır: sadece bir şehir dizisinden oluşan seferler ve iki farklı şehir dizisinde oluşan seferler. İlkinde, mevcut trenlerin hepsi bir şehir dizisinden oluşan günlük seferlerini gerçekleştirmede kullanılırlar. Daha sonra da, şehirleri bağlayan zincir ikiye bölünür ve mevcut trenler de oluşan iki ayrı zincire paylaştırılır. Yük taşımacılığı ayrıca iki operasyonel durumda incelendi. Bunlar, sisteme ayrı yük trenleri eklemek ve yük taşımacılığı için yolcularla aynı trenleri kullanmaktır. Varılan sonuç şudur ki, şehir dizisini ikiye bölmek gün içinde tren seferlerinin daha erken tamamlanmasını sağlar ve yük taşımacılığı için yolcularla aynı trenleri kullanmak sisteme daha çok zaman kazandıran bir yoldur. YHT'lerde yük taşımacılığı gerçekleştirilmesi zor bir iştir ve hesaba alınması gereken birçok faktör vardır. Bu tez, bu karmaşık işi ülkemizde gerçekleştirmeye yönelik ilk girişimdir.

Anahtar Kelimeler: Yük Taşımacılığı, Yüksek Hızlı Demiryolları, Tren Çizelgeleme Modeli, Karışık Trafik

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ABBREVIATIONS

A: Ankara

E: Eskişehir

İ: İstanbul

HSL: High Speed Line

HSR: High Speed Rail

HST: High Speed Train

K: Konya

S: Sivas

SCM: Supply Chain Management

TCDD: Turkish State Railways

TGV: Train à Grande Vitesse

TUBITAK: The Scientific and Technological Research Council of Turkey

INTRODUCTION

Supply Chain Management (SCM) is “the approach, in which the goods and services are used in the right place, in proper amounts, at the right time and through the appropriate system cost by combining suppliers, manufacturers, storages and stores effectively and at a minimum level” [1]. Another concept that is close to SCM is logistics. Logistics is the activity that facilitates the coordination of supply and demand while creating time and place benefit. In other words, it plans the flow of product, energy, information and other sources possible. However, what is important here is to manage it efficiently [2]. Logistics includes transportation, network design and inventory management.

SCM and logistics have different focus points. Logistics is related with integration of activities such as transportation, warehousing and clearance to transfer products to the place where they should be. SCM carries logistics a step further by organizing overall company activities and relationships with other companies of the chain [3].

As a part of logistics, the transportation can be done by highway, airway, railway, seaway. At the same time, multimodal transportation and intermodal transportation are the parts of transportation. Each mode serves for demands of freight and passenger traffic and has its own features and requirements. Highway means the transportation on road and it is essential in freight transportation especially. However, it causes more air pollution than any other modes. Airway means the transportation by planes and it is the fastest way of transportation but, it requires huge investment and it causes loss of goods or passengers in a case of accidents. Railway transportation is done by means of trains and it is the safest mode. Also, the capacity of trains is very large and it can be made larger by adding wagons. However, railway transportation requires a large investment and it also does not satisfy door to door service. Seaway transportation is achieved by ships. This transportation mode has a huge carrying capacity and consumes far less energy than other modes but, it has a very low speed and can be used if sufficient water is available. Moreover, there are two more types of transportation; intermodal and multimodal transportation. Intermodal transportation is "a logistic system which is connected to two or more modes. Each mode has a service characteristic which generally enables goods (or passengers) to move to another existing mode in one trip from origin to destination."[4]. Multimodal transportation is "a set of transport modes which provide connection from origin to destination. Even if intermodal transportation can be applied, this is not compulsory." [4].

Of these transportation modes, railway will be focused on in this thesis. Railway is ideal for very heavy and low-value shipments and for the shipments which are not time sensitive. It is more advantageous than other transportation modes when environmental effects and vulnerability to weather conditions are considered.

Trains basically are divided into two types; conventional trains and high speed trains (HST). The concept of 'HST' is also described as a rapidly developing new transportation mode. It is developed basically because of the need for increasing railway capacity and reducing travel times. Then, HST has become a competitive transportation mode since it meets these requirements. At the present day, HST is used in France, Germany, Spain, Italy, Japan, China, South Korea, Belgium, The Netherlands, United Kingdom, USA and Turkey [5]. Among these countries, Japan is the first country which used HST. In 1964, construction of Tokaido Shinkansen high speed line (HSL) between Tokyo and Osaka was completed and now it is the busiest line in the world. France is the second country which used HST. In 1967, they did the first test drive and TGV (Train à Grande Vitesse) went into service between Paris and Lyon in 1981 [6].

In Turkey, HSTs ("Yüksek Hızlı Tren" in Turkish), having the latest technology, can reach the speed of 250 km per hour. On 13/03/2009, the first HST service started officially between Ankara and Eskişehir. Then, on 21/08/2011, HST service started between Ankara and Konya [6]. Also, lines between Eskişehir - İstanbul and Ankara– Sivas are in process of construction. Preliminary planning was made for Ankara-İzmir, Halkalı - Bulgaria and Sivas-Erzincan, Erzurum - Kars lines [7].

As a new concept and future transportation mode, freight transportation in HST comes to mind. Freight transportation in HST is not widespread around the world and it is not an easy job since it requires further effort to handle operation times of freight and passenger traffic, to determine standard speed, weight of freight and the way of transporting freight, etc. In the world, TGV postal HST of France can be given as an example of freight transportation in HSTs and this train can reach the maximum speed of 270 km per hour.

In Turkey, while conventional trains are used to transport both passengers and freight, HSTs are used to transport only passengers. The concept of high speed rail (HSR) has been associated with passenger transportation and freight transportation has been performed on conventional lines and by using conventional trains up to now.

Turkish State Railways (TCDD) observes some problems in the system such as lack of operating freight trains and delay of delivering freights to customers. It is clear that these problems reduce the frequency of preferring railway mode for freight transportation. Thus, TCDD searches for a solution to eliminate problems related to freight transportation and tries to improve the system.

Freight transportation in HSR is considered as a solution by TCDD nowadays. Therefore, the aim of this study, which is on freight transportation in HSR, is to contribute to solution of their problems. This means that this study is not only pioneering in the field but also very necessary to address their problems.

In general, four different cases exist to operate freight trains in terms of rail and train types. The types are shown in Table1. The one on which this study focuses is freight transportation by HST on HSLs and this combination will be analyzed for the lines currently in operation (Ankara-Eskişehir, Ankara-Konya) and in construction (Eskişehir-İstanbul, Ankara-Sivas).

Table 1: Different cases in terms of rail and train types to operate freight trains

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">LINE</td></tr>
<tr><td>HIGH SPEED</td><td>CONVENTIONAL</td></tr>
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A
I
N</td><td>HIGH SPEED</td><td>Freight transportation by HST on HSLs</td><td>Freight transportation by HST on conventional lines</td></tr>
<tr><td>CONVENTIONAL</td><td>Freight transportation by conventional train on HSLs</td><td>Freight transportation by conventional train on conventional lines</td></tr>
</table>

To achieve freight transportation on HSLs and HSTs, there are many important factors to be considered. These are:

- ✓ Capacity: Transportation can be performed in conformity with capacity of lines. It must be determined that whether there is available space to load freight to HSTs which have been used for passengers up to now or not. Thus, number of trains necessary to transport freight can be calculated.
- ✓ Speed: The pressure that will be applied to the line because of weight will be different for freight transportation in comparison with passenger transportation. So, to not damage the line, speed of train must be determined.
- ✓ Time-table: Construction of a time-table will be needed since both passengers and freights will be transported on the same lines (mixed traffic). So, the list of trains that will transport freight can be determined.
- ✓ The way of transporting the freight: Density of lines must be considered and whether the freight will be transported with passengers in the same trains or will be transported with separate HSTs must be analyzed.

As it can be seen, it is a complex system that requires simultaneous analysis of the effects of these factors to the system. Thus, the objective of this thesis is to investigate the factors that influence the efficiency of HSTs such as time-table of freight and passenger traffic, standard speed, weight of freight and the way of transporting freight using Operations Research techniques.

This thesis is organized as follows. Chapter 1 introduces development of railway and HSTs in the world, advantages of railway and comparison of HSTs with other transportation modes. In Chapter 2, development of railway and HST in Turkey is analyzed in detail. Then, modeling starts with Chapter 3. In this chapter, literature survey about train scheduling is given and mixed traffic concept in HSLs is discussed. After these explanations, the model is introduced. HST scheduling problem for freight transportation is solved by using GAMS. In Chapter 4, experimental study is done.

CHAPTER I

1. DEVELOPMENT OF RAILWAY AND HSR IN THE WORLD

1.1. DEVELOPMENT OF RAILWAY IN THE WORLD

A railway is defined as an engineered structure consisting of two metal guiding rails on which cars are self-propelled or pulled by a locomotive [8] and it is a long hauler and slow mover of raw materials (coal, lumber and chemicals) and of low-valued manufactured products (food, paper, and wood products) and prefers to move shipment sizes of at least a full carload [9].

Railways became essential in tying the older eastern population and industrial centers together, and have provided reliable, rapid and economic transportation. There has been great growth in every respect since the first railways [8]. The first steam driven locomotives were constructed after invention of steam engine in 1785. Rail traffic increased in freight transportation in the first decades of nineteenth century and then, passenger transportation started on European railways in the 1830's [10].

Detailed plans for the schedules of public transportation were started to develop with definition of the routes and lines of railway network. Regular services had to be guaranteed to attract customers. The problems such as assignment of locomotives, personnel have started to occur. Long distance railways were introduced such as "Orient Express" from Paris to İstanbul, the "Golden Flyer" from London to Paris, and the "Train Blue" from Paris southbound to the Cote d'Azur. These stations were starting points for connections to minor centers. The huge railway network over Europe existed in spite of lack of systematic planning and optimization at European level [10].

In North America, the first construction of transcontinental railway connection was completed in Utah by 1869. The Canadian Pacific completed the first single company transcontinental line by 1885 and the Atlantic and Pacific were linked in Mexico [8].

In the 20th century, diesel-electric locomotives were built. Diesel-electric locomotives are described as electric locomotives with an on-board generator powered by a diesel engine. The first diesel locomotives were low-powered machines, diesel- mechanical types used in switching yards. Diesel and electric locomotives are cleaner, more efficient, and require less maintenance than steam locomotives. Their introduction reduced the power of railway unions in the United States. After working with technical difficulties in the early 1900s, diesel locomotives (first introduced in Canada in 1926) became mainstream after World War II. By the 1970s, diesel and electric power had replaced steam power in the world on a large scale [11].

In the 21st century, railway systems must overcome environmental problems and while doing this; it also must provide a high quality service and reduce their fixed costs and operating costs. By 2000, Acela Express was introduced on Northeast Corridor in the United States and in 2001, "Northeast China opened first electrified railway for business between Shenyang and Harbin."[12].

1.2. CHARACTERISTICS OF RAILWAY TRANSPORTATION

Railway transportation is accepted as the most economic mode for freight transportation on land, when long distances are considered, especially for raw materials [13]. Railways offer "expedited service to guarantee arrival within a certain number of hours; various stop-off privileges, which permit partial loading and unloading between origin and destination points; pickup and delivery; and diversion and re-consignment, which allow circuitous routing and changes in the final destination of a shipment while en route." [9].

In spite of high maintenance costs, operating costs of railway transportation are very low when compared to the other transportation modes. Therefore, especially for long distances, it is an economic and safe mode. Railway transportation is essential to denote the differences between countries in terms of development and it is generally operated by governments.

Because of low velocity, travel time by rail can be long so, railway is “ideal for very heavy, low-value shipments that are not very time sensitive. Coal, for example, is a major part of each railroad’s shipments. Small, time-sensitive, short-distance or short-lead-time shipments rarely go by rail.” [14].

Railway reduces the traffic load of highways and if transportation of freight by trucks and tractor trailers is mentioned, it is more advantageous than highway in terms of travel time. Also, reducing the traffic load in roads results in less air, water, noise and land pollution. When compared to highways, railways are less affected by climate conditions and need less land to construct. At the same time, investment for highway is more expensive than investment for train line.

Finally, railway consumes less energy in freight and passenger transportation than all other transportation modes. It also causes less environmental pollution and less overall cost.

1.3. DEVELOPMENT OF HSR IN THE WORLD

1.3.1. HSR IN PASSENGER TRANSPORTATION

Nowadays, railways are passing through an important technical progress to keep up with the system that globalization created. Reconstruction works have been going on for nearly all of the railways in the world.

HSR is gaining popularity in the world day after day. Many countries have been extending their rail networks and have been planning construction of new lines. The main reason of the coming up and becoming widespread of HSTs is environmental pollution and energy saving. Worth of HSTs is going up since they can transport more load in a shorter time and in a cheaper and safer way; so they are exact solution to the problems of intercity and international transportation. For intercity and international travels, whether the cities or countries are developed or not, traffic jam is decreasing day by day due to HSTs.

Furthermore, there are some challenges in the development of HSTs. They are “to develop a train and track that could maintain stability and the comfort of passengers (while the train is running at high speed), maintain the ability to stop safely, avoid a sharp increase in (train) operating costs and (track) maintenance costs, and avoid an increase in noise and vibration to areas adjacent to the line.” [15]. The data about HSR in the most related countries is given in Table 2.

Table 2: Information about HSR in the most related countries [16,17].

	The First Operation Year of HST	Total Length of HSLs (km)	Population of the Country
Japan	1964	2664 km	128 million
France	1981	2036 km	63 million
Italy	1981	923 km	60 million
Germany	1988	1334 km	82 million
Spain	1992	2144 km	46 million
Belgium	1997	209 km	11 million
United Kingdom	2003	113 km	62 million
Korea	2004	412 km	49 million
China	2008	6403 km	1.3 billion
The Netherlands	2009	120 km	17 million
Turkey	2009	447 km	74 million

In Table 2, the countries are examined in order of the date of first operation of HSTs and, total length of HSLs and population of the countries are also given.

Japan is a densely populated country and was the first to operate HSTs in the world. In 1964, HST passenger service was started between Tokyo and Osaka [16]. Today, Japan operates HSTs on a high speed network with a length of 2,664 kilometers including the new line to Shin Yatsushiro [17]. Many lines are also under construction and in the planning stage.

France is the second country that passes to HSR system in the world and is a leader in the world. "The French TGV began operation in 1981 and speed record for a 'steel wheel on steel rail' train of 515 kph was achieved in 1990 by a French TGV HST." [15]. Figure 1 belongs to the French TGV.

Figure 1: The French TGV (Train à Grande Vitesse)

The population of France is roughly 63 million people living evenly spread in the country. Paris can be the centre of the high speed network [16]. The overall length of the HS network currently amounts to 2,036 kilometers. Also, further projects are under construction[17].

China has the longest HSL in the world. Today, the overall length is about 6,403 kilometers [17]. The first operation was in 2008 between Jianan and Quingdao or Beijing and Tianjing [16].

