DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

FLEET SIZE OPTIMIZATION UNDER CERTAIN ENVIRONMENT

by
Nurhan DUDAKLI

January, 2016
İZMİR

FLEET SIZE OPTIMIZATION UNDER CERTAIN ENVIRONMENT

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of Science
in Industrial Engineering, Industrial Engineering Program

by

Nurhan DUDAKLI

January, 2016
İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"FLEET SIZE OPTIMIZATION UNDER CERTAIN ENVIRONMENT"** completed by **NURHAN DUDAKLI** under supervision of **PROF. DR. ADİL BAYKASOĞLU** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ACKNOWLEDGMENT

Firstly, I would like to express my gratitude to my supervisor, Prof. Dr. Adil BAYKASOĞLU for his guidance; unfailing advice, continuing support and encouragement that helped me overcome challenges throughout the present work.

I would like to present thanks to Assoc. Prof. Dr. A. Serdar TAŞAN for his guidance and suggestions. I would also thank to Res. Assist. Kemal SUBULAN for his contribution to this study.

I would like to thank, everyone who have helped me throughout the progress of dissertation, my colleagues and all staff member in department of Industrial Engineering. Especially I am grateful to my friends, Burcu KUBUR, M. Emre ŞENOL and F. Selen KARASLAN for their helpfulness, encouragement and listening to my complaints while writing this dissertation. Also, a special thanks to my friends Merve GÜNDOĞDU for giving moral and making more fun this period.

Finally, I would like to express my deep thankfulness to my family, who have loved and supported me whole my life, Nurettin DUDAKLI, Vedia DUDAKLI and elder brother Orhan DUDAKLI. But the most, I am grateful to my sister Nurcihan DUDAKLI for her endless patience, encouragement, continuous support and for providing me comfortable condition to finish my thesis.

This dissertation has been supported by TÜBİTAK - BİDEB in the scope of 2210-A General Domestic Graduate Scholarship Program.

This dissertation has been supported by Ministry of Science, Industry and Technology of Turkey in the scope of SAN-TEZ project No: 0617.STZ.2014.

Nurhan DUDAKLI

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ABSTRACT

This dissertation is conducted to determine optimal fleet size of vehicles on an intermodal transportation network with the perspective of drayage operators. Still, so many factors affecting fleet size such as infrastructure of intermodal network, service and route choices, allocation of resources etc. are taken into account. Thus, fleet size optimization and related problems in the intermodal transportation networks are investigated extensively. Consequently, it is deduced that appropriate fleet size cannot be determined without modeling and solving freight and fleet planning problems in an integrated and simultaneous way.

Accordingly, a mixed-integer linear programming (MILP) model is developed to solve fleet sizing problem of Ekol Logistics Company, which is an important logistics company in Turkey, under some assumptions. In scope of this dissertation, it is aimed to obtain an aggregated plan, which allows the company to conduct the right strategies and polices for one-year planning horizon. The ideal solution that minimizes total cost of the logistics system is obtained by executing the developed MILP model via optimization software LINGO 14.0. The optimum vehicle numbers are determined by constituting freight plan (transport modes and routes choice) and fleet plan (vehicle allocation, reallocation, loaded and empty vehicle movements).

Finally, the developed MILP model is used to analyze existing intermodal transportation network under different conditions and scenarios. Primarily, effects of implementing some strategic decisions are investigated in terms of total cost, freight and fleet plans. After that, the more general cases are discussed to find out effects of using different transportation policies such as shipment without rail and marine transport. Withal, modality effect on total costs, freight plan and fleet structure (especially on fleet size) are revealed by analysis. The results clearly show that integrating modes as much as possible is more efficient and cost effective way to transport fright.

Keywords: Fleet size optimization, freight and fleet planning in intermodal transportation, mixed integer linear programming, fleet management, intermodal transportation systems.

BELİRLİ ÇEVRE KOŞULLARI ALTINDA FİLO BÜYÜKLÜĞÜ OPTİMİZASYONU

ÖZ

Bu tez, karayolu taşımacılığını temel alarak, bir intermodal taşımacılık ağında ihtiyaç duyulan optimum filo büyüklüğünü belirmek için gerçekleştirilmiştir. Karayolu taşımacılığı temel alınmasına rağmen, intermodal taşıma ağının altyapısı, servis tipi ve rota seçimi, kaynakların konumlandırılması gibi filo büyüklüğüne etki eden birçok unsur göz önünde bulundurulmuştur. Bu nedenle, intermodal taşımacılıkta, filo büyüklüğü optimizasyonu ve onunla ilgili tüm problemler kapsamlı olarak araştırılmıştır. Sonuç olarak, doğru filo büyüklüğünün belirlenmesinin, ancak yük ve filo planlama problemlerinin entegre ve eş zamanlı modellenip çözülmesi ile mümkün olabileceği anlaşılmıştır.

Buna bağlamda, Türkiye'nin en büyük ve önemli lojistik firmalarından biri olan, Ekol Lojistik şirketinin filo büyüklüğü problemini, çeşitli varsayımlar altında çözmek için karma tamsayılı bir doğrusal programlama modeli geliştirilmiştir. Bu tez kapsamında, şirketin bir yıllık planlama dönemi boyunca doğru strateji ve politikalar geliştirmesine imkân sağlayacak, bütünleşik bir plan elde edilmek istenmiştir. Lojistik ağının toplam maliyetini minimize eden ideal sonuçlar, geliştirilen karma tamsayılı matematiksel modelin LİNGO 14.0 optimizasyon yazılımı kullanılarak çözülmesi ile elde edilmiştir. Optimum araç sayısı, eş zamanlı olarak yük planının (mod ve rota seçimi) ve filo planının (araç konumlandırma, yeniden konumlandırma, dolu ve boş araç hareketleri) oluşturulması ile elde edilmiştir.

Son olarak, geliştirilen matematiksel model yardımıyla, firmanın intermodal taşımacılık ağı faklı durum ve koşullar altında analiz edilmiştir. Öncelikle, bazı stratejik kararların uygulanmasının toplam maliyete, yük ve filo planına etkisi araştırılmıştır. Daha sonra, demiryolu ve deniz yolu taşımacılığını kullanmama gibi farklı taşıma politikalarının etkilerini ortaya çıkaracak daha genel analizler yapılmıştır. Bununla beraber, taşıma şekillerinin toplam maliyete, yük planına ve filo

planına (özellikle filo büyüklüğüne) etkisi ortaya konmuştur. Sonuçlar, olabildiğince çok modun entegre edilmesi ile daha verimli ve maliyet etkin taşımacılık yapıldığını açıkça göstermektedir.

Anahtar kelimeler: Filo büyüklüğü optimizasyonu, intermodal taşımacılıkta yük ve filo planlama, karma tamsayılı doğrusal programlama, filo yönetimi, intermodal taşımacılık sistemleri.

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CHAPTER ONE
INTRODUCTION

1.1 Importance of the Study

1.1.1 Aspect of Executers

Freight transportation is the flow of the goods, therefore the backbone of the commerce and a vital component of the economy. Recent studies indicate that logistics costs are almost 18-23%'s of the total product cost. With the increasing competitive environment in the globalized world, companies intend to reduce their logistics costs to be more competitive in the market as they cannot reduce their raw material costs (Okşaş, 2014). Withal, freight transportation is one of the most important logistics activities. In general scope, it is transportation of goods and has a significant share nearly 67% in logistics cost (Köfteci, 2008). Furthermore, it is important component of the national expenditure of any country.

A transportation system consists of various sub-modes with different characteristic; such as road, rail, maritime, inland waterways, air, and pipeline. Broadly, freight transportation can be divided in two major parts as unimodal and multimodal transportation. Traditionally, unimodal transportation system is operated by using only one of the road, rail, maritime, air and pipeline transport. However, general approach in recent years all over the world is considering transportation as a whole and using benefit of all transport systems in the same transportation chain. The multimodal transportation is a solution, which is operationally feasible, economically viable, and environmentally sustainable. On the other hand, intermodal is a particular type of the multimodal transportation in which goods are transported in one and same transport unit by successive modes of transport. It is aimed to combine transport modes in efficient and cost effective way to transport a load of goods to its final destinations by using best effect of each individual mode. In addition, there is equal importance of the environmentally beneficial objectives of reducing air pollution, noise, vibration and the risk of traffic accidence. However, the primary purpose of

the logistic companies, as all commercial companies, is to ensure customer satisfaction at minimum cost. Therefore, logistics companies require sufficient number of vehicle in order to meet transport demands. Fleet size problem can be summed as how many vehicles should a firm have on its transport fleet. Thus, determining the optimal fleet size is one of the most important tasks in fleet management in order to meet transport demands.

The problem of determining optimal fleet size compounds strategic, tactical and operational decisions. In detail, contradictory between capital expenditures related to vehicle purchases and service level lead to seeking optimum fleet size and composition in strategic level. Capital expenditure depending on vehicle purchasing and customer service level constitutes a conflict for companies. A small fleet might be insufficient to meet all transportation demands or to ensure high service level/quality. The companies could increase customer service level by having large number of vehicle by investing and expanding their fleet. On the other hand, they would increase capital spending, holding and maintenance cost due to having large number vehicles. In addition, logistics companies can use other logistic providers to transport their freight as well as their own transport fleet. These cause companies to avoid unnecessary large fleet size. Asset purchases and sales, outsourcing, demand/load and vehicle allocation constitute tactical level decisions, whereas operational level decisions involve vehicle routing and scheduling, empty vehicle repositioning issues etc. In spite of the decision hierarchy, problems are economically interdependent.

Hence, fleet size optimization should be considered with other decision problems since the fleet size is interdependent and linked economically with tactical and operational problems. In detail, fleet allocation problem deals with the optimal allocations of the total available vehicle to various routes (i.e., fleet size on various routes), in order to meet all expected demand (or some portion of it) and keep the operations cost at minimum. On the other hand, fleet sizing problem is closely related to practical decision-making problems such as how full and empty vehicles will be positioned along transportation network. A poorly designed equipment

redistribution policy can result in inefficient fleet utilization, and excessive fleet requirements. Thus, these problems have to be handled in an integrated way, too.

The other important issue is the mode selection problem in scope of freight planning. When shipping alternatives exist, the selection of the appropriate shipping alternative (mode) for each shipment may result in significant cost savings. Such a situation leads to mode selection (load allocation) problem, which highly related with vehicle routing, fleet allocation, and fleet sizing problems. Thus, load planning and fleet sizing should be considered in integrated way.

Eventually, we can conclude that the fleet-sizing problem should be addressed in integrated and simultaneous manner with all sub-problems of the fleet size. Appropriate freight planning and fleet sizing ensure not only efficiency and customer satisfaction but also reduction of environmental pollution. However, there are few tactical and practical studies in the literature concerned fleet sizing in this manner.

Fleet sizing problems, which are dealt with real cases, are more complex due to including all features that mentioned above. Although there are many theoretical studies on load planning and vehicle routing, the number of the real life applications such as decision support systems is considerably less than theoretical studies in literature (Couillard, & Martel, 1990; Jansen, et al., 2004; Fazi, et al., 2013). Such a decision support system provides cost and time efficient plan for logistics planners. However, Caris et al. (2013) stated that the inclusion of all the actors in the decision support tools is still an issue. Only looking at the problems from one point of view creates suboptimal solutions. A better understanding of all involved actors, and their objectives, will enable to integrate them in the decision support systems. Authors also hoped that these models would be more and more relied on by the policy makers, and would not be left in the scientific world.

Transportation systems are complex organizations, which involve great number of human and material resources. Besides, there are many complicated relationships and trade-offs among the various decisions and management policies. By its nature,

intermodal transport demonstrates an increased complexity due to the use of multiple modes of transportation and the involvement of multiple decision makers. Accordingly, planning problems in intermodal freight transportation can be related to four decision makers, based on four main activities in intermodal freight transport. These are drayage, terminal, network and intermodal operators. All operators in question face with different decision and management problems at strategic, tactical and operational levels. Besides, the term intermodal transport implies integration between different operators in the transport chain. The different transport modes should not only be optimized separately, but they should also be attuned to one another in intermodal systems.

1.1.2 Aspect of Researchers

Transportation vehicles are expensive capital items and fleet sizing is important issue for both transportation service providers and researcher. Fleet sizing problem is usually based on principle of establishing a balance between service capacity and demand and aims to determine optimal number of vehicles. Early studies handled fleet sizing problem, was comparatively simpler in terms of problem structures and solution approaches. The problem was mostly considered single-mode (road) and single-period with homogeneous fleets (Kirby, 1959; Mole, 1975; Parikh, 1977; Williams & Fowler, 1980). Especially fleet sizing problem was getting many aspects after the intermodal transportation system was being a significant transportation issue by the early 1990s. However, most of the studies concerning intermodal transportation focus on service network design, load planning, mode selection, etc. (Guelat et al. 1990; Bierwirth et al., 2012, Meisel et al., 2013). As far as known, there is no such a study dealing with optimal fleet size by taking into account all intermodal networks in an integrated manner.

Fleet sizing problem is not only associated with demand or service level, it is highly related with utilization of the vehicles. In detail, there are important interactions between vehicle allocation, empty vehicle reallocation/repositioning, loaded and empty vehicle movements. Even though voluminous studies exist in

literature for these problems, a few studies deal with combination of them. For instance, there are some works on fleet sizing and allocation (Beaujon & Tunquist, 1991; Köchel et al., 2003), fleet sizing and reallocation/repositioning (Sayarshad & Moghaddam, 2010, Carbajal et al., 2013), and fleet sizing and routing/scheduling (List et al., 2003; Wu et al., 2005; Nossack & Pesch, 2013). However, no work has been reported on the simultaneous optimization of the fleet size allocation, reallocation/redistribution and routing/scheduling due to complexity and NP hard structure of the problem.

Because vehicles are generally long-lived assets, there is uncertainty about the demands and about the conditions under which they will operate. Only few studies tackle with the uncertainty derived from demands or operations (List et al., 2003; Wu et al., 2005; Roy et. al., 2013). On the other hand, the problem may be static, considering an "isolated" or typical planning period, or dynamic, where the problem has to be solved over several contiguous periods. Fleet sizing is mostly considered as a static optimization problem and few studies examined the problem as a dynamic optimization problem (Zhao et al., 2001; List et al., 2003; Wu et al., 2005; Sayarshad & Ghoseiri, 2009; Cheon et al., 2012). However, fleet sizing problem has both stochastic and dynamic structure in real life and the number of studies handling dynamic and stochastic models is quite limited (List et al., 2003; Wu et al., 2005; Sayarshad & Moghaddam, 2010; Dong & Song, 2012).

Fleet size optimization problems handled in the literature has begun to be more complex due to fits real cases including all features that mentioned above. Although there are many theoretical studies on load planning and vehicle routing, the number of the real life applications such as decision support systems is considerably less than theoretical studies in literature (Couillard & Martel, 1990; Jansen et al., 2004; Fazi et al., 2013). Such a decision support system provides cost and time efficient plan for logistic planners.

Although Operational Research mostly focus on unimodal freight transportation problems, in recent years multi-modal (especially intermodal) transport systems has

become important issue for both executers and researchers because of environmental sensitivity as well as the overall efficiency due to using different transportation modes. However, load and fleet planning have got difficult owing to the complexity of the system. Already, this study is conducted to determine optimal fleet size on intermodal transportation network with the perspective of drayage operators by taking into account all aspects related with fleet size optimization. A mixed integer linear programming (MILP) model is developed to conduct multi-mode, multi-period freight plan and multi resource plan by considering all intermodal transportation networks. In addition, developed model will be the basis for a decision support system and will not be left in the scientific world.

Contributions of this study can be summarized in five main heading:

1. Integration of different decision makers (actors) and different planning problems (freight and fleet planning) in the intermodal network.
2. Integration of the different decision levels interrelated with fleet size (mode and route selection, fleet allocation, empty vehicle repositioning, etc).
3. Integration of different resource (train, trailer, truck).
4. Integration of three different transportation mode as intermodal transport (road, rail and maritime).
5. In addition to all, taking into account of dynamic aspects of the problems (multi-period planning for long-term).

1.2 Framework of the Dissertation

This dissertation is conducted to determine optimal fleet size and allocation of resources on an intermodal transportation network with the perspective of drayage operators. Thus, some strategic decisions such as network design, Ro-Ro vessel and train schedules, etc. are not considered in scope of this study. However, this information is taken into account and used as constraints of the intermodal network. On the other hand, freight flow (mode and route selection), number of required trains, trucks and trailers are determined. Appropriate number of trucks and trailers are allocated on the routes and nodes in order to minimize empty vehicle movements so as to minimize total cost of the transportation network. However, we should point out that this study carried out to obtain an aggregated plan, which allows the company to conduct the right strategies and polices for one-year planning horizon. Thus, operations management is not dealt in detail; only carried out in aggregated manner. Already, an aggregate plan should be constituted in able to construct a detailed operations plan.

We can summarize framework of the study as follow:

- A specific intermodal transportation network (belongs to Ekol Logistics Company) is considered in this study.
- It is aimed to model and solve the freight-planning problem (mode and route selection) and fleet-sizing problem (by considering allocation, repositioning, and outsourcing problem) in an integrated and simultaneous way.

Transportation mode combinations, which considered in the study, are:

1. Road Transportation
2. Marine + Road Transportation
3. Marine + Rail + Road Transportation

A mixed integer-programming model is developed to determine optimum fleet size of multi-resource by considering the whole transportation network. Additionally, a multi-mode, multi-period freight plan is constructed by solving developed mixed-integer linear programming model. Briefly, this study is carried out to determine:

1. Optimum routes of freights
2. Optimum fleet size of the resources
3. Optimum allocation of the resources

Developed model is based on the following situation and assumptions. These assumptions are made with experts of associate company and based on working conditions, agreements, contracts, customs clearance etc. Actually, these assumptions constitute the general structure of the problem handled in this study.

1. All operations, decisions and plans are conducted in aggregated manner since planning horizon of the company is 12 month/1 year.
2. Freights are shipped between specific origin-destination points in Turkey and Europe as import and export transportation.
3. Freights can be transported by all modes to all customers. There is no restriction about freight routes.
4. It is not allowed to delayed or deferred customer demands. All transport demand is met within the relevant period.
5. Consolidation and distribution of freights to end customers are not considered since an aggregated plan constructed.
6. Freights are not consolidated or stored on the ports and terminals.
7. Pre/end haulage in Turkey is not considered.
8. One transportation unit (TU) is one trailer.
9. Less than Truck loaded ((LTL) is not allowed.
10. Trailer requirements occur only at ports in Turkey and hubs in Europe because they do not go through any process meanwhile transportation.
11. Truck requirements occur at ports, terminals and hubs in order to transport trailers while transport mode of trailer changing.

12. All trucks are same, and all trailers are same (homogenous fleets).
13. Owned and other logistics providers' Ro-Ro vessels are used for marine transportation. Ro-Ro vessels have a fixed schedule and cannot be change.
14. Block and public trains are used for rail transportation.
15. There is upper bound about the number of trips of owned vessels/block trains per month. Additionally, each vessel and train has their own capacities.
16. There is no restriction about outsourcing.
17. Fleet size of vehicles is determined in each period by considering loaded and empty vehicle movements (repositioning), transportation times and length of the period, and vehicle availability.
18. Vehicles are optimally allocated to the different lines and nodes at the beginning of each period so as to minimize empty vehicle movements (repositioning).
19. Company has two different truck types as European and Turkish plated when one type trailer is available. Generally, only European plated trucks serve in Europe because of legal obligations.
20. Transportation times between nodes on network include loading and unloading times.
21. Transportation costs are per TU except for block trains. Transportation cost by block train is independent of unit cost.
22. Transportation times and costs are symmetric (same for both directions).
23. Total cost contains all transportation, outsourcing (variable costs) and vehicle costs (fixed costs) such as holding, maintenance costs.
24. Vehicle allocation to the lines and repositioning on the same line during each period is concerned. However, reallocation of the vehicles to different routes/nodes between different time periods is not concerned.
25. It is not allowed to fleet extension or reduction throughout the planning horizon. It is just aimed that to determine optimal number of vehicles required in each period.
26. It is assumed that customer demands, transportation times and all cost are exactly known and constant.

As mentioned before, fleet sizing is highly related with empty vehicle repositioning and freight flows. A poorly designed repositioning policy and freight flows can result in inefficient fleet utilization, and excessive fleet requirements. Therefore, a decision support systems based on mathematical modeling is developed for real-world intermodal planning problems. By solving these problems in an integrated and simultaneous way, effective freight plan and efficient fleet plan are obtained for a real intermodal transportation network.

1.3 Outline of the Dissertation

The dissertation involves six chapters. Following chapter contains concept of freight transportation and planning problem in freight transportation systems. In this section, transport systems are classified according to number of transport mode used during freight transportation. Chapter mainly focuses on intermodal transportation and planning problems in intermodal transportation systems.

Chapter three gives detailed information about fleet size optimization that one of the most important planning problems and subject of this dissertation. Problem definition including structure and hierarchy of related problems, and a literature survey on fleet sizing problem are given in this section. In addition, future prospects related to fleet management is specified as a result of extended literature review.