Germany also is experienced in HSTs. The first operation was started in 1988 between Fulda and Würzburg [16]. Later, different sections such as Berlin – Hamburg, Nürenberg – Ingolstadt as well as München – Augsburg were commissioned in recent years. The extent of the network amounts to 1,334 kilometers as of today. In addition, new sections are in the planning stage as well as under construction [17].

Korea has a population of 49 million as given in Table 2. Korea has a small HSR network with only two lines in operation. They are between Seoul and Daegu, which was opened in 2004, and between Daegu – Pusan, which was opened in 2010. The total length of the lines amounts to 412 [17].

Spain had the first HST operation in 1992 via Puertollano and Ciudad Real and has 46 million population [16]. The overall length of the network in operation amounts to 2,144 kilometers in 2012. In addition, many kilometers are under construction or planned [17].

The United Kingdom (UK) has the network length that amounts to 113 kilometers and the first operation started in 2003 as given in Table 2.

Italy also had the first HST experience between Rome and Florence in 1981 and the population of the country amounts to approximately 60 million [16]. Now, the overall length of the line became 923 kilometers with the construction of last line between Naples – Salerno in 2009 [17].

Belgium, which has a population of about 11 million, started operation between Brussels and the French border in 1997. The country has a network consisting of 209 km [16].

The Netherlands has HSL from Schiphol via Rotterdam to the Belgian Border, which was commissioned in 2009. When population of 17 million is considered, it can be thought as a densely populated country and has 120 km line [16].

Moreover, Poland, Portugal, Russia, Sweden, Switzerland are other countries which have HSLs in Europe.

India, Saudi Arabia and Turkey are other countries which have HSLs in Asia. Also, other HSR system exists in USA, has been planned in Brazil and is under construction in Morocco in the world [17]. Figure 2 represents HSR systems forecasted for 2025.

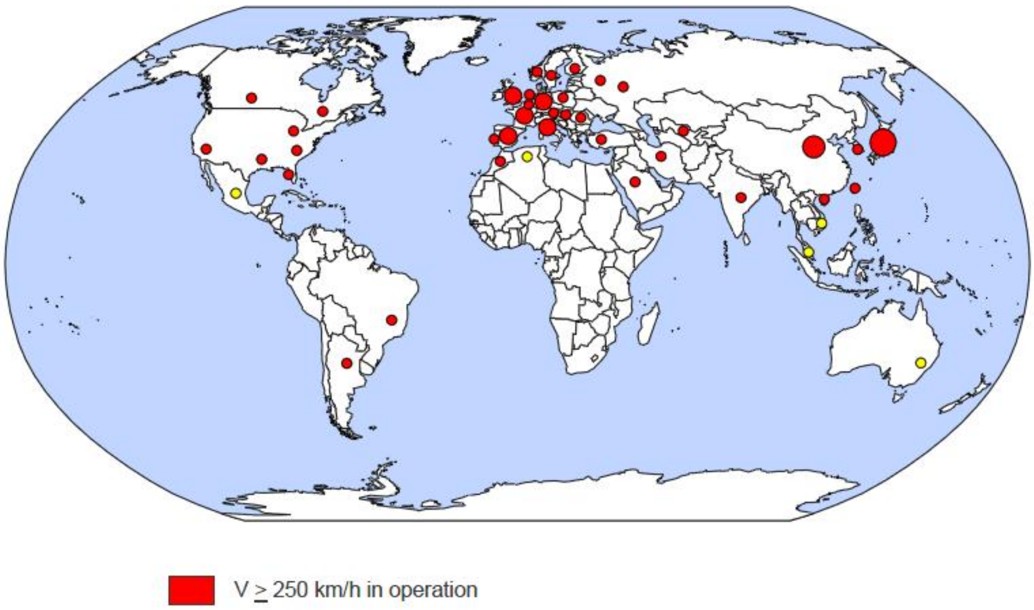

Figure 2: HSR systems forecast in 2025 [18]

HSLs which are in operation, under construction and planned in the world are given [17].

1.3.2. HSR IN FREIGHT TRANSPORTATION

HSRs are not only used by passengers but also they are used to transport freight. HSR for freight transportation marks the market of mail and express freight. The market of HSR is small but it is growing fast. The idea behind HSTs for freight transportation is that they are cheaper than airway transportation and faster than highway transportation.

HSR for freight can reduce the freight traffic of highway, so a national HSR network is important for countries. By constructing HSR network, negative impact such as delays and cost of highway traffic can be notably decayed. Moreover, this traffic is increasing day after day because of the increase of driver population.

There are different types of HST concepts for freight distribution from single wagons to freight multiple units. Passenger train technology is used for these types, some vehicles are even directly derived from passenger trains such as French TGV Postal which is the fastest freight train in the world with speed of 270 km/h since 1980-ies [19]. The HST types for freight transportation in the world are given below:

- TGV Postal Trains: This type of trains is used to carry mail between Paris and Lyon in France since 1984. “A total of 7 half-sets are available to the service. Two half-sets coupled together make up a full train consisting of 2 motor units and 8 freight cars. A full TGV Postal train can thus – unlike the TGV passenger trains – be split in the middle, which makes maintenance easier and reduces the need to hold trains in reserve.” [19]. The capacity of each TGV train is 75 tons. The capacity of the train can be increased by adding a half set into service. Energy consumed per ton on the Paris- Lyon line is 0.02 TEP (tonneéquivalentpétrole). The doors in the middle of the wagons are used to load and unload the freight and 30 containers can be loaded to each of the wagons [19].
- Freight Version of the ICE Trains: These trains are introduced at the beginning of the 1990’s. A possible pilot route was the Hamburg- Munich route in Germany. Mail is the basic load to transport for them. “The train would consist of 6-12 freight cars plus motor units. The vehicles are based on the ICE1 passenger trains. Each car would have a loading capacity of between 36 and 40 wheeled bins, giving a load weight of between 12.2 and 13.6 tons and a payload of approximately 8 tons per car. The axle load would then be a non-critical 12-13 tons, and thus lower than for the passenger coaches.” [19] Roller shutters exist along the whole length of the load area on wagons to load and unload the freight quickly. Therefore, the wheeled bins do not need to be moved [19].
- CargoSprinter: The German CargoSprinter is used to transport containers and contains two end wagons. These wagons are powered by two 265 kW diesel-engines and unpowered intermediate wagons. There are two versions of these trains. They are Windhoff version which has three two-axle intermediate wagons and Talbot version which has three (Jacobs-) bogie wagons. The units are equipped with automatic couplers to enable faster coupling and uncoupling [19].

- Postal Railcar Class 325 Royal Mail: British Royal Mail invested into new Freight Electrical Multiple Units, the Class 325 in 1996. "Royal Mail invested into new Freight Electrical Multiple Units, the Class 325. The Class 325 mail train multiple units are 4-car units with a length of 84 meters. Up to four units can be coupled. The trains can operate on 25 kV alternating current under live catenary and 750 V direct current supplied through a conductor rail with automatic system switching along the way. The trains can also be hauled by locomotives on non-electrified routes." [19]. These trains can reach the speed of 160 km/h and 400 tons can be loaded to each unit. Each wagon has two roller shutter doors on both sides. Crossing between wagons is impossible and the doors of wagons have security locks. Lighting, the door-opening mechanism and safety equipment are provided by generators and batteries, and external power source does not exist in the trains. At the same time, the floors are non-slip. These trains can be rebuilt into a passenger train if they are not used for mail services anymore [19].
- Green Cargo "B-mail" Wagon: This type of wagon belongs to Sweden. "In order to replace older class DV30 mail vans SJ decided in 1999 to purchase new wagons. As the class DV30 the new wagons of class Gblss-y are based on standard two-axle freight wagons which were modified. The running gear of type TF25SA, developed by Powell Duffryn, allows an increased maximum speed of 160 km/h and the wagons are today the world's fastest two-axle freight wagons in regular service. 70 wagons were built by TGOJ Eskilstuna and put into service under 2000 and 2001. Test runs showed very good running behavior up to 180 km/h. The wagons are today mainly deployed on the lines from Stockholm to Gothenburg, Malmö and Sundsvall." [19].
- DB Inter-Cargo-Express Container Wagon: German railway operator DB purchased bogie-container wagons in 1991 and they could reach the speed of 160 km/h. For security of loading units, automatically vertical-locking container pins of Buffers Inc. existed in wagons. The Talbot-bogies had type DRRS with disc-brakes; each bogie counted 6 brake-cylinders [19].

The operational issue about HSTs is coordination of freight traffic and passenger traffic in railway stations. Indeed, the problem can also occur with conventional (slow) freight traffic instead of passenger traffic. Timetabling and capacity problems rise and this situation affects the service quality.

Today, loading/unloading of courier goods, which is carried onboard of passenger trains, is done at passenger stations. These stations are used for transshipment of letter and parcel mail and can be used without bigger adaptations. Because, item sizes are very small. At the same time, courier goods have advantage since location of passenger stations is in the city centers.

Passenger stations have also been used for mail services for a long time. Mail offices have been located close to stations and passenger trains moved together with mail wagons. Infrastructure work for mail loading/unloading has been done. Platforms were connected with mail terminals by means of tunnels and elevators [19].HSLs for passenger and freight transportation in 2001 are given in the following Table 3.

Table 3: HSLs for passenger and freight transportation in 2001 [20]

Passengers + freight	* Trains designed specifically for passengers * Conventional locomotive-hauled passenger trains * Conventional locomotive-hauled freight trains **(T_3)**	$V_{máx}$= 250/300 km/h P= 16/17 t axleload $V_{máx}$= 160/220 km/h Locomotive : 20/22 t axleload Coachess : 12 à 14 t axleload $V_{máx}$= 100/160 km/h Locomotive : 20/22 t axleload Wagons : 16 à 20 t axleload	**In commercial service** * Hanover - Würzburg * Mannheim - Stuttgart * Hanover – Berlin * Rome - Florence **Planned in the short term** * Karlsruhe – Basle * Florence – Milan * Barcelona – French border
	* Trains designed specifically for passengers * Conventional locomotive-hauled freight trains **(T_4)**	$V_{máx}$= 250/300 km/h P= 16/17 t axleload $V_{máx}$= 160/200 km/h Locomotive : 20/22 t axleload Wagons : 16 t axleload	Certain sections of the Paris-Lyons line and the TGV Atlantique (since October 1997)

1.3.3. COMPARISON OF HSR WITH OTHER TRANSPORTATION MODES

HSR is essential when time-sensitive shipments are done. The inspiring point for this study is comparing it with trucks and airlines. That is, HSR for transporting freight is faster than trucks and cheaper than airlines. Therefore, it seems very reasonable to choose HSR.

HSRs are environmental friendly and have high capacity as much as high safety. They travel with a high level of speed, benefit a short travel time from door to door and work almost in every weather condition. HSRs have a higher level of comfort in terms of space, accelerations, noise, light than the plane, bus, or an average car [21].

HSTs have high energy efficiency since they do not create noise very much and their motors do not get heated very much. Namely, the energy used by these motors is not wasted substantially. 40% or 60% percent of energy provides movement of the trains. However, for planes, this rate is 10% [22].

Time is a crucial factor for HSTs since delays are not accepted. For instance, average delay time of trains in Japan is only 24 seconds. When distances between 400-800 kilometers are considered, there are no rivals for HSTs. Planes are thought as the fastest transportation vehicle but, airports are commonly outside the city centers since they require big areas to be built. While it takes thirty minutes on average to reach to airports, it takes much less time to get to train stations since they are built in city centers [22].

Pricing is another important factor to compare transportation modes. Planes are too costly since they consume much fuel and require huge airports. Operating costs of them are twice of cost of HSTs [22].

Safety and reduction of traffic accidents are also significant. When number of travels is thought, the risk of accident ending up with death for highway is 125 fold of HSR. Also, when distance traveled is considered, the safety of HSR is 40 fold of highway [23].

In summary, HSR systems increase railway capacity and reduce travel times substantially. These advantages advance the competitiveness of HSTs and divert people from conventional train to HST. Especially, for long distances between cities, HST is a requirement.

1.3.4. COMPARISON OF HSR WITH CONVENTIONAL RAILS

There are lots of properties that differentiate HSR from conventional rails. Distinguishing properties of HSR are as follows:

- Grade crossing does not exist along HSLs. They generally cause accidents in rail lines. For the lines that exceed speed of 140 km/h, grade crossings are forbidden.
- HSLs are surrounded with wire barriers and walls to eliminate risk of passing of people and animals.
- Infrastructure of HSLs has much more quality than conventional lines. High technology and international standards are used for materials.
- Distance between coming and going lines is wide. That is important since speed difference is 600 km/h when two HSTs in opposite direction pass each other side by side. This situation creates a huge differential pressure. To eliminate this differential pressure, the distance between lines is much more than conventional lines.
- Tunnels are built in such a way that they can eliminate high pressure that bidirectional high speeds create. Fire and ventilation systems exist in these tunnels [22].

CHAPTER II

2. DEVELOPMENT OF RAILWAY AND HSR IN TURKEY

2.1. DEVELOPMENT OF RAILWAY IN TURKEY

Railway development can be divided into three periods such as Pre-Republic period, Republic period (1923-1950 Period), and the period after 1950.Pre-republic period is the beginning of the Turkish railway history. The first railway line was constructed between İzmir and Aydın in 1856 and it was laid by a British company under the privilege granted to this company. The construction was completed in 1866. The reasons of selection of İzmir-Aydın region were that this region was “more populated than other regions, had higher commercial potential, hosted different ethnic elements suitable for becoming a market for British products, and had an easy access to raw materials. Besides, it had a strategic position for controlling Indian routes by dominating the Middle-East.” [24]. Britain, France and Germany were granted privileges in the field of railways by the Ottomans and had separate zones of influence in the territory of the Ottoman Empire. These countries constructed railways which became the most significant transportation mode with the industrial revolution to transport agricultural products to their countries. Therefore, the railways were shaped according to the economic and political goals of these countries [24].

“Between 1856 and 1922 following lines were constructed in the territory of Ottoman Empire totaling 8619 km:
Rumelia Railways: 2383 km standard gauge lines;
Anatolia - Baghdad Railways: 2424 km standard gauge lines;
Izmir - Kasaba and its extensions: 695 km standard gauge lines;
Izmir -Aydin and its branches: 610 km standard gauge lines;

Damascus - Hama and its extensions: 498 km narrow and standard gauge lines;
Jaffa - Jerusalem: 86 km standard gauge lines;
Bursa - Mudanya 42 km narrow lines; and
Ankara - Yahsihan 80 km narrow lines.[24]"

"In conclusion, a part of 4.000 km of the railways constructed by different foreign companies during the Pre-Republic period remained within the national borders that were determined with the proclamation of Republic. Young Republic received a legacy from Ottoman Empire a standard gauge line of 2.282 km and narrow line of 70 km that was owned by foreign companies and a standard gauge line of 1.378 km that was under the control of the State." [24].

In the Pre-Republic period, 70% of the lines were in the west of Ankara - Konya, after the Republic 78.6% were constructed in the east. Post-Republic period is divided into two; railways predomination period (1923-1950) and road predomination period (after 1950). In railways predomination period, the railways were constructed to serve national interests during the Post-Republic period and creating a self-sufficient national economy was aimed. In this period, basic industries such as iron & steel, coal, and machinery in the 1st and 2nd Five-Year Industrialization Plans which were prepared between 1932 and 1936 had priority. Transporting them in the cheapest way was aimed so, the railway lines were oriented towards national resources and establishing the locations during the process of national industrialization was based on railway lines [24].

Construction and operation of railways were driven successfully in this period. Although there was a shortage in these years, the progress of construction was very fast and the railway line of 3.208 km was built before 1940. Between 1940 and 1950, the constructions slowed down because of Second World War [24].

Railway transportation policy was divided into two phases. In the first phase, although there were serious financial challenges, railway lines that foreign companies owned were expropriated and some of them were taken over. In the second phase, connecting the Central and Eastern regions of the country to the centers and coasts was aimed. Because, many of existing lines were gathered in the

Western region. For that purpose, main lines were routed to guarantee the direct connection of lines to production centers. In this period, the main routes were Ankara-Kayseri-Sivas, Sivas-Erzurum (Caucasus line), Samsun-Kalin (Sivas), Irmak-Filyos (Zonguldak coal line), Adana-Fevzipaşa-Diyarbakir (Copper line), and Sivas-Çetinkaya (Iron line) [24].

Furthermore, the construction of junction lines which connected mainlines with each other was focused on between 1935 and 1945. That was significant in terms of national security. "Railways in the shape of a web in the early years of Republic gained two loops between Manisa-Balıkesir-Kütahya-Afyon and Eskişehir-Ankara-Kayseri-Kardesgedigi-Afyon in 1935. Moreover, Izmir-Denizli-Karakuyu-Afyon-Manisa and Kayseri-Kardesgedigi-Adana-Narli-Malatya-Çetinkaya loops were also attained. These loops were created by means of junction lines." [24].

After 1950, road predomination period starts. The Ottoman Empire left behind 18.355 km roads. 13.885 km of these roads were damaged surface narrow paved roads and 4.450 km were unimproved roads. Road predomination period was golden age of road and has the terms First Leap Term (1950-1963), Planned Leap Term (1963-1980), Transportation Master Plan Term (1983-1993), and Highways Term (1986-…). In this period, road constructions were started with Marshall aid and share of railways among transportation systems decreased slowly. After 1960, the aims for railways could not be achieved. It was planned to do new arrangements, modernization works, and investments on the railways since transportation needs of industry increased. However, this was never achieved. As a result, only 30 km of railways were constructed annually between 1950 and 1980 [24].

In the middle of 1980s, highway construction accelerated and up to the end of 1990s, nearly 2 billion dollars of investment was made annually. However, no project was applied for railways. Between 1983 and 1993, improving transportation system and decreasing the share of highways from 72% to 36% were aimed but, this plan was not performed. As a result, since 1950s, "the length of roads increased 80% between 1950 and 1997, but the length of railways increased by only 11%. As for the investment shares among the transportation sectors; while road got a share of 50% and railways got 30%, the share of the latter since 1985 has been below 10%." [24].

Between 1950 and 2003, only 1.700 km of new line was built. After 2003, railways again became primary sector and investment increased by almost eight-fold. With these investments, the railway sector started to reach success. Figure 3 [25] shows amounts of investments made between 2003 and 2011.

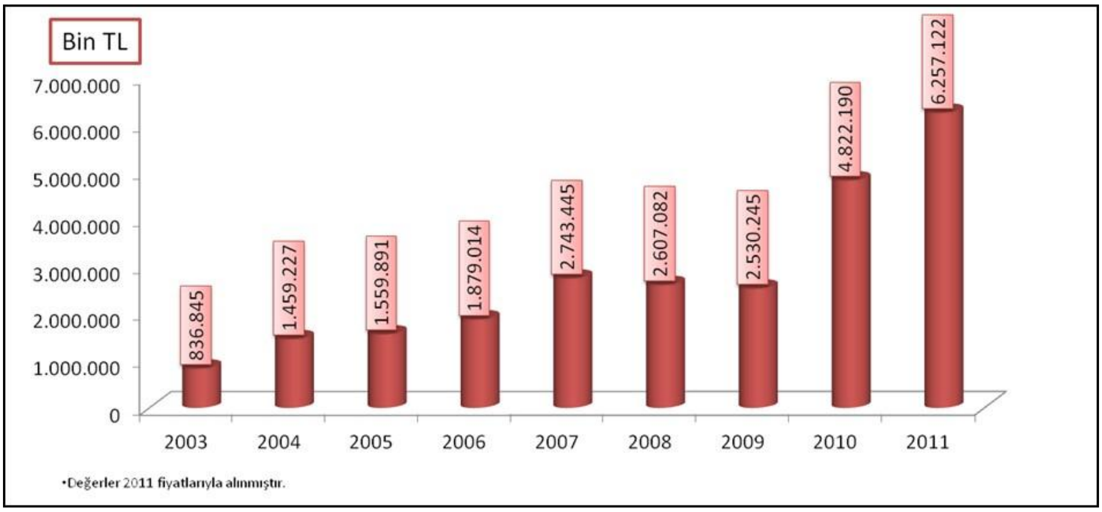

Figure 3: Amounts of investments made in TCDD between 2003 and 2011

Today, total length of railways is 10.992 km and 8.697 of this length is main track, with sidelines (junction lines within Organized Industrial Zones included). Turkey aims to enlarge its railway route and will be the heart of railway transport [25].

TCDD achieves passenger transportation to Europe and the Middle East as well as achieving it domestically. Figure 4 is a view from the TCDD station in Ankara.

Figure 4: A view from the TCDD station in Ankara

Beside passenger transportation, freight transportation is also significant for TCDD. It is possible to achieve freight transportation to European countries such as Serbia, Poland, Bulgaria, Romania, Czech Republic, Hungary, Slovakia, Macedonia, England, Spain, Yugoslavia, Greece, Sweden, Norway, Croatia, Slovenia, Germany, Austria, Luxembourg, Italy, Netherlands, Switzerland, Denmark, France, Belgium and Bosnia and Herzegovina. At the same time, it is possible to carry out freight transportation by railway from Turkey to Iran, Syria and Iraq [26].

"Container train runs were started between Istanbul (Haydarpaşa)-Tehran-Tashkent-Almaty (Kazakhstan) and Istanbul (Haydarpaşa)-Turkmenistan as a result of the studies carried out collectively with the railway administrations on South Eurasia Corridor (Turkey, Iran, Turkmenistan, Uzbekistan, Tajikistan, Kyrgyzstan, Kazakhstan) that are under the umbrella of Economic Cooperation Organization (ECO)." [26]. Figure 5 represents amount of freight transported versus years between 1930 and 2011.

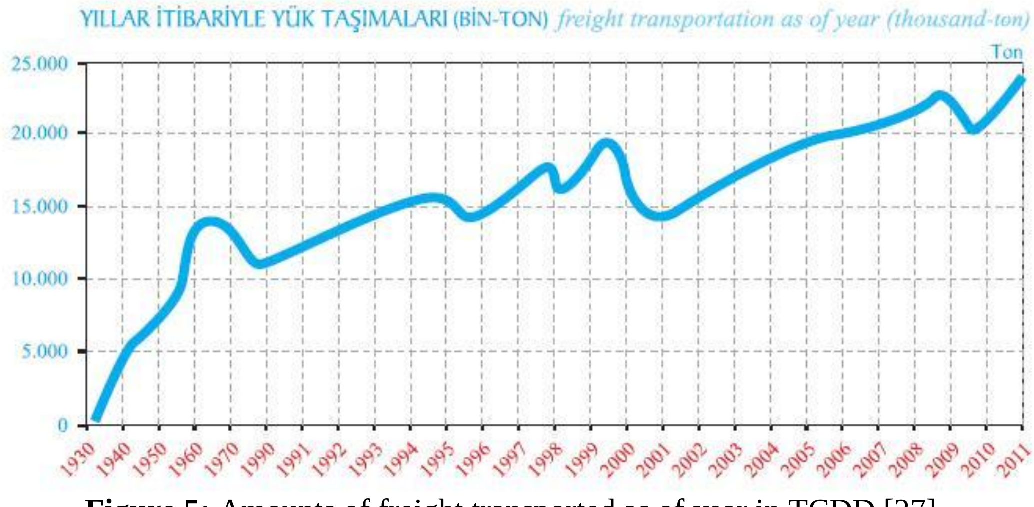

Figure 5: Amounts of freight transported as of year in TCDD [27]

According to the types of materials carried, wagon types used and amount of freight that can be loaded these wagons annually change. Figure 6 shows these amounts according to the years between 2006 and 2010.

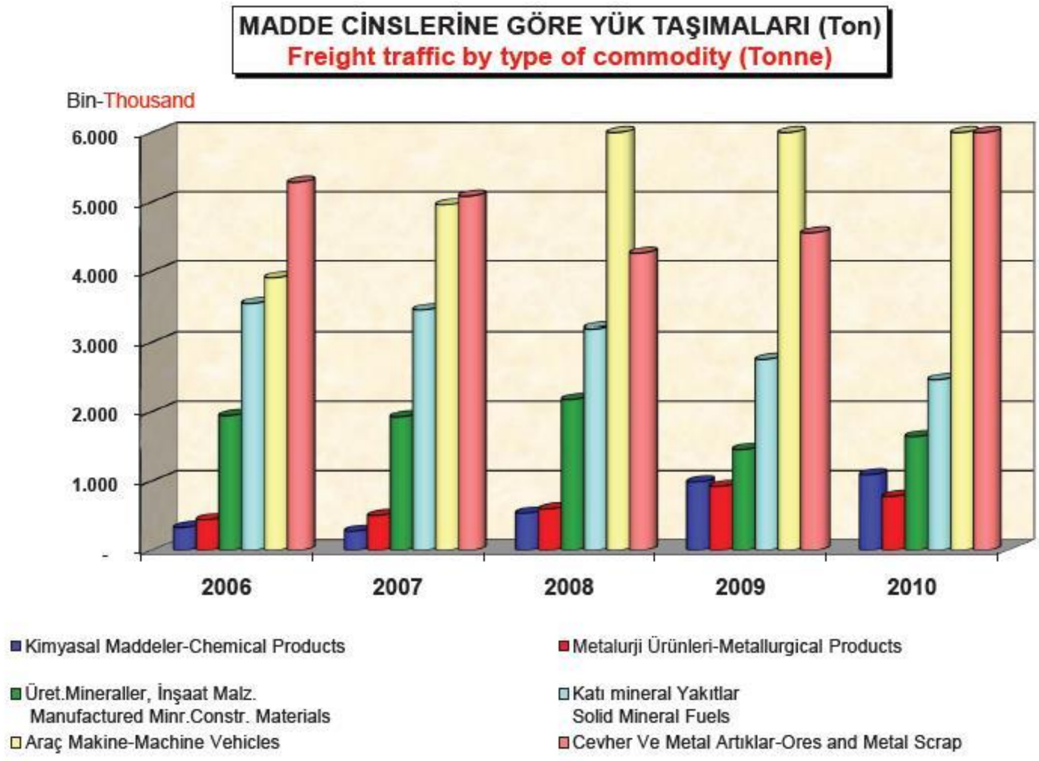

Figure 6: Freight traffic by type of commodity (tone) [28]

Logistic centers and ports are important for freight transportation and they enable to utilize transportation modes such as highway, seaway, etc. efficiently since they allow intermodal transportation. Ports in Turkey are in Haydarpaşa, Derince, İzmir, Bandırma, Samsun, Mersin and İskenderun. At the same time, there are logistic centers that have possibility for activities such as storage, maintenance, repair, loading, unloading, handling, packaging etc. in Eskişehir (Hasanbey), İzmit (Köseköy), Kayseri (Boğazköprü), İstanbul (Halkalı/Ispartakule), Samsun (Gelemen), Balıkesir (Gökköy), Mersin (Yenice), Uşak, Erzurum (Palandöken), Konya (Kayacık), Kaklık (Denizli), Bilecik (Bozüyük), Kahramanmaraş (Türkoğlu), Mardin, Kars and Sivas [29].

2.2. DEVELOPMENT OF HSR IN TURKEY

Up to now in this chapter, conventional trains, which are used to transport passengers and freight are mentioned. Now, HSTs will be mentioned. They are used to transport only passengers in Turkey. HSTs consist of six wagons purchased from the firm

CAF of Spain. Maximum comfort is provided for passengers in these trains. Air-conditioner, video, TV music system and necessary equipment for disabled people exist. For each service, there are 419 seats available [30].

Since 2003, developing railways have become a part of the state policy and works for HSTs that link big cities of our country have been started. The operations of HSTs were started on March 13, 2009 between Ankara-Eskişehir-Ankara with 8 services per day. This number increased to 9, 15 and 20 over time. Service time of track of 245 km between Ankara and Eskişehiris90 minutes [27].

Before HST operation, 572 passengers were being transported with conventional trains per day on the average. By means of HSTs, this number reached 7.000 passengers per day on the average. The train transportation share elevated from %8 to %72 between Ankara and Eskişehir with HSTs[27]. The following Table 4 shows number of passengers transported by conventional and HSTs between 2007 and 2011 [31].

Table 4: Number of passengers transported by conventional trains and HSTs between 2007 and 2011 [31]

Passenger transportation by railways					(Bin-Thousand)
	2007	2008	2009	2010	2011
Koltuk Kilometre - Seat Kilometer	**8 926 000**	**8 303 000**	**8 537 000**	**7 515 000**	**8 317 000**
Banliyö - Suburban	2 964 000	2 619 000	2 880 000	2 369 000	2 652 000
Ana hat - Main line	5 962 000	5 684 000	5 657 000	5 146 000	5 665 000
Yüksek Hızlı Tren - High Speed Train (1)	-	-	279 435	717 259	978 234
Yolcu sayısı - Number of passenger	**81 260**	**79 187**	**80 092**	**84 173**	**85 752**
Banliyö - Suburban	56 305	55 217	57 253	59 901	59 426
Ana hat - Main line	24 955	23 970	22 839	24 272	26 326
Yüksek Hızlı Tren - High Speed Train (1)	-	-	942	1 890	2 557
Yolcu kilometre - Passenger kilometer	**5 553 000**	**5 097 000**	**5 374 000**	**5 491 000**	**5 882 000**
Banliyö - Suburban	1 473 000	1 447 000	1 802 000	1 885 000	1 880 000
Ana hat - Main line	4 080 000	3 650 000	3 572 000	3 606 000	4 002 000
Yüksek Hızlı Tren - High Speed Train (1)	-	-	236 813	476 068	664 981

The second HSL between Ankara and Konya was opened to service on August 24, 2011. Total length of line between Ankara and Konya is 306 km. 94 km of this line belongs to the line between Ankara and Polatlı [6].