Chapter four focuses on a real-world fleet-sizing problem and specifications of the problem that belongs to Ekol Logistic Inc., and the proposed mixed integer linear programming model is presented in this chapter. In general, chapter four consists of two main parts. The first part describes the large and complex intermodal transportation network where the company serves its customers located mostly in Europe and Turkey. Besides, framework of the problem, assumptions and notation related to the developed model is given in succeeding section. The second part is constituted by developing mathematical programming model. The objective function, freight and fleet constraints related to the developed mixed-integer linear programming model is explained in detail in relevant sections. At the end of the

chapter, an illustrative example is given for a better understanding how to determine fleet size and how to allocate optimally.

Chapter five is where the developed model is implemented to the real intermodal transportation network belonging to Ekol Logistics Company. The ideal solution that obtained after executing MILP model is presented in the first section of the chapter. On the succeeding sections, the results, which are obtained under different conditions and scenarios, are discussed and analyzed. Primarily, effects of implementing some strategic decisions are investigated in terms of total cost, freight and fleet plan. Later, the more general cases are discussed to find out effects of using different transportation policies such as shipment without rail and marine transport. Moreover, modality effect on total costs, freight transportation and fleet structure are revealed by analysis.

Finally, in addition to summary of the dissertation, the contributions of the study and future works that will improve this study are discussed in the conclusion chapter.

CHAPTER TWO
FREIGT TRANSPORTATION AND PLANNING PROBLEMS

2.1 Introduction

Logistics has gained importance in 21st century as the ability of moving all resources through entire organization in a harmonies way in order to achieve goals of the business. Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements" (Council of Logistic Management- CLM). Logistics, briefly, are significant "value-added activities" within a framework in which right product are transported to the right place at right time in an undamaged way (Tuna, 2001).

Contrary on the thought, studies considered transportation and logistics are not quite new. This interest goes up to the transportation economics lecture opening in Yale University in 1850s. Throughout history, the emphasis and development of the transport bring about development of economy, thus it has increased interest among economists. However, with the emergence of new modes of transport, complex transportation systems are no longer concern of the economists (Orhan, 2003). In the 1970s, the foundation of the modern logistics has occurred. During these years, companies have considered logistics management and carried out studies to have done logistics activities better and at less cost. In the 1990s, researches have gained great momentum by increasing academics interest in parallel with the interest of the companies in this area. Thus, theories about renewal of the logistics systems have begun to be implemented.

Developments in the word markets in the last quarter of the 20th century led companies to reconsider their market access and speed. Consequently, logistics companies are born to create solutions for different needs of customers with competitive cost in an optimum time thereby gathering logistics activities under the

same roof. Logistics sector is a service sector having close relation and affecting directly all other sectors. Today, logistics sector has significant share in the service sector and the effect created is an important criterion in determining the development level of the countries. When considering growing economies in parallel of increasing word population, importance of the logistics will increase, too.

2.2 Freight Transportation

Recent studies indicate that logistics costs are almost 18-23%'s of the total product cost. With the increasing competitive environment in the globalized world, companies intend to reduce their logistics costs to be more competitive in the market since they cannot reduce their raw material costs (Okşaş, 2014). Withal, freight transportation is one of the most important logistics activities. In general scope, it's transportation of goods and has a significant share nearly 67% in logistics cost (Köfteci, 2008). Furthermore, it's important component of the national expenditure of any country.

Freight transportation is the flow of the goods, therefore the backbone of the commerce and a vital component of the economy. It supports production, trade and, consumption activities by ensuring the efficient movement and timely availability of a raw materials and finished goods. Demand for freight transportation drives from the interplay between producers and customers, and significant distances that usually separate them. Producer of goods require transportation services to move raw materials and intermediate products, and to distribute final goods in order to meet demands.

A transportation system consists of various sub-modes with different characteristic; such as road, rail, maritime, inland waterways, air, and pipeline (UNECE, 2009), as shown in Table 2.1, each one has distinct advantages and disadvantages.

Table 2.1 Comparison of transport modes in freight transportation (Çancı & Erdal, 2003)

Transportation Mode	Relative Cost	Relative Speed	Relative Network	Relative Flexibility	Relative Frequency	Relative Reliability
Road	High	High	Extensive	High	High	High
Rail	Low	Medium	Limited& Fixed	High	Low	High
Maritime	Very Low	Very Low	Restricted	Very High	Very Low	Medium
Inland Waterways	Low	Low	Restricted	High	Low	Medium
Air	Very High	Very High	Limited	Low	High	Very High
Pipeline	Low	Low	Very Limited	Very Low	Medium	Very High

The carried goods, the type of transport, transportation modes, transportation distances and environmental effects are different for each transportation system. The choice of transportation mode requires cost analysis between fast shipping and slower but less costly methods. For instance, value-intensive products are handled by air in spite of high cost, because it involves less risk than other transportation modes. Maritime is cost effective, slowest but least risky transportation mode thus, usually used to transport great mass and relatively low value goods. Road transportation cost is in the middle of the sea and air transportation costs and most common form of transportation. Rail is cost effective than road and expensive than maritime, but environmentally friendly and low risky transportation mode.

The freight transportation industry must achieve high performance level in terms of economic efficiency and quality of service. The former, a transportation firm must make a profit while evolving in a competitive and cost-driver market. The latter, transportation services must conform to the high standards impose by the paradigms production and management such as small or no inventory associated with just-in-time procurement, production and distribution on-time personalized services and, customer-driven quality control of the entire logistics chain (Crainic, 2003).

Dramatic improvements, which occur in information and materials handling technologies, have brought opportunities to make serious change in transportation systems. All modes technically has been much faster and safer and reached the point that cannot be even imagined according to the last century. People and goods can pass easily from one mode to another. Consequently, different combination of these modes has been used for effective and efficient planning instead of traditional transportation system. Because of the integration of transportation modes, protection of the natural environment and lower energy consumption concepts have already being discussed and new systems have appeared. At the same time, new policies and regulations resulting from quality of life concerns, significantly affect the operations of the freight transportation. Briefly, two major factors modify how freight transportation is organized and operated. The first one is the evolution of technology in freight transportation caused by industrial innovations, information and software technologies. These improvements allow operationally efficient and cost-effective delivery of goods. The second one is changes in regulatory environment, which includes fixing of tariffs, routes and environmental concerns. Especially in Europe, integrated transportation systems are supported because of environmentally consciousness. In this sense, multimodal and intermodal transportation systems are most commonly used integrated transportation.

Broadly, freight transportation can be divided in two major parts according to the number of the modes used to transport goods. These are the unimodal and the multimodal transportation. Unimodal is the single mode transportation systems in which just one transportation mode is used. However, the network of different combinations of the modes is mostly more powerful than the unimodal. Hence, integrated transportation, which contains more than one transportation mode, is used to satisfy utilization, efficiency, high service quality and environmental sustainability. We can classify transportation systems as in the Figure 2.1.

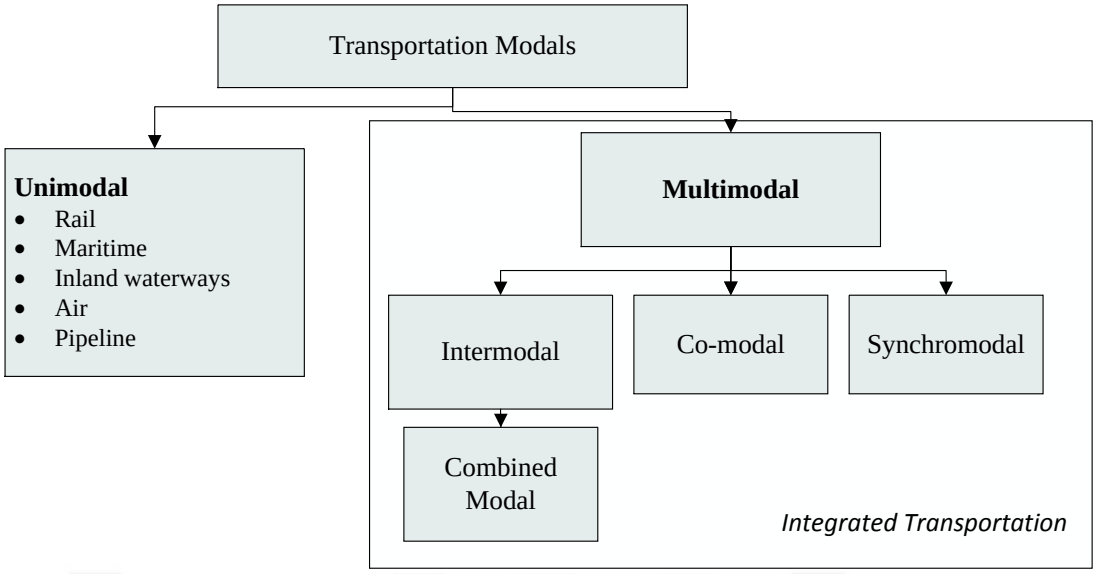


Figure 2.1 Freight transportation modals and integrated transportation

Multimodal, intermodal, co-modal and synchromodal transportation are the example of the integrated systems. Multimodal transportation has the broadest definition and includes other notions. Intermodal is the particular type of the multimodal whereas combined modal is a special type of the intermodal. Co-modal focuses on resource utilization while synchromodal emphasizes the (real time) flexibility aspect. Co-modal and synchromodal are quite new terms and there is no Operations Research (OR) literature concerns these transportation systems (SteadieSeifi, Dellaert, Nuijten, Van Woensel & Raoufi, 2014). Thus, the study proceeds solely on multimodal and intermodal transportation as integrated systems.

2.2.1 Unimodal Transportation

Unimodal is the single mode transportation systems operated by using only one of the road, rail, maritime, air and pipeline transport. The reason for the choice of mode is an important issue in the transportation economy. The factors that determine effectiveness of the modes are listed as speed, suitability for mass transport, network conformity, regularity, continuity, security, energy consumption, investment and operating cost (Saatçioğlu, 2011). One mode can be advantageous and/or disadvantageous to another mode according to counted elements.

However, the cost is the most important factor taken into consideration. Still, the most important factor related to the transport cost is the amount of energy spent for each unit being moved, which is commonly related to the economies of scale that can be achieved with each transport mode. Under such circumstances, maritime transportation is commonly the mode with the lowest cost per ton-mile, while air transportation has higher transport cost. According to the US Department of Transportation, average cost of freight transportation by marine, rail, road and air were respectively 1.16 cents, 3.70 cents, 42.38 cents, 133.23 cents per ton-mile in 2008 (Figure 2.2).