Today, number of HSTs which are in operation between Ankara-Eskişehir and Ankara-Konya is 12 in total. Number of conventional trains and HSTs used between 2007 and 2011 is given in Table 5 as below.

Table 5: Number of conventional trains and HSTs between 2007 and 2011 [31]

Number of diesel locomotives and wagons

	2007	2008	2009	2010	2011
Yüksek Hızlı Tren- High Speed Train	-	-	7	12	12
Dizel lokomotif - Diesel locomotives	**530**	**549**	**550**	**544**	**542**
Ana hat - Main line	472	494	502	498	496
Manevra - Maneuver	58	55	48	46	46
Elektrikli Lokomotif- Electric Loco	67	64	64	64	45
Elektrikli Dizi- Electric Railcar	83	83	83	99	101
Dizelli Dizi- Diesel Railcar	44	44	52	55	56
Yük vagonu - Freight Wagon	17 041	17 079	17 607	17 773	18 200
Yolcu vagonu - Passenger Coache	1 010	995	990	965	962

TCDD has several HST projects. The construction work for the second phase of Ankara-İstanbul, Eskişehir-İstanbul, Ankara-Sivas HSL projects are going on. After completion of these lines, service time will be reduced to 3 hours between Ankara-Sivas and Ankara-İstanbul. The construction work for Ankara-İzmir and Bursa-Bilecik lines are also going on. Kars-Baku-Tbilisi and Marmaray Projects are also significant in the international railway transportation. The other projects planned are Halkalı- Bulgaria and Sivas-Erzincan-Erzurum-Kars HSLs [7].

2.3. FUTURE PROJECTS

TCDD has visions to achieve, thus 45 billion dollars will be invested for railways until 2023 [32].

The targets to be achieved until 2023 are listed below:

- To complete restructuring of Turkish Railways to increase service quality and decrease service losses,
- To modernize existing lines to increase share of railways,

- To complete signalization of non-signaled lines which are 67% percent of all lines,
- To complete electrification of non-electrified lines which are 73,5% percent of all lines,
- To complete HSR network of 10.000 km,
- To improve conventional railway network and construct 4.000 km line,
- To complete the Marmaray Project,
- To complete Başkentray Project which has length of 36 km and has speed of 160 km/h.
- To complete Egeray Project,
- To increase the number of rolling stock fleet,
- İstanbul-Basra, İstanbul-Kars-Tbilisi-Baku, Kavqaz-Samsun-Basra, İstanbul-Aleppo-Makkah, İstanbul-Aleppo-the North Africa/the South East Asia transport corridors will be improved,
- To produce new rolling stocks according to the UIC, EN and TSI standards,
- To increase share of private sector in production and maintenance of rolling stock,
- To make train operations by a single driver,
- To provide internet access in all trains,
- To increase share of private sector up to 50 % in rail operations,
- To plan and actualize "Global Logistics Centres" which are in scales and dimensions to meet geographical, historical and cultural needs of Turkey (İstanbul, Mersin, İzmir and Samsun),
- To link all organized industrial zones and important production centers through direct lines,
- To establish a Railway Institute under the Ministry of Transport, Maritime Affairs and Communications, University or TUBITAK (The Scientific and Technological Research Council of Turkey) and an internationally accredited railway testing and certification centre,
- To introduce and improve Turkish railway supply industry in the global railway sector,

- To raise rail share at the rate of 10% in passenger transportation and 15% in freight transportation,
- To make a customs law for facilitating the existing customs affairs and procedures affecting the freight operations negatively,
- To minimize accidents by building underpasses, overpasses or level crossings with automatic barriers on heavy traffic lines,
- To increase axle loads up to 22.5 tons at least to improve geometric conditions of the existing lines [33].

Figure 7 shows high speed and conventional lines planned to be constructed up to 2023.

Figure 7: High speed and conventional lines planned to be constructed up to 2023 [34]

2.4. INTERMODAL TRANSPORTATION WITH HSTs

Intermodal transportation refers to the transportation of people or freight from their origin to their destination by a sequence of at least two transportation modes [35].

Today, HSTs can allow intermodal transportation for passengers. With HST-conventional train and HST-bus connections, travel times are reduced significantly for many cities. For instance, thanks to HSL between Ankara and Eskişehir, travel times are reduced by HST-conventional train connection for İstanbul, Kütahya and Afyon. At the same time, travel times are reduced by HST-bus connection for Bursa.

Thanks to HSL between Ankara and Konya, it is possible to connect Konya and Antalya or Konya and Mersin by buses [27].

Freight transportation by HSTs is not realized up to now but, it can be convenient for especially long distances when light goods (e.g., postal mail) which must be delivered in a short time interval are of concern. By rail-truck combination, which is the most common intermodal transportation combination, optimum utilization of sources can be achieved.

Moreover, the lines for conventional and HSTs can be used for both types of trains. However, the speed of the trains can be reduced.

When highway freight transportation and conventional railway freight transportation are compared, highway is selected to transport freight mostly since travel time is less thanks to higher speed [36]. The speed problem can be overcome by using HSTs and HSR-truck intermodal combination can allow transportation with higher speed and low energy consumption. Therefore, HSTs will increase use of railway in intermodal transportation.

CHAPTER III

3. MODELING

3.1. LITERATURE SURVEY

Mathematical models for freight transport on HSTs were not investigated as much as passenger transport by rail up to now since there are few application examples in the world. To the best of our knowledge, research for freight transportation on HSTs is limited in the literature. On the other hand, HSTs increase the capacity of railway systems substantially since they have higher frequency than conventional trains thanks to their higher speed and up-to-date signaling systems. Therefore, it can be very advantageous to benefit from HSTs in freight transportation.

Some studies on freight transportation by trains are given in the following. Pazour et al. 2010 [37] present the arcs where HSLs for freight distribution can be constructed as parallel to existing highway network and to do this, they construct a mathematical model as a network design problem. Dobruszkes (2011) [38] presents the important points of competition between HSTs and air transport in Western Europe and explains the advantages of these two transportation modes. In that article, it is concluded that HSR remains limited compared to the increase of air services. Ergin et al. (2007) [39] investigate the use of intermodal transportation (between conventional railway and highway) to transport fast-moving consumer goods and determine the arcs where railway should be used rather than highway. The route that minimizes the total cost is determined in Ergin et al. (2007) [39]. Troche (2005) [19] studied development of HSR freight and defined this term in detail by taking into account speed, type of cargo, operating principles and vehicle concepts, terminals, loading units and transloading techniques. Ways of coordinating passenger and HSR freight are considered. Xie et al. (2009) [40] studied train schedule with fixed number of passengers per train in an intercity HSR line and constructed the model to optimize the schedule concerning passenger’s delay and income of operating company. Kuo et al. (2010) [41] used train slot selection model to schedule conventional freight trains with elastic demand. This model takes into account the operating cost and train delays, and satisfies the demand. Cordeau et al. (1988) [42] analyzed the optimization models for rail transportation problems and did this by dividing models into two groups which are routing and scheduling problems. Cacchiani et al. (2010) [43] presented a scheduling model for extra conventional freight trains in railway networks where both of freight and passenger trains are run. The model aimed to add extra freight trains to the existing system and takes into account the differences between actual time-table and ideal one.

The main article that was benefited from in this thesis is Carey and Lockwood (1995) [44]. In this article, a model of train pathing for conventional trains and for passenger transportation is introduced. In this model, there are separate platforms for trains in each direction and trains often have a choice of platforms at stations. This is the case in Turkey, too. Also, as in Cacchiani et al. (2010) [43], the model takes into account differences between the actual time-table and the preferred one which is impossible for Turkey. Because, there is not an actual schedule for freight transportation in HSR in Turkey today and the aim of our model cannot be minimizing the deviation between the actual and the preferred schedules. Consequently, it is clear that existing relevant studies in the literature are not identical to the work done in this thesis. Freight transportation in HSTs is not analyzed without a predefined time-table before.

3.2. MIXED TRAFFIC IN HSTs FOR TURKEY

HSLs are usually used to transport passengers by HSTs currently. To transport freight on HSLs by HSTs is a concept that must be elaborated from many aspects. Construction of a time-table will be needed if both passengers and freight will be transported on the same lines, which is named by mixed traffic. While some HSTs can be used for only freight transportation, some trains can be used for transporting both freight and passenger. To determine this, passenger trains are examined whether there is empty space for freight or not. If there is available space, freight can be transported by passenger trains and sharing passenger platforms with freight loading/unloading can create some problems such as stopping times at stations. If there is not available space, freight is transported by separate trains, but in coordination with passenger trains. In this case, freight transportation is done after completing passenger transportation within the day. The reason is preventing disruption of passenger transportation and collision of freight and passenger trains.

At the same time, speed of HSTs differs according to the way of transporting freight. Therefore, travel times differ, too. There are four different ways of coordinating high-speed freight and passenger traffic according to [19] and these are named as Case A, B, C and D, respectively. Figure 8 shows these possibilities.

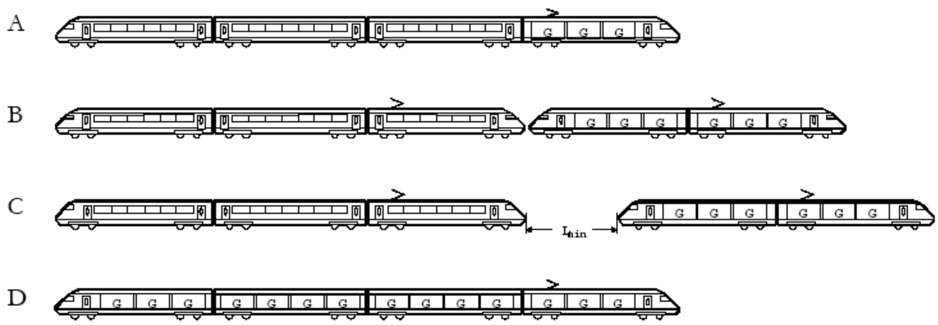

Figure 8: Ways of coordinating high-speed freight and passenger traffic [19]

Case A and C correspond to the methods modeled in this thesis, which are transportation of freight and passenger in the same train and transportation of freight by different trains, but in coordination with passenger traffic. Case C gives an opportunity to load and unload freight at different times and to stop at different stations from passengers' stations. However, in Case C, extra driver is needed.

In Figure 8, Case B gives transportation of freight and passenger in separate trains that can be multiple-coupled and allows these trains to have different starting points and destinations. Case D also represents transportation of freight fully independently from passenger traffic.

The capacity is another important aspect to be examined. As explained before, to determine whether there is available capacity or space to load freight, number of trains and wagons available must be known. There are 12 train sets in Turkey. One of them is used to do measurement on rails, four of them are reserved to use in emergencies and the remaining seven train sets are used for 36 services in a day. 20 of these services are done by using four sets between Ankara-Eskişehir and 16 services are done by using three sets between Ankara-Konya in the present day according to the information retrieved from TCDD. Also, each train set has six wagons as shown in Figure 9.

Figure 9: A HST set with six wagons

Speed of the train is also an important factor to be determined since the pressure applied to the line will be higher because of the weight of the freight. Therefore, speed of the trains is needed to be determined to not damage the lines.

Another factor affecting the speed of trains is the safety system. This system ensures minimum distances between trains. In our country, the signal system allows two consecutive trains to leave the station with 15 min time intervals and has braking system with green, yellow and red signals. Green light allows train to go on at this velocity, yellow means that the train must slow down and red means that the train must stop to avoid a collision. Figure 10 shows this safety system when red light is on.

Figure 10: Signal system on HSLs

3.3. PROBLEM DESCRIPTION

Scheduling is a concept including both manufacturing industries and service industries. In service industries, a customer does not like to wait and number of resources like trucks, planes, trains may vary. As a kind of service scheduling models, transportation scheduling models are constructed to help vehicle controllers. In these models, a vehicle is similar to a machine in manufacturing industries and a trip must take place within a given time.

A train schedule consists of arrival and departure times for each train at each station. These events occur with a certain frequency within the basic period T which is described as planning horizon. The schedule must satisfy system requirements such as demands and minimum distances between trains. Moreover, freight train schedule models are more difficult to construct since they require different assumptions for speed, capacity, etc. Also, schedule of freight trains must accommodate with schedule of passenger trains.

The model in this thesis is similar to the one in Carey and Lockwood (1995) [44]. The assumptions for this model are that there exist enough platforms for arrivals and departures at the stations and the time-table obtained from this model, which is daily, is valid for all days of the week. Also, time interval between departures is taken as 15 minutes (minimum interval that can be taken), which is not the case in real life. The reason of more frequent departures is to allow more time for freight within a day. To increase the number of train services in a day, 45 minutes are taken as minimum time interval between arrival time of a train to a station and departure time of the train from that station. 20minutes are also taken as minimum time interval between arrivals. The last two assumptions are that there exist two different lines for two different directions between city pairs and at the end of the day, trains arrive at the beginning station. Figure 11 represents the logic behind the model:

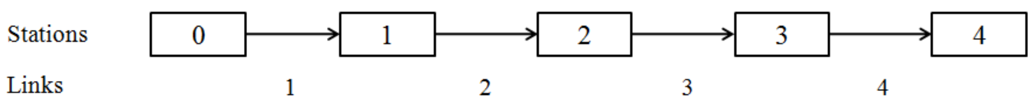

Figure 11: Stations and links as considered in the model

Let J denote the set of links and a link j joins station j-1 to station j as shown above. The stations are repetitive in our model. Namely, a city and leaving from the city are represented by separate links. This can be considered as another assumption of the model and this assumption is reasonable since HSL network is not wide. Let also I denote the set of trains with fixed sequence. These are indices of the model in this thesis.

After defining the planning horizon, allowable departure and arrival times for trains in that planning horizon must be determined. For safety reasons, it is necessary to determine time intervals between arrivals and departures of two consecutive trains. At the same time, it is crucial that minimum time interval between arrival time of a train to a station and departure time of the train from that station must be identified.