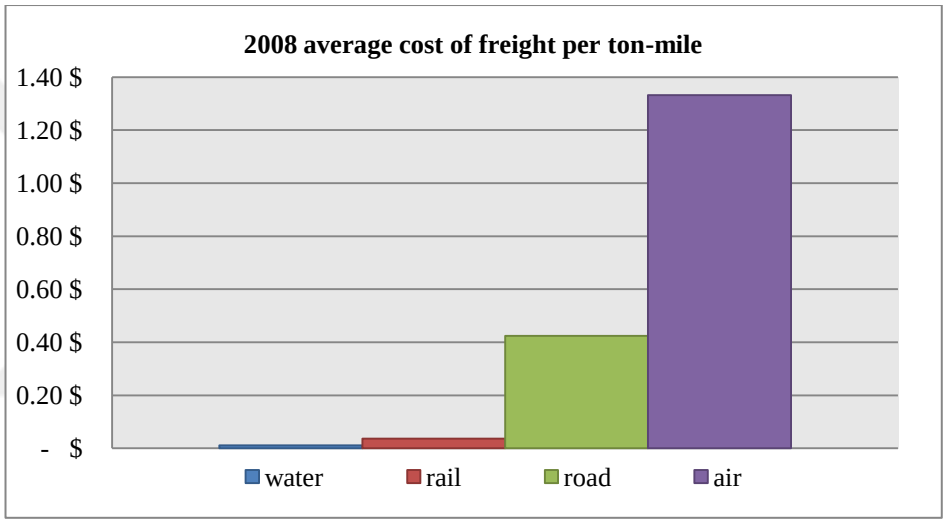


Figure 2.2 Average cost of freight per ton-mile (US Department of Transportation, 2008)

On the other hand, transportation modes have different cost functions related to service distance. Road, rail and maritime transport which are mostly used in freight transportation have respectively a C1, C2 and C3 cost functions as shown in Figure 2.3. While road has a lower cost function for short distances, its cost function climbs faster than rail and maritime cost functions. At a distance D1, it becomes more profitable to use rail transport than road transport while from a distance D2, maritime transport becomes more advantageous. Point D1 is generally located between 500 and 750 km of the point of departure while D2 is near 1,500 km. Even though the relation is straightforward, it gives us approximate distances. Nevertheless, it should be noted that there are also regional differences affecting the breakeven distance.

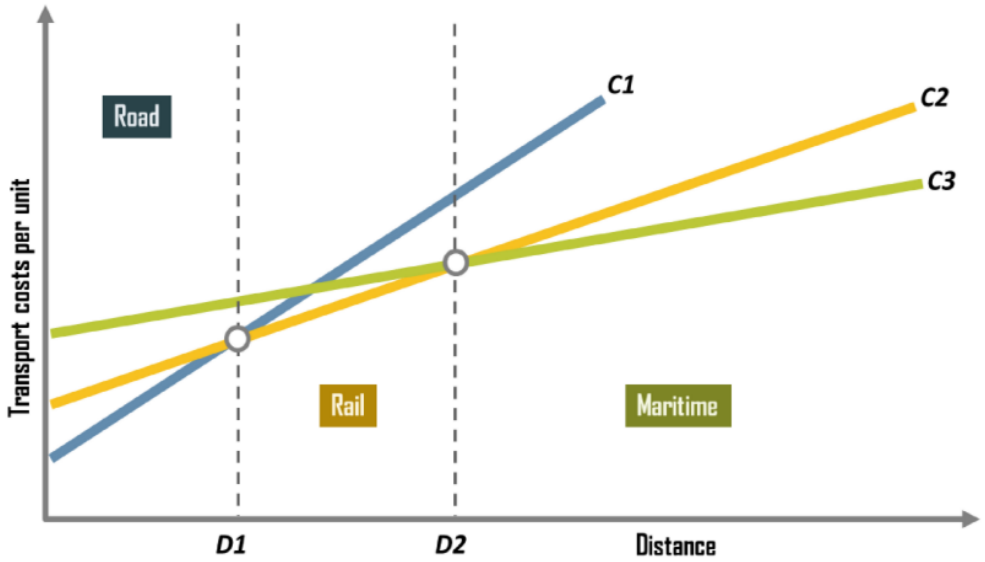


Figure 2.3 Distance, model choice and transport cost (Rodrigue, 2013)

Road offers a more flexible and versatile service when compared with other modes. Although it can provide door-to-door service between suppliers and retailers, its carrying capacity is lower than other modes. Rail offers low transportation cost to move large amount of freight over long distance. However, rail transport has rather less flexibility due to lacking of door-to-door service. Similarly, door-to-door service is quite impossible and speed is low in maritime, but it is more economical to move large amount of freight than all other transportation modes. That is why the maritime is the most commonly used mode in international transportation. On the other hand, the most expensive but the fast and reliable system is the air transportation. Pipeline transportation is used so often in daily life due to using to transport specific loads.

Briefly, only road can provide door-to-door transportation except for special cases. Although widely used, road transportation is not suitable for large amount of freight transporting over long distances particularly for long-haul transportation, as it is expensive. However, in developing and globalizing world, using more than one transport mode has been inventible as a result of the increasing demands in door-to-door transport. Therefore, the use of multimode and integrated transportation is necessary to transport freight economically and safely.

2.2.2 Multimodal Transportation

General approach in recent years all over the world is considering transportation as a whole and using benefit of all transport systems in the same transportation chain. The multimodal transportation is a solution, which is operationally feasible, economically viable and, most importantly environmentally sustainable. Multimodal concept is simple to comprehend. It is defined as the transport of goods by a sequence of at least two different modes of transportation (UNECE, 2009). Transportation units can be a box, container, swap body, vehicle, or a vessel. Regional or national scale and long-distance pickup and delivery services are example of the multimodal transportation (SteadieSeifi et al., 2014).

Even though multimodal and intermodal are used interchangeable in the literature, multimodal is the broadest definition and includes all other integrated and combined systems. Broadly, it is aimed to combine transport modes in efficient and cost effective way to transport a load of goods to its final destinations by using best effect of each individual mode. In addition, there is equal importance of the environmentally beneficial objectives of reducing air pollution, noise, vibration and the risk of traffic accidence. Therefore, multimodal systems are supported because of environmentally consciousness especially in Europe.

2.2.3 Intermodal Transportation

Intermodal and intermodalism practices are relatively new. Although the term of intermodalism is being absent in 1980, the concept that used and implemented in present days emerged by the early 1990s. Intermodal and multi-modal transportation are mostly confused and used interchangeable in the literature as well as in daily life. However, as mentioned before, multimodal is the broadest definition and includes all other combined and integrated transportation chains. Yet, intermodal freight transportation is multimodal transport of goods in one and same intermodal transport unit by successive modes of transport without handling goods themselves when changing modes. Intermodal transport unit can be a container, swap body, or a road

or rail vehicle or a vessel (UNECE, 2009). An example of intermodal transportation is shown in Figure 2.4. Intermodal is a particular type of the multimodal transportation and the key point of the definition is the *same loading unit*. Briefly, intermodal focuses on same loading unit and, this gives flexibility and economies of scale to companies owing to multiple modes. The benefits of the unit-load can be summarized as below (Lowe, 2006);

- lower transit costs over long journeys;
- potentially faster delivery times in certain circumstances (these obviously need to be individually assessed for particular cases);
- a reduction in road congestion (a major beneficial factor in these modern times);
- a more environmentally acceptable solution to congestion and related problems (such as the emission of noise and fumes, the damage caused to the built environment by vibration and so on);
- reduced consumption of fossil fuels since the long-haul section of the route is more fuel efficient;
- safer transit for some dangerous products.

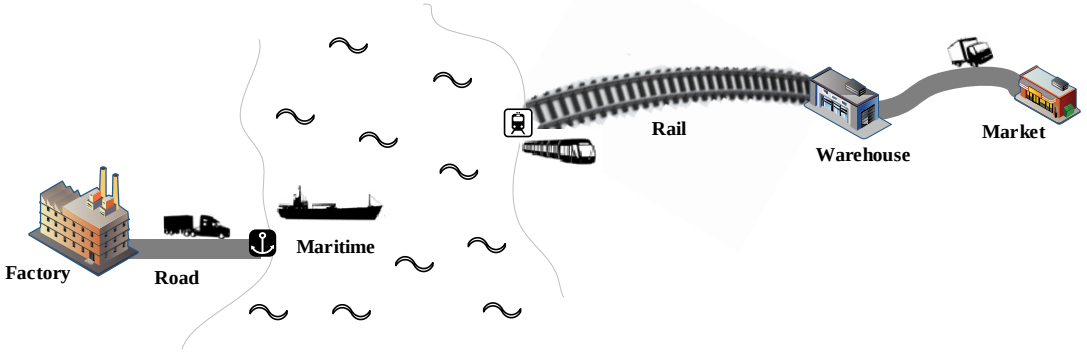


Figure 2.4 An example of intermodal transportation

Road haulage is invariably in the intermodal transportation systems, especially in combination of rail transport. Using these two modes together – commonly referred to as combined road–rail transport – is the predominant intermodal solution. Transportation in this manner is called as combined freight transportation. Combined

freight transport is a special intermodal transport system where the major part of the journey is by rail, inland waterway or sea and any initial and/or final leg carried out by road is as short as possible. Road distance should be (as the crow flies) less than 100 km for road-rail transport and 150 km for road-inland water or sea (UNECE, 2009). Hierarchical relation between these three integrated transportation systems was shown in Figure 2.1.

The intermodal concept is simple to comprehend. Nevertheless, the whys and wherefores of effecting delivery of a particular freight consignment either by a single mode or by utilizing a combination of different modes, is a much more complex issue. Intermodal transport concept is supported in the White Paper of European Transport Policy for 2010: *Time to Decide,* by European Commission for the reason that it contributes to the desirable objective of shifting the balance between modes. As the Commission says (Lowe, 2006, p. xxi):

> Each mode of transport has its own advantages; for example, potential capacity, high levels of safety, flexibility, low energy consumption, low environmental impact. Intermodal transport allows each mode to play its role in building transport chains, which overall, are more efficient, cost effective and sustainable.

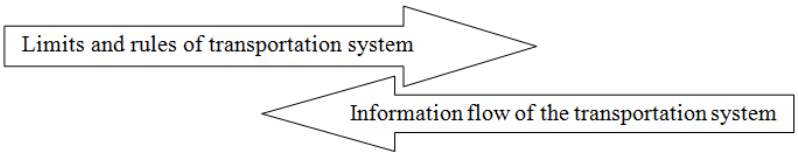
Broadly, the aim of intermodalism is to utilize the most operationally efficient and cost effective combination of transport modes to convey a load of goods to its final destination by using best effect of each individual mode. However, in equal importance, intermodalism is the need to switch freight traffic from inadequate and overcrowded road network on to rail or on to waterway systems, principally with the environmentally beneficial objectives of reducing air pollution, noise, vibration and the risk of road traffic accidents. While the commercial considerations are obviously important to shippers delivering the goods, achieving environmental harmony is a key objective of the sustainable transport policies of governments (Lowe, 2006). Therefore, for many years the European Union has allocated significant funds to work on this issue.

2.3 Planning Problems in Freight Transportation

Transportation systems are complex organizations, which involve great number of human and material resources. Besides, there are many complicated relationships and trade-offs among the various decisions and management policies. Decisions and management problems at issue can be classified in three planning levels based on different time horizons (Table 2.2). These are strategic, tactical and operational planning problems. Broadly, strategic level (long-term) decisions are made for a long time horizon such as 5-10 years whereas tactical levels (medium term) involve a monthly/weekly time periods. Finally, at the operational level (short term) day-to-day or real time decisions are made (Table 2.2).

Table 2.2 Planning problems levels of freight transportation

Decision levels	Strategic	Tactical	Operational
Time horizon	Long term	Medium term	Short term
Time period	Years	Months/Weeks	Day-to-day/Real time
Management topics	Policies	Goals/Rules	Operations
Main concerns	Physical network design	Service network design	Dispatching and scheduling



Strategic decisions include highest level of management and require large capital investments over a long time horizon. This type of decisions can be generalized as design of the physical network, location of the facilities and resources acquisition, which are difficult to change easily and need to a large amount of capital.

The tactical decisions involve a time period monthly/weekly, which aims to ensure efficient and rational allocation of the resource in order to improve the whole performance of the system. It is important to claim that at this level, data is aggregated, policies are abstracted, and decisions are sensitive only to broad variation in data and parameters without incorporating the day-to-day information.

Tactical decisions mainly concern the design of the service network such as route choice and type of service to operate, work allocation, repositioning the resources (e.g. empty vehicles) for use in the next planning period.

Operational decisions are made by local management in highly dynamic environment where time factor is so important. Scheduling, routing and dispatching of vehicles and crews, resource allocation and reallocation are important operational decisions. All decision levels and problems are illustrated in Figure 2.5.

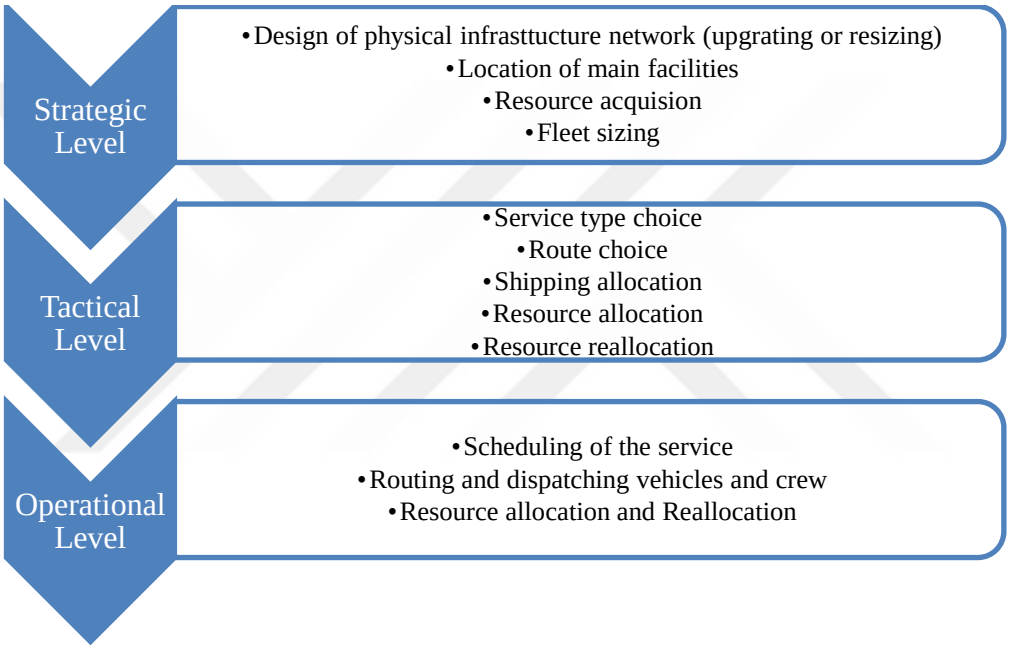


Figure 2.5 Hierarchical relationships of the planning problems

The strategic level sets the general polices and guidelines for the decisions taken at the tactical level, which determines goal, rules, and limits for the operational decision level regulating the transportation system. The data flow takes place in opposite direction, each level of planning supplying information for the decision making process at the higher level. This hierarchical relationship (Figure 2.5) prevents formulation of a unique model for the planning of the transportation systems and calls for different model formulations addressing specific problems at specific levels of decision-making (Crainic & Laporte, 1997).

2.4 Planning Problems in Intermodal Freight Transportation

By its nature, intermodal transport demonstrates an increased complexity due to the use of multiple modes of transportation and the involvement of multiple decision makers. (Caris, Macharis & Janssens, 2013). Planning problems in intermodal freight transportation can be related to four decision makers, based on four main activities in intermodal freight transport (Caris, Macharis & Janssens, 2008; Macharis & Bontekoning, 2004).

1. *Drayage Operators* who organize planning and scheduling trucks between terminals, shippers and receivers.
2. *Terminal Operators* who manage transshipment operation from marine and rail to road, or from road to rail and marine.
3. *Network Operators* who are responsible for the infrastructure planning and organization all transport.
4. *Intermodal Operators* who use intermodal infrastructure and services and select the most appropriate modes and routes for shipments through the whole intermodal network.

Each decision maker of the intermodal system faces with planning problems mentioned in the previous section. When considering these two criteria, type of operator and decision levels of the operations problem, a classification matrix is obtained with 12 categories of intermodal operations problems as shown in Table 2.3. This Table provides a structured overview of planning problems in intermodal transport involving a single decision level and a single decision maker. However, when the transport chain fully integrated a new transportation mode arises. The term intermodal transport further implies integration between different operators in the transport chain. The different transport modes should not only be optimized separately, but they should also be attuned to one another (Caris et al., 2013).

Table 2.3 The relationship between the decision makers and decision levels of the intermodal planning problems (adopted: Caris et al., 2008; Macharis & Bontekoning, 2004)

Decision maker	**Decision levels**		
	Strategic	**Tactical**	**Operational**
Drayage operator	Co-operation between drayage companies Truck and trailer fleet sizing	Allocation of the shippers and receivers locations to terminals Pricing strategies	Vehicle routing and scheduling Redistribution of load units and trailers
Terminal operator	Terminal design	Capacity levels of equipment and labor Redesign of operational routines and layout structure	Resource allocation Scheduling of jobs
Network operator	Infrastructure of the network configuration Location of terminals	Configuration consolidation network Type of production model Pricing strategies	Load orders to the resources Redistribution of railcars, barges and load units
Intermodal operator	n.a.	n.a.	Selection of routes and services Routing and repositioning

CHAPTER THREE
PROBLEM DEFINITION AND LITERATURE REVIEW ON FLEET SIZING PROBLEM

3.1 The Fleet Sizing Problem

Common purpose of the logistic companies, as all commercial companies, is to ensure customer satisfaction at minimum cost. Logistics companies require sufficient number of vehicle that affects transport capacity in order to meet transport demands. Thus, determining the optimal fleet size is one of the most important tasks in fleet management in order to meet transport demands. Additionally, the fleet size depends on the total vehicle travel time, which consists of loaded travel time, empty travel time, loading time, and unloading time. Fleet management decisions, which are considered within the scope of fleet sizing, are shown in Figure 3.1.

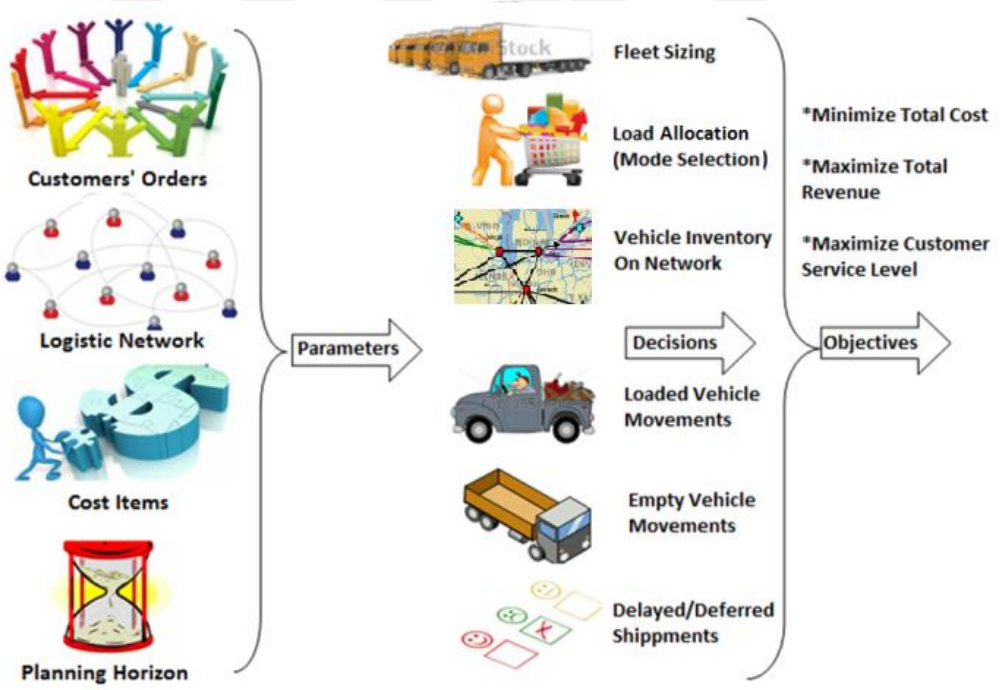


Figure 3.1 Structure of fleet management problems

The problem of determining optimal fleet size compounds strategic, tactical and operational decisions. In detail, contradictory between capital expenditures related to

vehicle purchases and customer service level lead to seeking optimum fleet size and composition in strategic level. Capital expenditure depending on vehicle purchasing and customer service level constitutes a conflict for companies. A small fleet might be insufficient to meet all transportation demands or to ensure high service level/quality. The companies could increase customer service level by having large number of vehicle by investing and expanding their fleet. On the other hand, they would increase capital spending, holding and maintenance cost due to having large number vehicles. In addition, logistics companies can use other logistic providers to transport their freight as well as their own transport fleet. These cause companies to avoid unnecessary large fleet size.