Moreover, service times for freight and passenger trains must be given. Since speed of freight trains is lower than passenger trains, service times will be higher although the distance travelled is the same. Also, service times between cities must be known. To realize these conditions, the parameters are given as follows:

T: Planning horizon (number of minutes in a day: 24x60=1440 min)

D_{min}: Minimum departure time allowed in a day

D_{max}: Maximum departure time allowed in a day

A_{min}: Minimum arrival time allowed in a day

A_{max}: Maximum arrival time allowed in a day

S_{ij}: Service time of train $i$on link j

I_A: Minimum time interval for arrival between two consecutive trains

I_D: Minimum time interval for departure between two consecutive trains

I_{AD}: Minimum time interval between arrival time of a train to a station and departure time of the train from that station

M: Sufficiently large number (100000)

The decision variables of the model are given below:

$A_{(i,j)}$: Arrival time of train *i* to station *j* (Arrival time of train *i* to the station after completing travel on link *j*)

$D_{(i,j)}$: Departure time of train *i* from station *j*-1 (Departure time of train *i* to travel on link *j*)

$X_{(h,i,j)}$: $\begin{cases} 1 & if\ train\ h\ immediately\ precedes\ train\ i\ on\ link\ j \\ 0 & otherwise \end{cases}$

C_{max}: Maximum of all arrival times for all trains and links

The aim of the proposed model is to maximize time remaining to transport freight so, the objective function and the constraints of the model are as follows:

$$\max \quad 1440 - C_{max}$$

subject to;

$$X_{(h,i,j)} + X_{(i,h,j)} = 1 \qquad \forall\ h, i, j\ and\ i \neq h \qquad (1)$$

$$D_{min} \leq D_{(i,j)} \leq D_{max} \qquad \forall\ i\ and\ j \qquad (2)$$

$$A_{min} \leq A_{(i,j)} \leq A_{max} \qquad \forall\ i, j \qquad (3)$$

$$D_{ij} + S_{ij} = A_{ij} \qquad \forall\ i\ and\ j \qquad (4)$$

$$A_{hj} + I_A \leq A_{ij} + \left(1 - X_{(h,i,j)}\right) * M \qquad \forall\ h, i, j\ and\ i \neq h \qquad (5)$$

$$D_{hj} + I_D \leq D_{ij} + \left(1 - X_{(h,i,j)}\right) * M \qquad \forall\ h, i, j\ and\ i \neq h \qquad (6)$$

$$A_{ij} + I_{AD} \leq D_{i,j+1} \qquad \forall\ i\ and\ j \qquad (7)$$

$$A_{ij} \leq C_{max} \qquad \forall\ i\ and\ j \qquad (8)$$

$$A_{ij}, D_{ij}, C_{max} \geq 0 \qquad \forall\, i \ and\ j \qquad (9)$$

$$X_{(h,i,j)} \in \{0,1\} \qquad \forall\, h, i, j \ and\ i \neq h \qquad (10)$$

Constraint (1) guarantees that if train *h* immediately precedes train *i* on link *j*, reverse is impossible. Constraints (2) and (3) give upper and lower bounds of departure and arrival times. Constraint (4) is the travel time constraint. It guarantees that after departure of train *i* to travel on link *j*, service time must pass to arrive at station *j*. Constraint (5) forbids arrival of next train after arrival of a train if minimum time interval does not pass. Constraint (6) forbids departure of next train after departure of a train if minimum time interval does not pass. Constraint (7) expresses that if a train arrives at a station, it cannot depart from there till minimum time interval passes. Constraint (8) gives the last arrival time of all trains to all stations. Constraint (9) is non-negativity constraint and Constraint (10) gives the binary variables.

The model in this thesis differs from the one suggested by Carey and Lockwood (1995) [44] in some aspects. To ensure that each train has one and only one immediate predecessor on a link and is the immediate predecessor of one and only one other train, there exist two different constraints. In the model in this thesis, constraint (1) ensures these singly.

Before experimental study, proposed model is solved for the line between Ankara and Eskişehir for one-day period to compare results with the case in real life. In real life, four HSTs are used for this line and each of them completes five services within a day. In Figure 12, daily services of only one train are analyzed to observe the differences and similarities between real life and the model. It is seen that in the model, daily services of a train is completed before the case in real life. Because, our model is constructed to increase system utilization and finish services as early as possible. It should be also noticed that sequence of arrivals and departures between the cities is the same with real life.

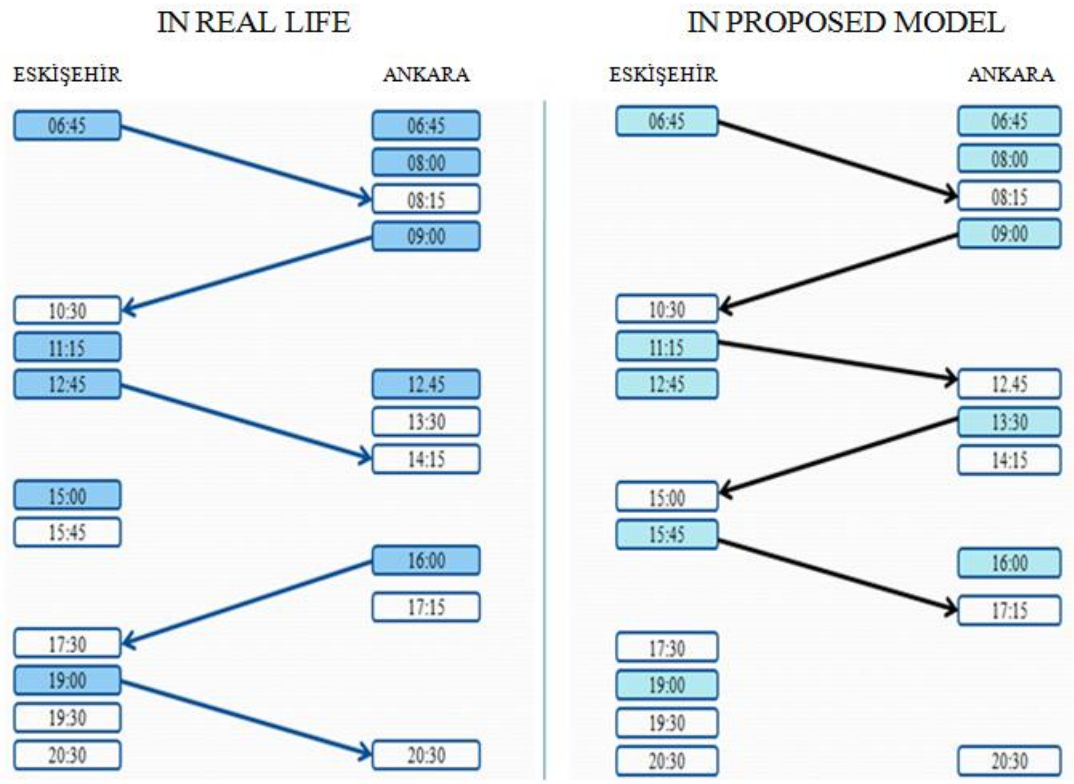

Figure 12: Comparison of the situation in real life and the situation proposed by the model for line between Eskişehir-Ankara

CHAPTER IV

4. EXPERIMENTAL STUDY

HST systems require costly investments and have to be utilized efficiently. One way to increase the utilization of HST systems is to use them for freight transportation. This idea was confirmed by TCDD in a preliminary visit.

In this chapter,theproposed model is tested with some real life scenarios inspired from operations of TCDD. TCDD aims to improve the efficiency of freight transportation. To realize this idea, literature and real life applications were investigated and the model was constructed in such a way that it would reflect real life applications. After some progress in the thesis, we presented our study to Research Planning and Coordination Department Vice Chairman, Safi Çatal, and Project Planning and Evaluation Department Manager, Abdulkadir Aksu on the 23rd of December, 2011. Then, we went to İstanbul on the 3rd of February, 2012 to present our work to ASE cargo company on request of Ankara Department Manager, Atalay Demirbaş. The reason of the visit was to inform the cargo company about our study and show them the advantages of transporting their cargos by using HST systems.

In the light of these meetings, we constructed several scenarios for freight transportation on existing HSLs and HSLs under construction such as Ankara-Konya, Ankara-Eskişehir, Ankara-İstanbul and Ankara-Sivas. Figure 13 represents a map of HSLs on which the scenarios are based.

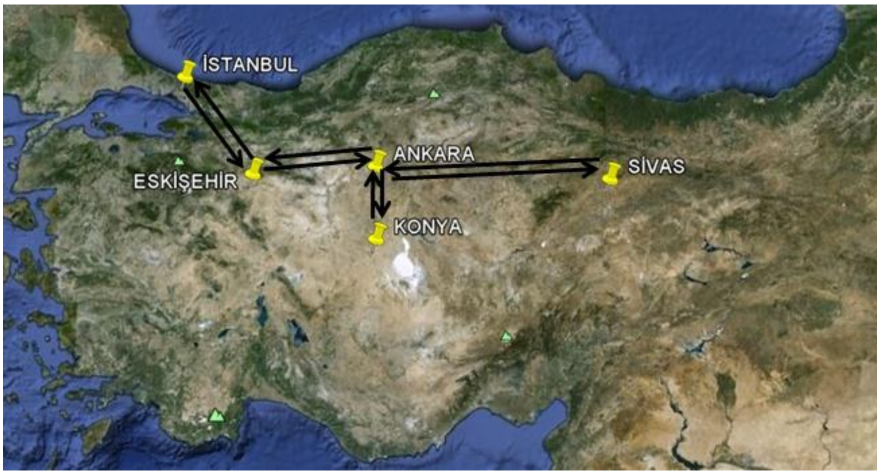

Figure 13: Map of HSLs which are worked on in the thesis

As shown in Figure 12, since number of HSLs is limited, a train can go to the station in İstanbul after stopping at the station in Eskişehir if it departs from Ankara station. Similarly, after departure from Konya station, the train should first arrive at Ankara station to go to Sivas station, or vice versa.

In the scenarios, arrival and departure between pairs of cities (Ankara-Eskişehir, Eskişehir-İstanbul, Ankara-Konya and Ankara-Sivas) are considered as in Figure 14.

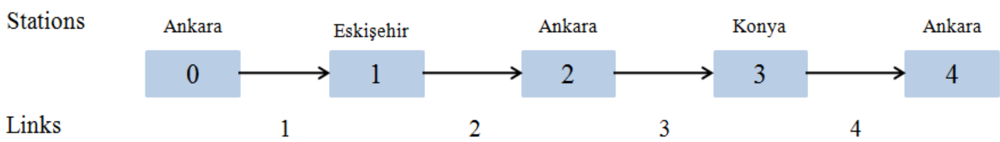

Figure 14: Arrival and departure between pairs of cities in the model

Figure 14 is only one of scenarios in this thesis and the logic behind it is that each of the arrival and departure between city pairs is taken as a separate link. Namely, if link one is travelling from Ankara to Eskişehir, then link two is returning from Eskişehir to Ankara. After arriving at Ankara, the next service of the trains is for Konya from Ankara. At the end, the train arrives at Ankara station which is the beginning. So, there is a closed loop for all of the scenarios.

4.1. PASSENGER EXPERIMENTS

Today, there are 12 HST sets in TCDD. One of them is used to do measurement on rails, four of them are reserved for use in emergencies and the remaining seven train sets are used for 36 services in a day. 20 services are done by using four sets between Eskişehir and Ankara and 16 services are done by using three sets between Konya and Ankara. At the same time, each train consists of six wagons and can transport 419 passengers at a time [30]. However, the capacity utilization is 70% for Ankara-Eskişehir line and 78% for Ankara- Konya line between years 2009-2011 [27]. This means that at least one of the six wagons can be emptied on average and passengers can travel in five wagons. Thus, one of the wagons can be used for freight transportation if freight and passenger will be transported in the same train.

The model parameters are constructed in such a way that frequent departures are achieved in a day to utilize more from the system and to realize also freight transportation. Time interval between departures must be at least 15 minutes for all scenarios, which is the minimum interval. This is not the case in real life since minimum time interval between departures is one hour and 15 minutes [45]. Between arrivals at a station, at least 20 minutes interval must also be observed for all scenarios. Additionally, minimum 45 minutes time interval for departure of a train after arrival at the station must be taken for all scenarios. Finally, the earliest departure time of a train can be 5:00 A.M. in a day (300^{th} minute of 1440 minutes which corresponds to total number of minutes in a day) and the latest arrival time at a station can be taken as 1400 which corresponds to the end of the day.

First, the model is solved by GAMS for only passenger transportation, and then freight transportation is added to the model in two cases which are Case A (same train) and Case C (separate trains). When the model is solved to evaluate a schedule for passenger transportation, the objective is to maximize the number of minutes left for freight transportation in a day. It should be noted that travel times between city pairs are as follows. For Ankara-Eskişehir (A-E) and Ankara-Konya (A-K), they are 90 and 115 minutes respectively and these values are taken as average from the values in real life. Travel times between Eskişehir-İstanbul (E-İ) and Ankara-Sivas (A-S) are also 105 and 170 respectively and these values are calculated as average by considering the length of HSLs.

The first scenario is for departure from Ankara, then arriving at Eskişehir and going to Konya after returning to Ankara from Eskişehir, which gives the case in Figure 13, with four trains. In all scenarios, it is essential that trains return to the beginning station at the end of the day, which is Ankara for Scenario 1. After the sequence of cities is completed with four passenger trains, 535 minutes are left within a day.

Then, İstanbul is added to the model as Scenario 2 in two different ways such as A-E-İ-E-A-K-A and İ-E-A-K-A-E-İ with four trains, which have different beginning and ending stations. For both ways, GAMS gives the same objective function value, 235 minutes. Because, total distance travelled and the total time spent in stations in a day for each way is the same. When Scenario 1 and 2 are compared, time left for freight transportation in a day reduces from 535 min to 235 min in the second scenario. It is reasonable since İstanbul is added to the model, so Figure 15 gives the relationship between number of the links in the model and time left for freight transportation in a day:

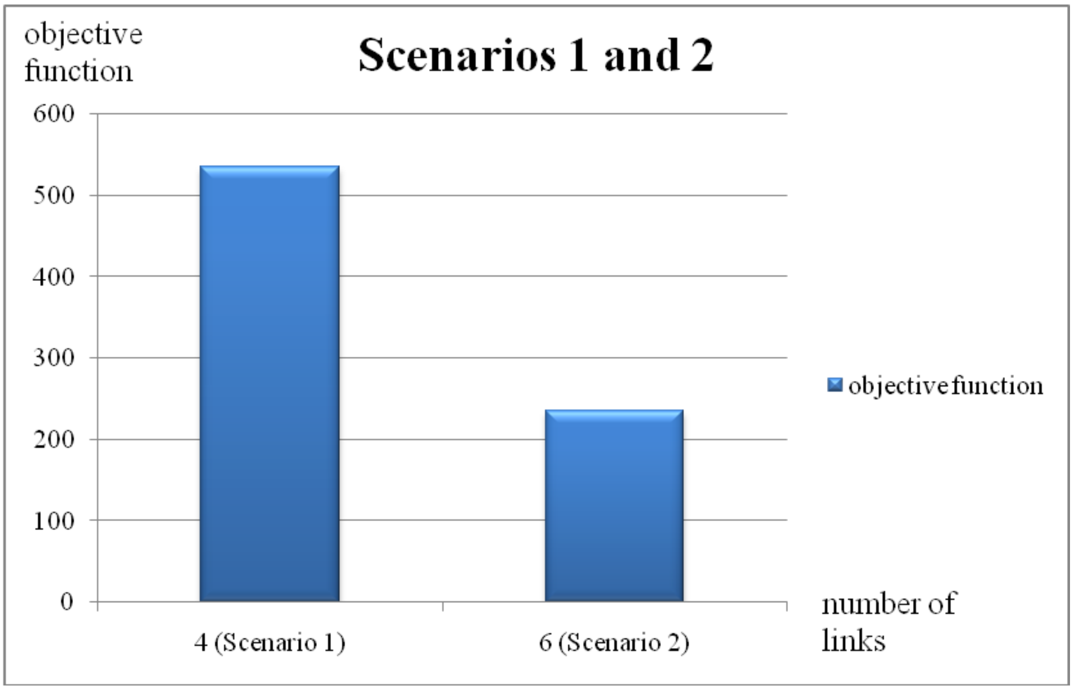

Figure 15: The effect of number of links on the objective function value for Scenario 1 and 2

In Scenario 3, Sivas is added to the model lastly in two different ways such as İ-E-A-K-A-S-A-E-İ and A-E-İ-E-A-K-A-S-A. However, number of minutes in a day is not enough to realize the scenarios in a day reasonably since time left in a day was 235 min in Scenario 2 and 340 min (=170x2) are needed for only travel between Ankara and Sivas.