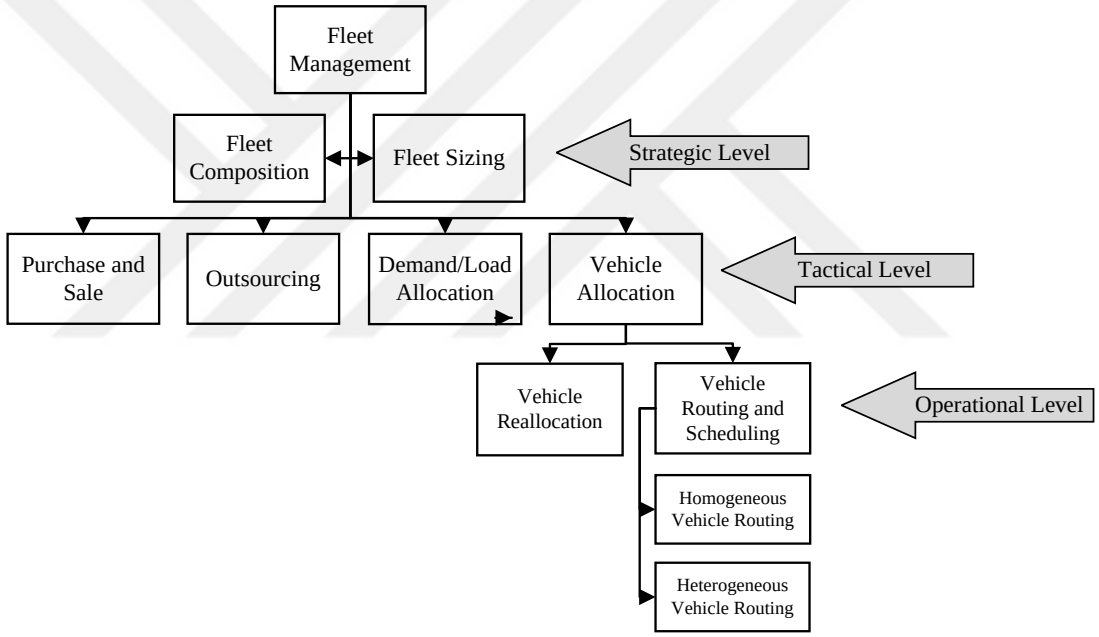


Figure 3.2 Hierarchical relationships of the fleet sizing problem

Asset purchases and sales, outsourcing, demand/load and vehicle allocation constitute tactical level decisions, whereas operational level decisions involve vehicle routing and scheduling, empty vehicle repositioning issues etc. In spite of the hierarchy depicted in Figure 3.2, all decision problems are economically interdependent (Wu, Hartman & Wilson, 2005). A brief definition is made in the following sections to understand these problems and the relationships.

3.1.1 Strategic Level Decision Problems

Fleet size and composition optimization, which balances demand and supply of transport, are main subjects of the strategic fleet management for logistic companies. The companies could increase customer service level by having large number of vehicle by investing and expanding their fleet. On the other hand, they would increase capital spending, holding and maintenance cost due to having large number vehicles. Already, fleet sizing problem is based on principle of establishing a balance between service capacity and demand and it aims to determine optimal number of vehicles by an operator/carrier.

Actually, the problem of determining fleet size and fleet composition problem is separated in literature. Fleet size problem can be summed as how many vehicles should a firm have on its transport fleet whereas fleet composition problem dealing with type of vehicle operated and also number of each type. Fleets are composed of different vehicles, which have different capacity, fixed and variable cost, therefore fleets are usually heterogeneous in real life applications (Çetin, Özkütük & Gencer, 2011). In other word, fleet composition problem is to find the optimal fleet size of a heterogeneous fleet. Besides, fleet composition problem is not sort-term decision problem; it deals with long-term decisions determining types and number of vehicles simultaneously (Etezadi & Beasley, 1983).

In addition to all, Fleet sizing/composition problem should be considered with other decision problems because fleet size/composition interdependent and linked economically with tactical and operational problems. Thus, fleet sizing problem should be addressed in integrated and simultaneous manner with all sub-problems of the fleet sizing. Yet, there are few tactical and practical studies in the literature concerned fleet sizing and composition problem by this way.

3.1.2 Tactical Level Decision Problems

Allocation of a vehicle fleet to a given number of locations and redistribute free vehicles are important control problems (Köchel, 1997). The vehicles travel continuously between two nodes on a fixed route so as to satisfy the sales or production requirement in each period. The fleet allocation problem deals with the optimal distribution of the total available vehicle to various routes (i.e., fleet size on various routes), in order to meet all expected demand (or some portion of it) and keep the operations cost at minimum (New, 1975; Parikh, 1977).

On the other hand, fleet sizing problem is closely related to practical decision-making problems such as how full and empty vehicles will be positioned along transportation network. Fleet sizing/composition problem lead to empty resources repositioning problem occurring because of demand imbalance between locations. In other words, imbalance occurs in the vehicle inventories on certain routes. Therefore, an optimal assignment and reallocation of the vehicles are required in order to serve future demand along the transportation network (Köchel, Kunze & Nielander, 2003).

Fleet sizing and empty equipment redistribution are critical problems in managing a fleet of equipment over a transportation network. These two problems are highly related to each other. A poorly designed equipment redistribution policy can result in inefficient fleet utilization, and excessive fleet requirements. Thus, these problems have to be handled in an integrated way (Du & Hall, 1997).

When shipping alternatives exist, the selection of the appropriate shipping alternative (mode) for each shipment may result in significant cost savings. Such a situation leads to mode selection (load allocation) problem that highly related with vehicle routing, fleet allocation, and fleet sizing problems. Thus, load planning and fleet sizing should be considered in integrated way. Appropriate freight planning and fleet sizing ensure not only efficiency and customer satisfaction but also reduction of environmental pollution.

3.1.3 Operational Level Decision Problems

There are many research work on freight transportation which deals with determine the sequence of vehicle's visit to request location. These types of problems are closely related to the salesman problem (TSP), Multiple TSP, and general vehicle routing problem. The Vehicle Routing Problem (VRP) is combinatorial optimization problems in which the number of routes and total travelling time/distance of all vehicles are minimized while serve certain number of depot or customer with limited fleet capacity (M., Bielli, A., Bielli & Rossi, 2011).

A good scheduling minimizes waiting times and total transport times and provides efficient utilization. Consequently, efficient utilization of the fleet minimizes the required number of vehicles. However, there is no work on simultaneous optimization fleet size, allocation, and schedule due to complexity of the problem (Chakroborty, Deb & Sharma, 2001)

The vehicle routing problem in container transportation is slightly different from these research works in that a location may be visited by the number of containers to be delivered as many times as, and a container should be delivered to a specific destination once loaded. Thus, it is similar to the single-capacity pickup-delivery transportation problem with sequence dependency. The transportation capacity constraint that a vehicle can move only a single container at a time makes the current problem more difficult to solve than the TSP which is known to be NP-hard (Koo, Lee & Jang, 2005).

Fleet sizing/composition problem, vehicle allocation, and routing problems are mostly considered independent and handled separately. There are few studies that integrate the fleet sizing/composition and routing problems that is known as fleet size and mixed routing problem in literature. Fleet size and mix routing problem is the decision of composition and size of the fleet and setting appropriate routes for serving known demand with minimum total cost. However, these studies deal with fleet sizing problem at operational level (Wu et al., 2005).

Appropriate fleet management increases the economic efficiency of the entire transport system and/or customer service level. Fleet size and composition optimization balancing demand and supply of transport are main subjects of the strategic fleet management. The fleet size depends on the total vehicle travel time which consists of loaded travel time, empty travel time, loading time, and unloading time. In spite of the hierarchy depicted on Figure 3.1, all decision problems and sub-problems associated with fleet sizing should be dealt in an integrated way. Since strategic, tactical, and operational problems are interdependent and linked economically, solving these problems in effective and efficient way prevents fixed cost arising from having excess vehicle and operating vehicle under the particular utilization rate. Besides, appropriate fleet sizing ensure not only customer satisfaction but also right investment, economic growth and reduction of environmental pollution.

3.2 Literature Review on Fleet Sizing Problem

Transportation vehicles are expensive capital items and fleet sizing is important issue for both transportation service providers and researchers. Fleet sizing problem is usually based on principle of establishing a balance between service capacity and demand and aims to determine optimal number of vehicles. Early studies handled fleet sizing problem, was comparatively simpler in terms of problem structures and solution approaches. The problem was mostly considered single-mode (road) and single-period with homogeneous fleets (Kirby, 1959; Mole, 1975; Parikh, 1977; Williams & Fowler, 1980), except for few studies until the beginning of 1980s. After that, heterogeneous fleets attracted more attention, so problem structure shifted to be mostly fleet composition problem (Gould, 1969; Etezadi & Beasley, 1983; New, 1975; Gheysens et al., 1984; Redmer et al., 2000; Zhao et al., 2001; List et al., 2003; Qiuping et al., 2009).

Fleet sizing problem is not only associated with demand or service level, it is highly related with utilization of the vehicles. In detail, there are important interactions between vehicle allocation, empty vehicle reallocation/repositioning, loaded and empty vehicle movements. Even though voluminous studies exist in

literature for these problems, a few studies deal with combination of them. For instance, there are some works on fleet sizing and allocation (Parikh, 1977; Beaujon & Tunquist, 1991; Köchel et al., 2003), fleet sizing and reallocation/repositioning (Köchel, 1997; Du & Hall 1997, Dong & Song, 2009, Sayarshad & Moghaddam, 2010; Carbajal et al., 2013), fleet sizing and routing/scheduling (Etezadi & Beasly, 1983; Lin & Ma, 1999; List et al., 2003; Wu et al., 2005; Qiuping & Weiwei, 2009; Nossack & Pesch, 2013). However, no work has been reported on the simultaneous optimization of the fleet size allocation, reallocation/redistribution and routing/scheduling due to complexity and NP hard structure of the problem.

Especially fleet sizing problem was getting many aspects after the intermodal transportation system was being a significant transportation issue by the early 1990s. However, most of the studies concerning intermodal transportation focus on service network design, load planning, mode selection, etc. (Guelat et al. 1990; Bierwirth et al., 2012; Meisel et al., 2013). Furthermore, most of these studies do not consider all resources used on intermodal network. Existing studies mostly deal with container management problems (Choong et al., 2002; Bin & Zhongchen, 2007; Dong & Song, 2012; Fazi et al., 2013), and only few of them concern container sizing and allocation problem (Dong & Song, 2012; Fazi et al., 2013). As far as known, there is no such a study dealing with optimal fleet size by taking into account all intermodal networks and all resources used on the network. Additionally, in spite of many theoretical studies on load planning and vehicle routing, the number of the real life applications such as decision support systems is considerably less than theoretical studies in literature (Powell & Sheffi, 1989; Couillard & Martel, 1990; Jansen et al., 2004; Fazi et al., 2013). This is because fleet-sizing problems related to real-world cases are large scale and more complex. However, progress in solution methods provides opportunities to solve problems partially.

Because vehicles are generally long-lived assets, there is uncertainty about the demands and about the conditions under which they will operate. Although both researchers and operators recognize the importance of this uncertainty, fleet sizing problems are often quite difficult to solve even under deterministic assumptions, and

most of the work in the literature focuses on deterministic models. Only few studies tackle with the uncertainty derived from demands or operations (List et al., 2003; Wu et al., 2005; Sayarshad & Moghaddam, 2010; Roy et. al., 2013). On the other hand, the problem may be static, where the problem considers an "isolated" or typical planning period, or dynamic, where the problem has to be solved over several contiguous time periods. In many studies in literature, the problem is considered as a static optimization problem and there are few studies examining the problem as a dynamic optimization problem (Zhao et al., 2001; List et al., 2003; Wu et al., 2005; Sayarshad & Ghoseiri, 2009; Cheon et al., 2012). However, fleet sizing problem has both stochastic and dynamic structure in real life and the number of studies handling dynamic and stochastic models is quite limited (List et al., 2003; Wu et al., 2005; Sayarshad & Moghaddam, 2010; Dong & Song, 2012).

When examined, it is seen in Figure 3.3 that different solution techniques are used according to modeling approach and problem structure/assumption. Mathematical programming optimization, stochastic optimization and simulation could be used as solution techniques depending on modeling approach. Generally, mathematical programming (linear, non-linear, integer, etc.) is used to solve developed static and deterministic models (Etezadi & Beasley, 1983; Powell & Sheffi, 1989; Lin & Ma, 1999; Redmer et al., 2000; Zhao, et al., 2001; Cheon et. al, 2012; Bierwith et al., 2012). However, mathematical programming is mostly sufficient for problems covering strategic and tactical decisions whereas inadequate for problems covering operational decisions. In such cases, various meta-heuristic algorithms are used for especially fleet sizing and routing/scheduling problem because of the size and NP hard structure of the problem (Gheysens et al., 1984; Köchel et al., 2003; Jansen et al., 2004; Wu et al., 2005; Sayarshad & Moghaddam, 2010; Redmer at al., 2012). Stochastic programming or simulation is used in the studies deal with problems containing stochastic parameters (William & Fowler, 1980; List et al., 2003; Köchel et al., 2003; Dong & Song 2012). Queuing theory is used to obtain approximate but quick solutions, especially for models with time-dependent parameters and variables (Parikh, 1977; Redmer et al., 2000).

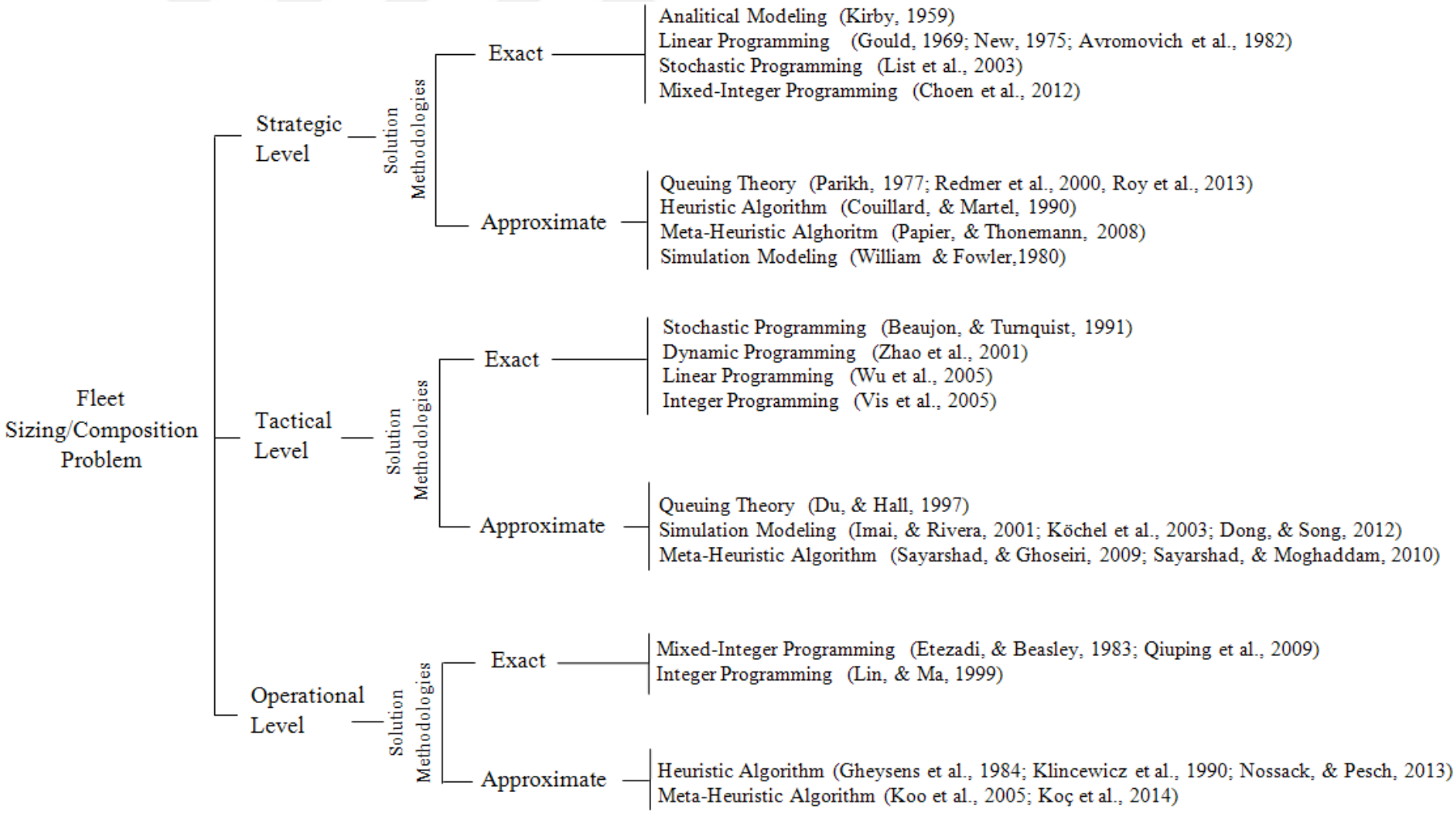


Figure 3.3 An overview of solution methodologies in the literature on fleet sizing problem

Although Operational Research mostly focus on unimodal freight transportation problems, in recent years multimodal (especially intermodal) transport systems has become important issue for both executers and researchers because of environmental sensitivity as well as the overall efficiency due to using different transportation modes. However, load and fleet planning have got difficult owing to the complexity of the system. Structure of the problems, solution approaches and methods show great differences in unimodal, and multimodal transportation. Thus, studies dealt with fleet sizing problem basically can be classified in two separate sections: in unimodal transportation and multimodal transportation systems.

3.2.1 Fleet Sizing in Unimodal Transport Systems

An early attempt to tackle the problem of the fleet size optimization was made by Kirby (1959). The problem arose during studies of small railway system with the question of that if the wagon fleet is the right size. The reason of asking this question was achieving balance between fixed costs of owned wagons and extra costs derive from use of outside hire. When large wagon fleet would have low utilization, small wagon fleet would cause extra hired cost. Kirby developed expression for the total expected cost per a day, which contains owned and hired cost with probability distribution of the needed wagons for each day. In this regard, Kirby approached to and modeled the problem as newsboy problem. Thus, He was able to determine the number of owned and hired wagons that would minimize total cost. This was the first study in literature that tackle fleet size optimization problem, even though the problem and solution approach was extremely lean.

Wyatt (1961) extended Kirby's approach by adding variable cost to the total transport cost, which is related to owned vehicles as per unit capacity, per day. In real life situation, vehicles are not uniform size, consequently fixed, variable and hired costs are not constants. However, Wyatt used average values of these costs and obtained optimal fleet size by derivation method in like manner Kirby. Wyatt indicated that the fleet should be big enough to meet average demand when seasonal demand fluctuation is occurred.

Gould's (1969) study was different from Kirby and Wyatt due to propose a linear programming model that considered the size and composition of fleets. Vehicle size problem can be summed as how many vehicle should a firm have on its transport fleet whereas vehicle composition problem dealing with type of vehicle to operate and also number of each type (Etezadi and Beasley, 1983). Gould carried out a case study in which a company had to meet (known) seasonal demand with different vehicle types. In the study each period is considered separately even the problem consisted multi-period. However, the proposed model allows modifying tanks from one to another. The optimal number of tanks for each type was determined and this study showed that the company could meet demand with smaller fleet size. As a result of the study mainly two recommendations were produced; the first one was reduction in the size of company fleet, the second one was more emphasis on large vehicles. Gould's study was important, as it was the first study considered heterogeneous fleet and used linear programming model to obtain optimum fleet composition.

Mole (1975) developed an algorithm for dynamic optimization of vehicle fleet size. The main differentiation of the study was that the optimum fleet size was time dependent. That mean algorithm gave an optimal solution for decisions when and how many vehicles should be acquired. Planning horizon was divided into periods and forecast of demand available on each period. Also, he assumed that total operating costs (fixed, variable and hired costs) on each period were piecewise linear. Mole initially decided to timing of investment in new vehicles in response to the demand trend while reduction of capacity was not practicable. Once the sequence of purchase periods have been traced backwards the optimal policy would been determined. Afterward, he considered disposal policy in order to allow obsolescence of vehicles when purchase policies are not reasonable because of decreased demand. However, this study considered only single type demand and homogeneous (single type vehicle) fleet.

Another case study that was realized for an airline fleet was carried out by New (1975). He developed a linear programming model that could plan acquisition and

disposal of aircrafts in the fleet by using notion of long-range capacity planning models. New describe of size and composition of a fleet is considered as a set of interrelated capital investment projects, which subject to demand, availability, budgetary and technological constraints. His model handled allocation problem in addition to fleet composition problem. The airline in question had various routes and a certain fleet size composed of different types of aircraft all of varying capacity, ages, operating costs and ranges. Proposed model was responsible for allocating aircrafts to appropriate routes when decided to if a new aircraft(s) should be acquired on further periods. A binary variable was used to reflect fixed cost caused by acquisition. Although New covered many real problem constraints (demand, capacity, inventory, budgetary etc.) in his model, he ignored integer constraints such as number of aircrafts.