Now, the scenarios will be obtained by dividing the sequence of cities into two so, by allocating the trains to these sequences. The trains will be allocated separately in two ways. Firstly, three trains will be used for lines among cities of Ankara, Eskişehir and İstanbul since population density is much more in these lines and one train will be used for lines among cities of Ankara, Konya and Sivas. Then, number of trains will be divided into two to observe the effect on the system and two of four trains will be for trio of Ankara-Eskişehir-İstanbul and the remaining two trains will be for trio of Ankara-Konya-Sivas.

In Scenario 4, the case of three trains for Ankara-Eskişehir-İstanbul lines and one train for Ankara-Konya-Sivas lines. In Scenario 4, the sequence of cities in Scenario 2 are divided into two such as A-E-İ-E-A and A-K-A or İ-E-A-E-İ and A-K-A. The objective function value, which is again the same for two ways reasonably as in Scenario 2, increases from 235 min to 575 min. This means that separating trains and sequence provides 340 minutes (=575-235) in a day so, time left in a day is more than the case that all trains have the same sequence although total number of links and trains, and total distance travelled are the same with Scenario 2.

In Scenario 5, number of trains is divided into two and two of four trains will be allocated to A-E-İ-E-A and the remaining two trains will be allocated to A-K-A. In this case, the objective function value becomes 595 min. This value is higher than the value in Scenario 4. Namely, dividing number of trains into two provides a better solution. Therefore, Figure 16 gives the relationship among Scenarios 2, 4 and 5:

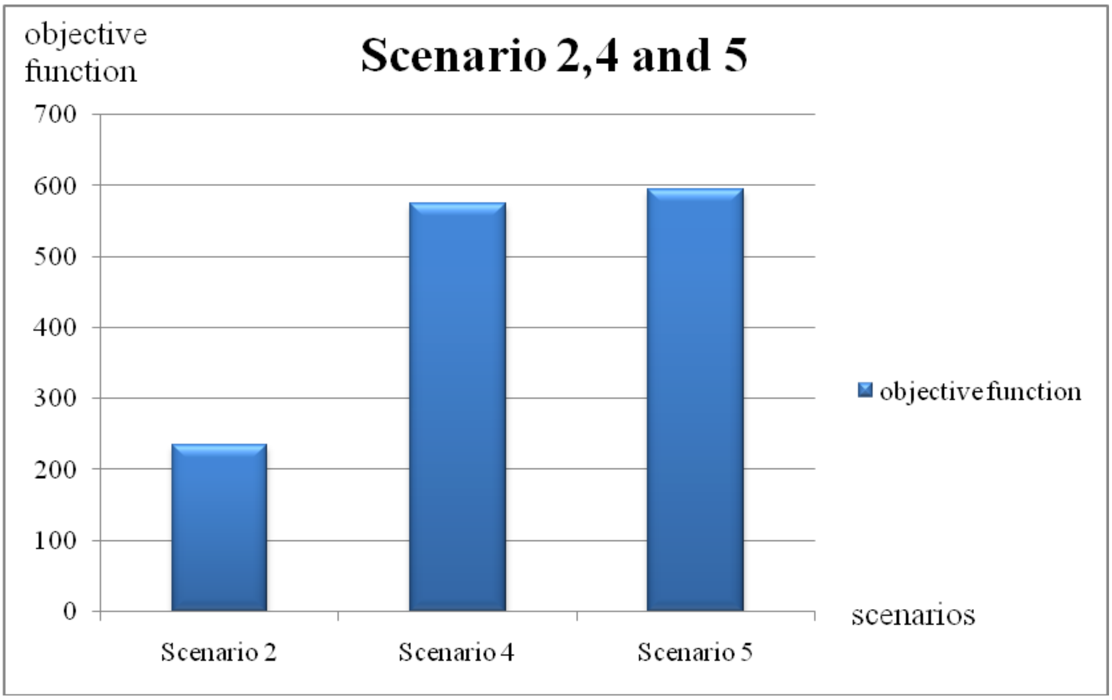

Figure 16: The comparison of Scenarios 2, 4 and 5 in terms of objective function values

Scenario 6 is obtained by adding Sivas station to Scenario 4. In Scenario 3, when Sivas is added to the model, number of minutes in a day was not enough to realize the scenario in a day. In Scenario 6, it is enough since 4 trains are divided into two in such a way that three trains for A-E-İ-E-A and one train for A-K-A-S-A. The objective function becomes 435 min so, 435 min are even left for freight transportation in a day.

In Scenario 7, number of trains is divided into two parts and two of four trains are allocated to A-E-İ-E-A and the remaining two trains are allocated to A-K-A-S-A. Namely, Sivas is only added to Scenario 5. In this case, the objective function becomes 415. This value is less than the value in Scenario 6. Namely, dividing number of trains into two gives a worse solution and less time for freight passenger. Therefore, Scenario 6 can be preferred instead of Scenario 7. Figure 17 gives the relationship between Scenarios 6 and 7:

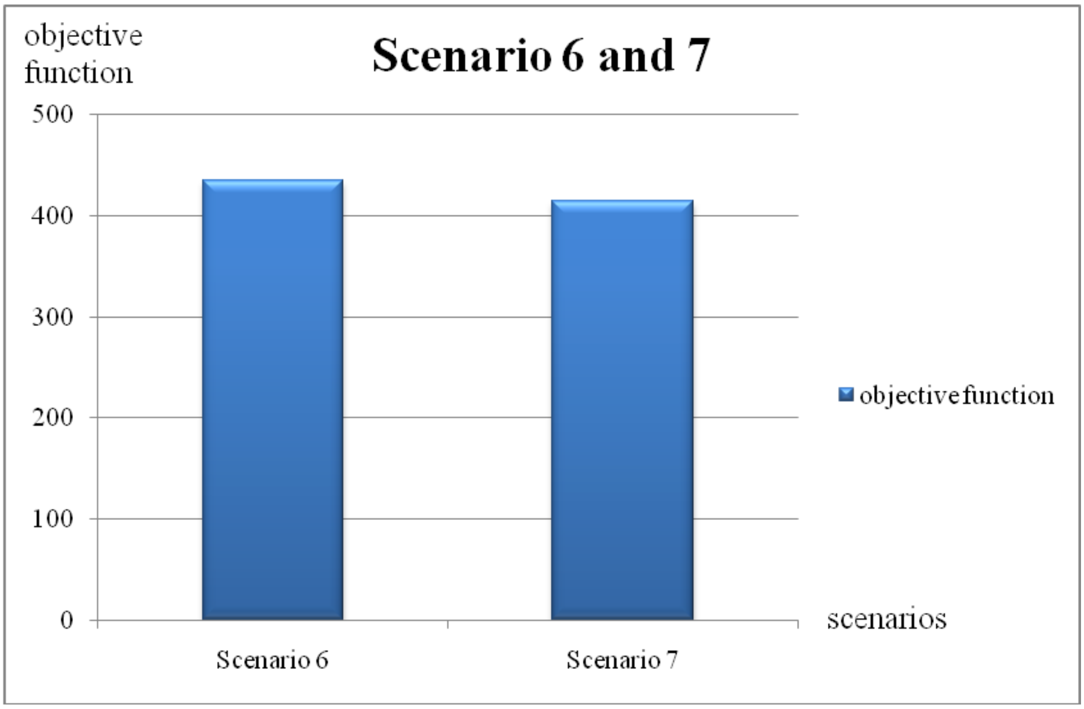

Figure 17: The comparison of Scenarios 6 and 7 in terms of objective function values

If Scenario 7 is repeated two times (A-E-İ-E-A-E-İ-E-A and A-K-A-S-A-K-A-S-A), that is two trains arrive at İstanbul two times and left two trains arrive at Konya, Sivas stations two times in a day, number of minutes in a day becomes insufficient to realize these services. Two days are needed although trains and sequence are divided into two. Table 6 summarizes the Scenarios from 1 to 7.

Table 6: Summary of the Scenarios from 1 to 7.

NUMBER OF SCENARIOS	FACTORS		OBJECTIVE FUNCTION (MIN)	SEQUENCE OF CITIES (INITIAL OF CITIES)
	LINKS	TRAINS		
Scenario 1	4	4	535	A-E-A-K-A
Scenario 2	6	4	235	A-E-İ-E-A-K-A
Scenario 3	8	4	A day is not enough	A-E-İ-E-A-K-A-S-A
Scenario 4	6	4	575	A-E-İ-E-A (three trains) A-K-A (one train)
Scenario 5	6	4	595	A-E-İ-E-A (two trains) A-K-A (two trains)
Scenario 6	8	4	435	A-E-İ-E-A (three trains) A-K-A-S-A (one train)
Scenario 7	8	4	415	A-E-İ-E-A (two trains) A-K-A-S-A (two trains)

4.2. MIXED TRAFFIC EXPERIMENTS

In mixed traffic experiments, freight transportation is added to the HST system. The model is constructed in such a way that freight transportation is done after passenger services to avoid delays for passengers and benefit from late hours within a day for freight transportation. Also, if the freight is transported by the same train with passengers, one of the six wagons can be allocated for freight loading on average as explained in section 5.1.

4.2.1. TRANSPORTATION OF FREIGHT BY SEPERATE TRAINS FROM PASSENGERS

Separate high speed freight trains from passenger trains are added to the HSLs in the model. This case is divided into two in itself. That is, if the sequence of cities is not divided into two, two freight trains are added after passenger trains. Otherwise, one freight train is added to one of the sequences and another freight train is added to the other sequence. In total, two freight trains are again added to the system.

This section corresponds to Case C as given in Chapter 4. Figure 18 gives transportation of freight by different trains, but in coordination with passenger traffic. Since the freight trains are slower than passenger trains and operate after passenger trains, calculating minimum distance between these two kinds of trains is not a necessity in our model.

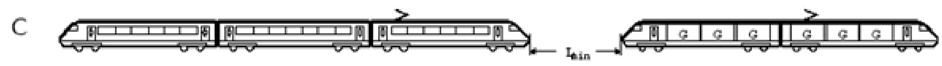

Figure 18: Transportation of freight by different trains from passengers

When the model is solved to evaluate a schedule for mixed traffic, the objective is again to calculate the number of minutes left in a day after transportation of both passengers and freights. While travel times between city pairs for passengers remain the same, travel times for freight trains increase since they are much slower than passenger trains. Travel times for freight trains between Ankara-Eskişehir (A-E), Ankara-Konya (A-K), Eskişehir-İstanbul (E-İ) and Ankara-Sivas (A-S) are taken as 120, 155, 145 and 230 minutes respectively in the model. These values are calculated as average by considering the distances between cities and speed of the trains. Speed of the freight trains is assumed to be 120 km/h in this thesis, which is a feasible speed in real life since light goods such as postal mail will be transported. When freight trains are added to the model, all of the objective function values decrease certainly. Now, the scenarios are analyzed again by adding freight trains.

Scenario 8 is for the sequence A-E-A-K-A with four passenger trains and two freight trains (six trains in total). GAMS gives the objective function value as 360 minutes. That is, 360 min is left within a day although two freight trains are operated. This value for this scenario was 535 min when only four passenger trains are considered. Figure 19 gives this relationship between Scenario 1 and 8:

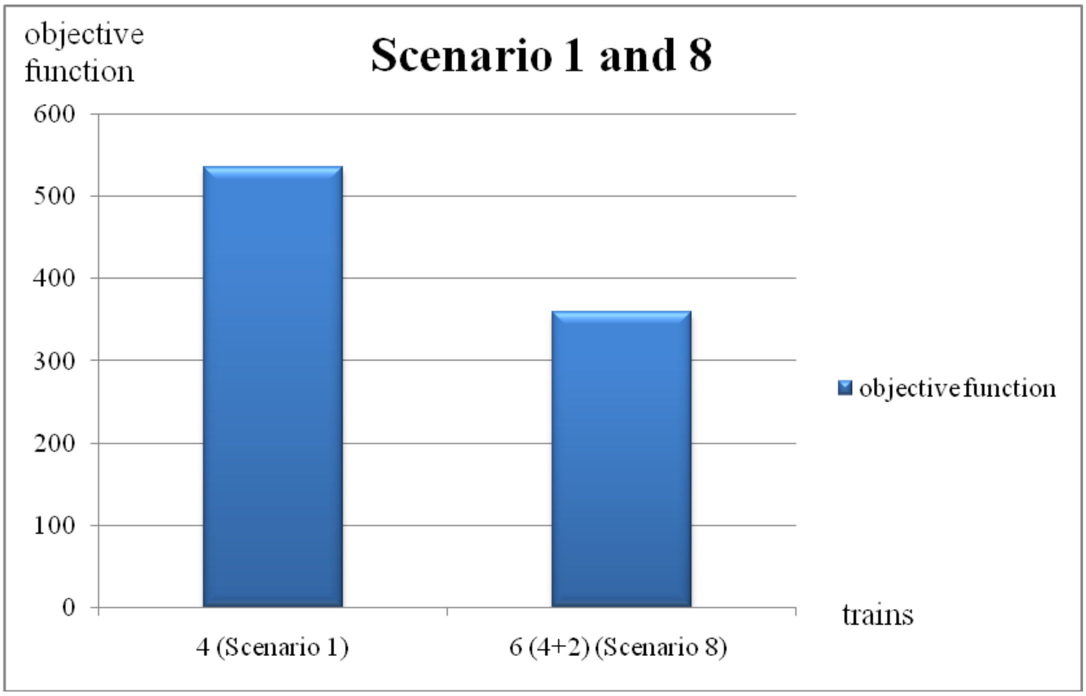

Figure 19: The comparison of Scenarios 1 and 8 in terms of objective function values

Then, İstanbul is added to the model as Scenario 9 and the sequence becomes A-E-İ-E-A-K-A. However, number of minutes in a day is not enough to realize this scenario in a day while it was enough to realize for only passenger trains in the previous section. Furthermore, it cannot be thought to add Sivas to the sequence of cities without dividing the sequence and trains into two. Therefore, the next scenario is obtained by dividing the sequence of cities into two, so, by allocating the trains to these sequences. The trains are allocated separately in two ways. Firstly, three passenger trains and one freight train (four trains in total) are used for lines between cities of Ankara, Eskişehir and İstanbul. One passenger and one freight train (two trains in total) are used for lines between cities of Ankara, Konya and Sivas. Then, number of trains is divided into two and two passenger trains and one freight train (three trains in total) will be used for lines between cities of Ankara, Eskişehir and İstanbul. Also, two passenger trains and one freight train (three trains in total) are used for lines among cities of Ankara, Konya and Sivas.

While Scenario 9 could not be solved within a day time horizon, in Scenario 10, it can be solved since the sequence of cities are divided into two such as A-E-İ-E-A and A-K-A or İ-E-A-E-İ and A-K-A. The number of trains is also divided in such a way that three passenger trains and one freight train (four trains in total) will be used for the sequenceA-E-İ-E-A, and one passenger and one freight train (two trains in total) will be used for the sequenceA-K-A. The objective function value becomes 420minutes. Namely, 420 minutes are left after completing services.

In Scenario 11, the only difference from Scenario 10 is that number of trains will be divided into two and two passenger trains and one freight train (three trains in total) will be used for lines between cities of Ankara, Eskişehir and İstanbul. Also, two passenger trains and one freight train (three trains in total) will be used for lines between Ankara and Konya. In this scenario, the objective function value becomes 440. This value is higher than the value in Scenario 10. Namely, dividing number of trains into two gives better solution. Therefore, Figure 20 gives the relationship between Scenarios 10 and 11:

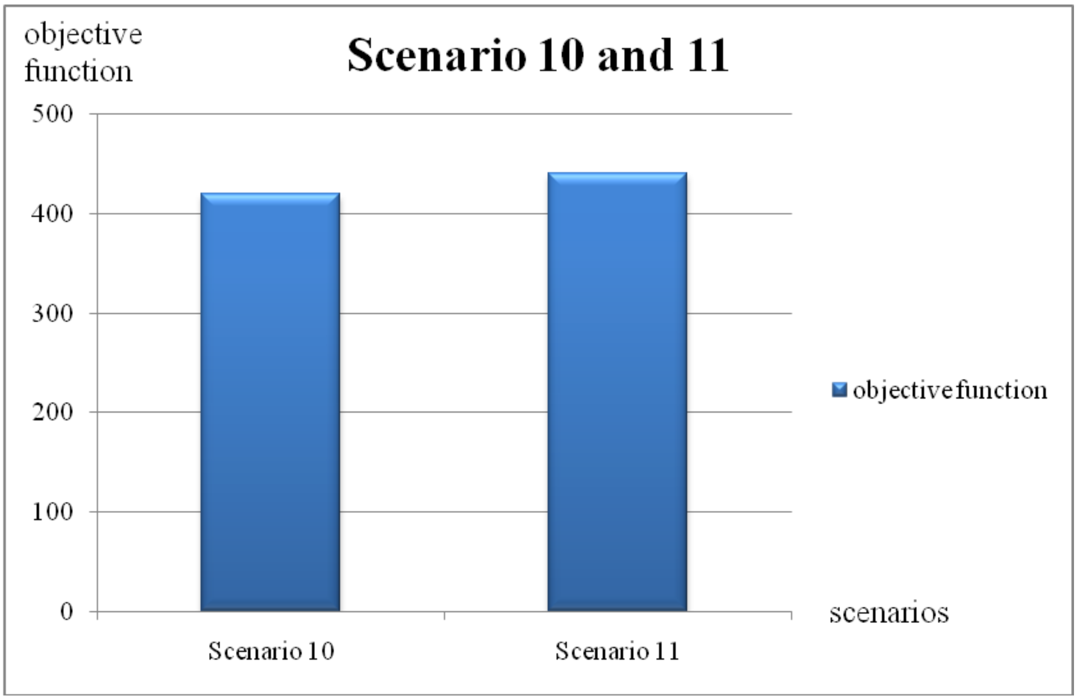

Figure 20: The relationship between Scenarios 10 and 11 in terms of objective function values

Scenario 12 is obtained by adding Sivas station to Scenario 10 and the sequence of cities become A-E-İ-E-A and A-K-A-S-A. The objective function value becomes 220 minutes so, 220 minutes are left for within a day after completing services.

In Scenario 13, number of trains is divided into two as in Scenario 11. Also, two passenger trains and one freight train will be allocated to A-E-İ-E-A and two other passenger trains and another freight train will be allocated to A-K-A-S-A. Namely, Sivas is only added to Scenario 11. In this case, the objective function value becomes

200 min. This value is less than the value in Scenario 12. Namely, dividing number of trains into two gives a worse solution than dividing them into two as four trains in total for A-E-İ-E-A and two trains in total for A-K-A-S-A. Therefore, Scenario 12 can be preferred instead of Scenario 13. Figure 21 gives the relationship between Scenarios 12 and 13:

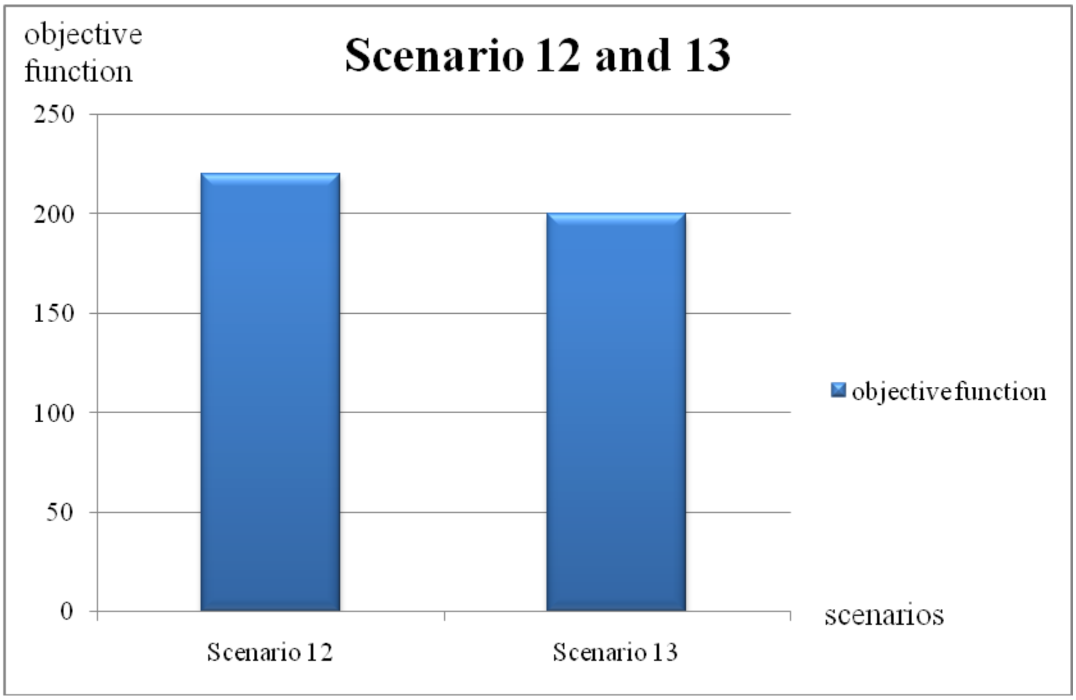

Figure 21: The relationship between Scenarios 12 and 13

Table 7 summarizes the Scenarios from 8 to 13 as below:

Table 7: Summary of the Scenarios from 8 to 13

<table>
<tr><th rowspan="2">NUMBER OF SCENARIOS</th><th colspan="2">FACTORS</th><th rowspan="2">OBJECTIVE FUNCTION (MIN)</th><th rowspan="2">SEQUENCE OF CITIES (INITIAL OF CITIES)</th></tr>
<tr><th>LINKS</th><th>TRAINS</th></tr>
<tr><td>Scenario 8</td><td>4</td><td>4 passenger
2 freight</td><td>360</td><td>A-E-A-K-A</td></tr>
<tr><td>Scenario 9</td><td>6</td><td>4 passenger
2 freight</td><td>A day isn’t enough</td><td>A-E-İ-E-A-K-A</td></tr>
<tr><td rowspan="2">Scenario 10</td><td rowspan="2">6</td><td rowspan="2">4 passenger
2 freight</td><td rowspan="2">420</td><td>A-E-İ-E-A
(three passenger trains and one freight train)</td></tr>
<tr><td>A-K-A (one passenger train and one freight train)</td></tr>
<tr><td rowspan="2">Scenario 11</td><td rowspan="2">6</td><td rowspan="2">4 passenger
2 freight</td><td rowspan="2">440</td><td>A-E-İ-E-A
(two passenger trains and one freight train)</td></tr>
<tr><td>A-K-A (two passenger trains and one freight train)</td></tr>
<tr><td rowspan="2">Scenario 12</td><td rowspan="2">8</td><td rowspan="2">4 passenger
2 freight</td><td rowspan="2">220</td><td>A-E-İ-E-A
(three passenger trains and one freight train)</td></tr>
<tr><td>A-K-A-S-A (one passenger train and one freight train)</td></tr>
<tr><td rowspan="2">Scenario 13</td><td rowspan="2">8</td><td rowspan="2">4 passenger
2 freight</td><td rowspan="2">200</td><td>A-E-İ-E-A
(two passenger trains and one freight train)</td></tr>
<tr><td>A-K-A-S-A (two passenger trains and one freight train)</td></tr>
</table>

4.2.2. TRANSPORTATION OF FREIGHT BY THE SAME TRAINS WITH PASSENGERS

In this section, freight transportation by the same trains with passengers is tested. This is Case A as given in Chapter 4. Figure 22 below gives transportation of freight by the same trains with passenger.

A

Figure 22: Transportation of freight by the same trains with passengers

In this case, to satisfy also transportation of passengers, the speed of the HSTs cannot be reduced so much, which was the case in transportation of freight by different trains from passengers. The model will be solved to evaluate a schedule for trains and calculate number of minutes left within a day after daily freight and passenger transportations are carried out. Travel times for trains that transport both passengers and freight becomes lower than the case in which freight is transported by different HSTs and higher than the case in which only passengers are transported by HSTs. Travel times between Ankara-Eskişehir (A-E), Ankara-Konya (A-K), Eskişehir-İstanbul (E-İ) and Ankara-Sivas (A-S) are taken as 100, 125, 120 and 190 minutes respectively in the model. These values are calculated as average by considering the distances between the cities and speed of the trains. Speed of the trains which transport both passenger and freight is assumed to be 145 km/h in this thesis, which is a feasible speed in real life since light goods such as postal mail will be transported. In Table 8, service times and average speeds of freight and passenger trains are summarized for each pair of cities used in the experimental study:

Table 8: Service times and average speeds of freight and passenger HSTs

	Between A-E	Between A-K	Between E-İ	Between A-S	Average Speed
Only passenger	90 min	115 min	105 min	170 min	165 km/h
Case A	100 min	125 min	120 min	190 min	145 km/h
Case C	120 min	155 min	145 min	230 min	120 km/h

Since freight is added to the model again in this case, all the objective function values decrease in all scenarios when compared with the case in which only passenger experiments are observed. Now, the scenarios will be repeated for this case and the results will be compared with the results of freight transportation by different trains from passengers.

In Scenario 14, the sequence of cities A-E-A-K-A with six trains by which freight and passengers are transported is observed. The objective function value becomes 455 minutes so, 455 minutes are left in a day after transportation of freight and passengers.

Now, İstanbul is added to the model as Scenario 15 in two different ways such as A-E-İ-E-A-K-A and İ-E-A-K-A-E-İ with six trains. The only difference between these ways is that they have different beginning and ending stations. The same objective function value is obtained since total distance travelled and the total time spent in stations in a day for each way amount to the same thing. In Scenario 15, it is observed that 125 min are left within a day. After adding İstanbul to the sequence, time left in a day reduces to 125 min. Figure 23 gives this relationship, namely shows effect of increasing number of links on objective function value:

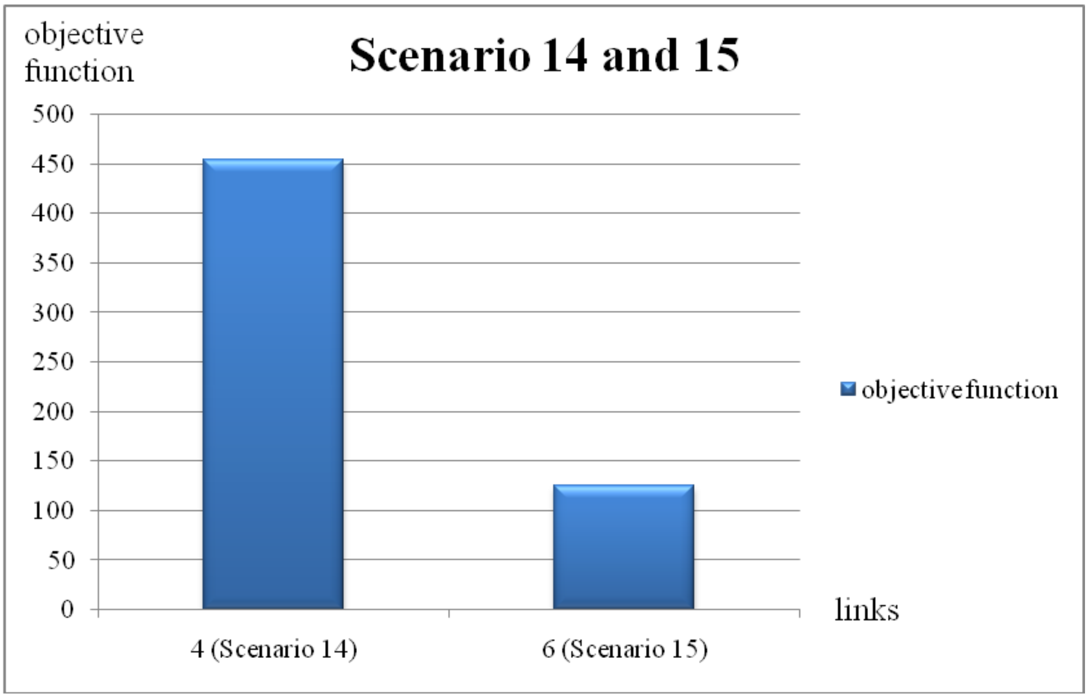

Figure 23: The effect of number of links on the objective function value for Scenario 14 and 15

In Scenario 16, Sivas is added to the model. However, number of minutes in a day is not enough to realize this scenario in a day since time left in a day was 125 minutes in Scenario 15 and 380 minutes (=190x2) are needed for only travel between Ankara and Sivas. Therefore, the scenarios will be realized now by dividing the sequence of cities into two; so, by allocating the trains to these sequences.

Firstly, the sequence of cities in Scenario 15 are divided into two such as A-E-İ-E-A and A-K-A or İ-E-A-E-İ and A-K-A in Scenario 17. Four trains will be used for the sequence A-E-İ-E-A and two trains will be used for the sequence A-K-A (or, four trains for İ-E-A-E-İ and two trains for A-K-A). The objective function value, which is again the same for two ways as in Scenario 15, increases from 125 min to 505min in Scenario 17. This provides 380 min (=505-125) in a day, namely dividing the sequence of cities and number of trains into two as four trains for A-E-İ-E-A and two trains for A-K-A is more advantageous then using all of six trains for the same sequence (A-E-İ-E-A-K-A).

Secondly, in Scenario 18, number of trains will be divided into two. That is, three of six trains will be allocated for A-E-İ-E-A and the remaining three trains will be allocated for A-K-A. The objective function becomes 525 min which is higher than 505 min (Scenario 17). Then, dividing number of trains into two becomes more advantageous than dividing them as four trains for A-E-İ-E-A and two trains for A-K-A. Therefore, Figure 24 gives the relationship between Scenarios 15, 17 and 18:

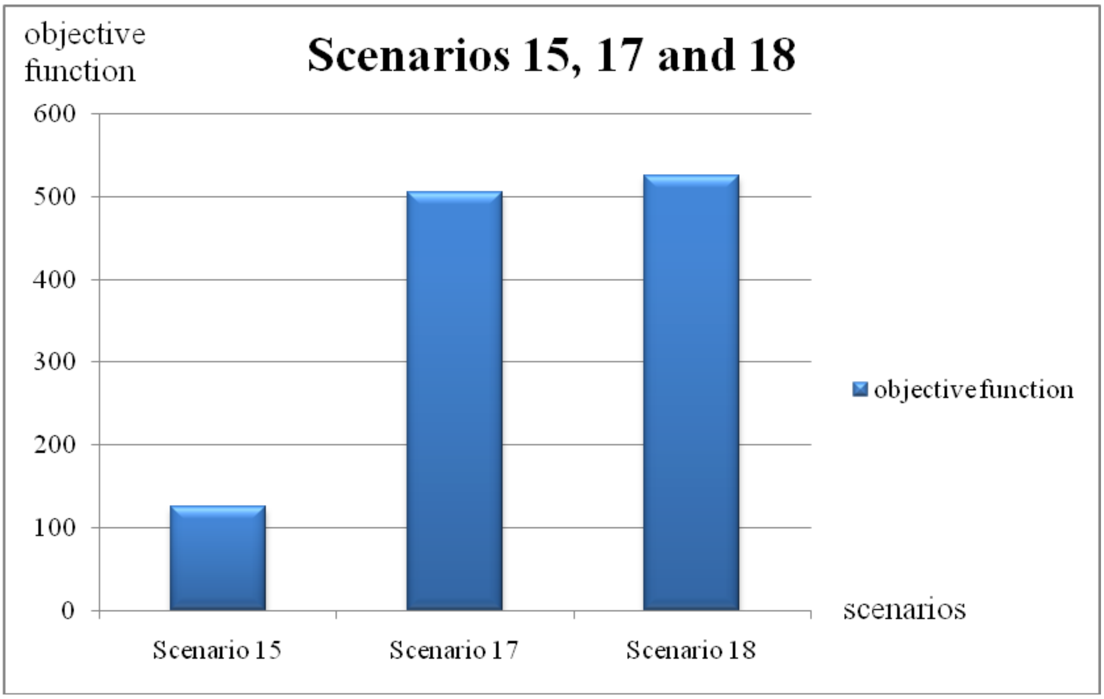

Figure 24: The comparison of Scenarios 15, 17 and 18 in terms of objective function values

Scenario 19 is obtained by dividing the sequence of cities in Scenario 16 into two as A-E-İ-E-A with four trains and A-K-A-S-A with two trains. Number of minutes in a day was not enough to realize Scenario 16 in a day. In Scenario 19, 355 min are left in a day after completing the sequence.

In Scenario 20, the only difference from Scenario 19 is allocation of trains. In this scenario, number of trains is divided intotwo. Three trains are allocated for the sequence A-E-İ-E-A and the remaining three trains will be allocated for the sequence A-K-A-S-A. The objective function value becomes 335 min. This value is less than the value in Scenario 19 which was 355 min. Therefore, Scenario 19 is more advantageous than Scenario 20. That is, dividing them into two as four trains for A-E-İ-E-A and two trains for A-K-A-S-A is more advantageous. Figure 25 gives the relationship between Scenarios 19 and 20.

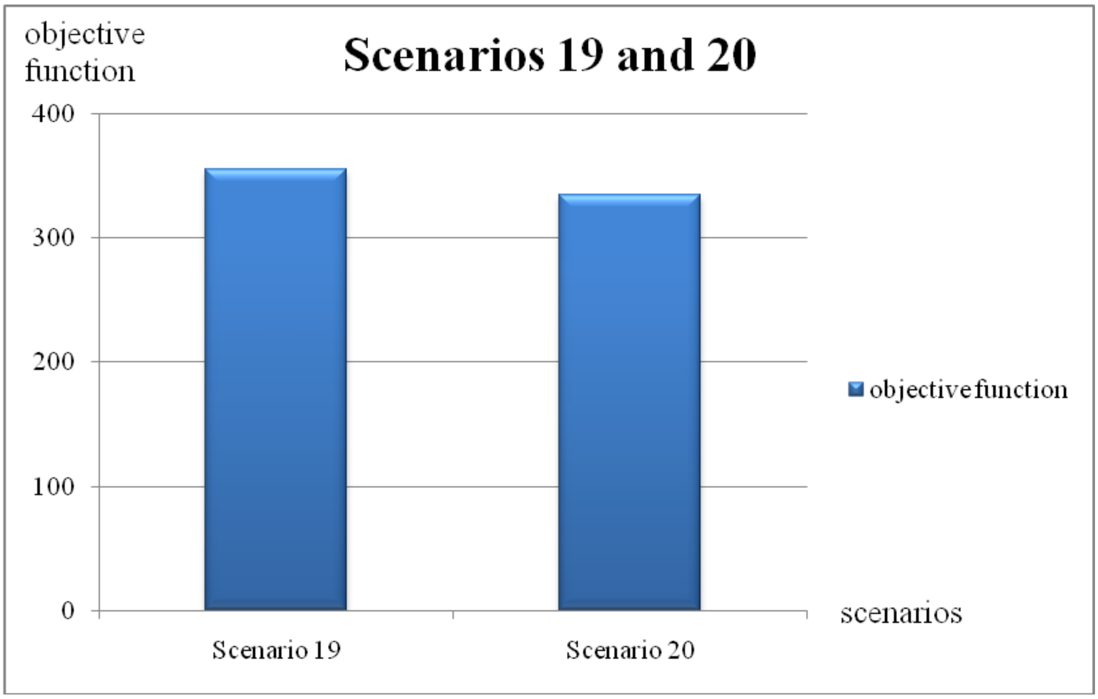

Figure 25: The comparison of Scenarios 19 and 20 in terms of objective function values

Table 9 summarizes the Scenarios from 14 to 20.

Table 9: Summary of the Scenarios from 14 to 20

NUMBER OF SCENARIOS	FACTORS		OBJECTIVE FUNCTION (MIN)	SEQUENCE OF CITIES (INITIAL OF CITIES)
	LINKS	TRAINS		
Scenario 14	4	6	455	A-E-A-K-A
Scenario 15	6	6	125	A-E-İ-E-A-K-A
Scenario 16	8	6	A day is not enough	A-E-İ-E-A-K-A-S-A
Scenario 17	6	6	505	A-E-İ-E-A (four trains)
				A-K-A (two trains)
Scenario 18	6	6	525	A-E-İ-E-A (three trains)
				A-K-A (three trains)
Scenario 19	8	6	355	A-E-İ-E-A (four trains)
				A-K-A-S-A (two trains)
Scenario 20	8	6	335	A-E-İ-E-A (three trains)
				A-K-A-S-A (three trains)

Now, the comparison of three types of experiments, freight transportation by separate trains from passengers (Case C), by the same trains with passengers (Case A) and only passenger transportation is done. Figure26 gives this comparison as below.

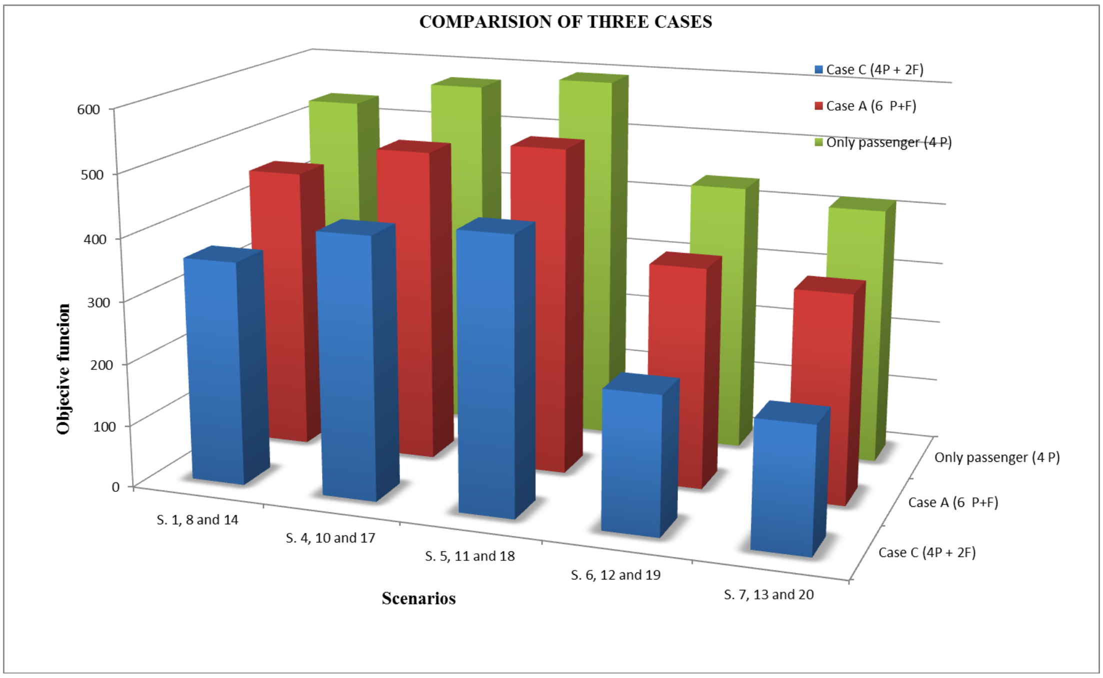

Figure 26: Comparison of three experimental cases

First of all, passenger experiments have the highest objective function values as required. Also, transporting freight by the same trains with passengers gives higher objective function values than transporting it by separate freight trains as shown in Figure 26. This means that freight transportation by the same trains with passengers is more advantageous than the other case for all scenarios; that is, using six trains in common for freight and passengers provides more time savings than the case in which four passenger trains and two freight trains are used separately. However, it should be noted that when six trains are used in common, number of freight wagons is six since one wagon of each train is separated for freight, in the other case, number of freight wagons is 12 (6x2) since two separate freight trains are used and each train has six wagons. Namely, while time saving is higher in advantageous case, number of freight wagons is lower. This point is important and should be balanced by TCDD.

CONCLUSION

In this thesis, development of railway transportation in the world and in Turkey is analyzed in detail. After discussing advantages of railway transportation including High Speed Rail (HSR) system, freight transportation in HSR system (mixed traffic) is examined from many aspects for Turkish State Railways (TCDD). A scheduling model is constructed to see the effects of freight transportation on the current system. Today, HSR system is used to transport only passengers in Turkey and a new concept is developed for freight transportation in the world. High Speed Trains (HSTs) increase the capacity of railway systems substantially thanks to high speed and up-to-date signaling systems. Therefore, it can be very advantageous to use HSTs in transportation of freight such as postal mail and small cargo.

When mixed traffic is discussed, construction of a time-table becomes vital. If there is empty room for freight transportation in a HST set, freight can be transported by the same trains with passengers by emptying one of the six wagons for freight loading and by reducing the speed of the train. The feasibility for this case is high since average fill rate of HSTs is 70% (for existing lines). If not, freight can be transported by separate trains which can have lower speed than the first case after passenger transportation is completed in a day. These cases are reflected to the model which is solved by GAMS and scenarios are repeated for both of them.

The model in this thesis sequences the trains and gives departure and arrival times of them. The objective function gives time left in a day after completion of daily services. Before observing the effect of freight on the system, scenarios are firstly solved for only passenger transportation. The scenarios are created by taking into account lines between Ankara-Eskişehir (A-E), Ankara-Konya (A-K), Ankara-Sivas (A-S) and Eskişehir-İstanbul (E-İ). In the scenarios, the sequence of cities that trains must complete each day is extended and divided into two if number of minutes in a day is not enough to realize that sequence. The trains are also allocated to these sequences in different ways to see the effect of them on objective function. When the model is solved for only passenger transportation in High Speed Lines (HSLs) with four trains in a day, the allocation of the trains is done in such a way that three trains are used for lines between the cities of Ankara, Eskişehir and İstanbul and one train is used for lines between the cities of Ankara, Konya and Sivas. Then, number of trains is divided into two for these sequences of cities.

When freight is added to the system, time left in a day after completion of services is reduced for both cases which are freight transportation by the same trains with passengers and by separate freight trains. For the first case of transporting freight by separate freight trains, two freight trains are added to the system which had only four passenger trains. If a day is not enough to realize the sequence, the allocation of trains becomes as the following. Three passenger trains and one freight train (four trains in total) are used for the lines between the cities of Ankara, Eskişehir and İstanbul. One passenger and one freight train (two trains in total) are used for the lines between the cities of Ankara, Konya and Sivas. Then, number of trains is divided into two and, two passenger trains and one freight train (three trains in total) are used for these sequences of cities.

For the second case of transporting freight by the same trains with passengers, two freight trains are again added to the system.Four trains are used for the lines between the cities of Ankara, Eskişehir and İstanbul. Two trains are used for thelines between thecities of Ankara, Konya and Sivas. Then, number of trains is divided into two equally and, threetrains at a time are used for these sequences of cities.

Dividing the sequence of cities into two and allocating the trains to them always give better solution in the scenarios. Daily services of trains finishes much earlier and this provides more time savings. However, while some scenarios give better solution for allocation of trains equally to the sequences, the other ones give worse solution, vice versa. Therefore, it cannot be generalized.

When freight transportation by the same trains with passengers is examined, it can be concluded that it is more advantageous than the case in which freight is transported by separate trains. This means that using six trains in common for freight and passengers provides more time saving than the case in which four passenger trains and two freight trains are used separately.

As a result, freight transportation in HSR is a complex task to achieve and requires many factors to be taken into account. This thesis is a first attempt to tackle this complex task. As a new concept, it can be realized by TCDD in the light of information in this thesis. Thus, the problems in freight transportation system can be removed and the capacity of the lines can be increased.

In this thesis, the sequences of cities are not comprehensive. All of the possible city pairs are not considered. This is left for future studies. Also, allocating different number of trains to different sequences for freight and passenger is not analyzed in a full experimental setting. Only selected scenarios were investigated. Future studies should search for all possibilities.

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APPENDIX-I

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