A different approach for fleet sizing and allocation problem was developed by using of queuing theory by Parikh (1977). The method in question gave an approximate but quick solution for an optimal allocation of the total available transport vehicle units to many fleets in such a way all fleets provided (as possible as) a uniform service level. Service level was measured of the fraction of arriving orders delayed due to lack of available transport vehicle units. A real life situation problem of a nationwide transportation company, which had 250 fleets consisted 10,000 transport vehicles units (TVU), was considered. The problem was thought as two sub problems: a fleet sizing problem and a transport vehicle units (TVU) allocation problem. In the fleet sizing problem, the number of TVU's that a fleet should have when demand and shipping times were known in probabilistic term was determined (total number of TVU). Suggested model best fitted the company's problem when customer orders' arrivals were Poisson and service time was Erlangian. Besides, in the fleet allocation problem, the allocation of the total available TVU's to various fleets was determined so that a uniform service level was provided by all fleets. However, this study was considered single type vehicle and single period fleet sizing and allocation problem.

Williams and Fowler (1980) carried out a study for the University of Tennessee motor pool in order to determine minimum cost fleet size that facilitated the institutional travel requirement administration, faculty, staff and students. The load on the fleet was characterized by significant time-dependent fluctuation as well travel mileage and trip duration times. Various stochastic distributions had been specified and a simulation model was constructed after the vehicle request, service time and travel mileage data had been collected, organized and analyzed. 15 years of simulated experience was generated for seven alternative fleet size then a regression model was developed to determine the minimum cost fleet size that travel mileage specific to the fleet cost components as a function of fleet size. The study showed that over 95% of all request could still satisfied even if the fleet size decreased by one-third. Although the fleet size problem was considered single-period and single type vehicle, distribution of vehicle demand, travel mileage and service time was not stationary in contrast to other studies.

Fleet composition and vehicle routing problem were handled together by Etezadi and Beasley (1983). They concerned with the problem of deciding of optimal fleet mix as well fleet size for a central depot which had to supply a number of customers. They defined that the vehicle composition problem dealing with type of vehicle to operate and also number of each type whereas vehicle size problem concern with how many vehicle should a firm have on its transport fleet. Especially vehicle routing problem were expensive in terms of computer time because of many sets of vehicle routes for each vehicle composition and sampling of demand when a simulation approach was considered. They developed a mixed-integer linear programming model that could determine number and type of vehicles in the fleet thereby taking into account of vehicle routing problem. It was crucial since the cost of vehicle represent a significant proportion of the physical distribution.

Gheysens et al. (1984) compared some heuristics for solving the fleet size and mix vehicle routing problem. Fleet size and mix routing problem is the decision of composition and size of the fleet and setting appropriate routes for serving known demand with minimum total cost. The total cost of the problem consisted vehicle

acquisition costs for different vehicle (heterogeneous fleet) and routing cost for customer delivers. Vehicle routing problem has some specified constraints such as each customer is served by exactly one vehicle, each route begins and ends at the depot, total demand of the route must not exceed the capacity of the vehicle assigned to that route. Addition to the existed methods Gheysens et al. proposed a new two-stage heuristic that determine vehicle mixes with lower bound procedure then use generalized assignment heuristic to solve vehicle routing problem. Proposed algorithm was superior to other algorithms in terms of accuracy even so running times of the algorithm were much larger than others.

Turnquist and Jordan (1986) handled fleet sizing problem in freight transportation between a component plant and many assembly plants (one-to-many) that considered production cycles. In that case a single container type was used to ship parts between plants and also used to as storage until parts assembled at the assembly plants. Thus, production rate, usage rate and travel times, briefly production cycle was significant in order to determine the fleet size. Primarily they developed a model to determine number of containers under deterministic production cycle and travel times. In that, model was composed of containers, which are at component plant, at assembly plants and in-transit. Proposed model was extended to investigate the impact of travel time uncertainty. Production cycle was deterministic while travel times were stochastic in the last model. Containers shortage could occur because of different travel times. Thus, trade-off between fleet size and shortage probability was investigated for different level of travel time's uncertainty. Although both models associated fleet size with production cycle and travel times, they did not consider any type of costs about fleet. Also this study could be extended from one-to-many shipping pattern to many-to-many shipping pattern which allows reallocations between shortage and surplus plants.

An extensive paper concerned, especially, empty flows and fleet management in freight transportation was prepared by Dejax and Cranic (1987). They classified fleet management problem according to their term that covered. Long and medium term decisions such as demand forecasting, fleet sizing network design etc. were classified

as strategic decisions when short term decisions such as empty vehicle flows, dispatching of empty or loaded vehicles were classified operational decisions. They exposed that empty fleet flows affected almost all fleet management problems as much as fleet sizing problem. Also, type of flow, transportation mode, fleet homogeneity and type of company were characteristics of the inspected problems. Those problems could be static or dynamic in terms of time domain and deterministic or stochastic in terms of performance measures. Mathematical programming optimization, stochastic optimization and simulation could be used as solution techniques depending on modeling approach.

Avramovich et al. (1982) developed a decision support system for fleet management of a large truck transportation company in North America. The decision support system was a linear programming model, which helped manager to decide what type and size of tractors to sell or to trade in each week. Especially, the system is used to Figure out significant financial impacts of fleet management decisions. The system was constituted by three basis stages; parameter module, which is used by Linear Programming (LP) model, LP module, and reporting module which is generated by LP model to provide sales mix decisions and subsequent financial planning and forecasting reports. The parameter module contains numerous types of appropriate parameters and formats these parameters. The LP module enable the user to supply desired global characteristic of the LP model and generates suggested tractor sales mix with in the given parameters and other assumptions. Main objective of the LP model is maximize net contribution realize from the sale of tractors of different years, model, makes and axle types to different customer types. By the time there are many physical (capacities, demand and etc.) and financial constraints (contracts, allowances, and financial agreements). Reporting module generate reports which provide basis developing and executing operational plans and reflect financial impact of forecasted sales. The whole system provide a mechanism by which manager can estimate financial cost associated with fleet size levels, used inventory levels, units to be wholesaled and mixes of new and used tractors sales. By the way the system increased quality of fleet decisions such as buying, selling and trading-in

of tractor units and improved timeless of the planning process and provide man-power savings.

Powell and Sheffi (1989) worked on software (decision support system, APOLLO) which was an interactive optimization system for network design for three years. They concerned with the loading planning consisted consolidation and routing freight over a less than truckload motor carrier network. They defined a unique problem structure and developed a mixed integer programming to solve problem. A particular decomposition strategy was produced since the problem had large and complex structure because of several real world concerns. The real problem was divided into four sub-problems (hierarchically); network design problem, routing sub problem, truckload freight routing problem, empty balancing sub problem. Sub problems were solved in the reverse order of their natural hierarchy. APOLLO used some heuristic such as shortest path for the truckload routing problem, batch heuristic for network design problem in order to handling complexity of the problem and keep the problem tractable. Conducted software was also allowed users work over the model (costs, terminals routes etc.) to make judgments regarding certain constraints and tradeoff by convenient interface.

Couillard and Martel (1990) developed a decision support system for planning the size and composition of a fleet in order to satisfy transportation service demand for a Canadian road carrier. This system generated minimal discounted cost plans covering the purchase, replacement, sale and rental of the vehicles necessary to deal with seasonal stochastic demand. Planning the size and composition of a fleet is fundamental in the management of a trucking company withal complexity in practice. The reasons of this complexity are the demand that is rarely known in advance, and the possibility of using resource (purchase, rental etc.). When there are not enough vehicles in the fleet, managers have to balance the operating costs of fleet with the cost of resource. In the same way adjusting their fleet size overcapacity led to decline in profit. Therefore Couillard an Martel developed a mathematical model which decided to company's fleet composition varying sizes and ages by using own vehicle and/or brokers at any given time. This model minimized expected discounted

cost over the planning horizon under the demand and budget constraints. Thus, the model was transformed to a two stage stochastic program and the mathematical programming problem was solved with a grid refinement technique. The system enabled managers to generate vehicles acquisition/disposal plans, which yield compromise between the qualitative, and quantitative criteria, however, utilization of the model was somehow limited because of the quantity of information required. Besides, tactical and operational decisions were not taken into account in this study despite of closely related with fleet sizing and composition.

The delivery of goods from warehouse to local customers is a critical aspect of material logistics systems. Klincewicz, Luss and Pilcher (1990) developed a methodology to determine the appropriate private fleet size and outside carrier services as long range (e.g. a year) planning decision. They divided the considered geographic area into sectors since actual customer location change from day to day. Proposed model determined fleet size and assigned each sector to private fleet or outside carrier. Generally vehicle assignment namely static routing problem is solved when the number of vehicles is given. However, they provided flexibility to optimal fleet size by using single-source facility location formulation. Time and cost used in mathematical programming model were not static because of varying delivery location. Besides, fixed cost and variable cost were used respectively for private vehicle and outside carrier's charge. They used p-heuristic to determine optimal vehicle number than solve single-source capacitated facility location to find out which sector would be served by each vehicle (private vehicle or outside carrier).

Most of the studies on empty vehicle distribution focus on efficient utilization of a given, fixed vehicle fleet, in order to reduce operating cost, and do not address the long term decision of investment in the vehicle fleet. However, improved utilization has much more potential benefits on investment in capital resources than reducing operating cost. Beaujon and Turnquist (1991) made one of the most comprehensive studies which consider these issues in unimodal transportation system. This study aimed to answer these crucial questions:

1. How many vehicles should be in the fleet?
2. Where should vehicle pools be allocated?
3. How large should these pools be at any given time, and location?
4. How should available vehicle be allocated to loaded, empty movements?

The heart of the study was the interaction between inventory decisions and vehicle routing decisions. Moreover, dynamic and uncertain characteristic of the transportation systems were take into consideration. First of all, they developed the exact mathematical model for fleet sizing and allocation problem consisting loaded and empty vehicle movements. Then they proposed a solution procedure for solving non-linear network programming model resulted from expected value formulation. Finally, after some experiments, they concluded that failure to explicitly represent both the stochastic and dynamic aspects of the transportation system can lead the significant loss of economic opportunities.

Crainic and Laporte (1997) presented a quite extensive and valuable paper about some of the main issues freight transportation planning and operations. They classified freight transportation problem according to decision-making levels, they also presented appropriate Operations Research models and methods for strategic, tactical and operational problems as computer based planning tools. Eventually, they concluded that inevitable hierarchical relationship prevents formulation of a unique model for the planning of the transportation systems and calls for different model formulations addressing specific problems at specific levels of decision-making.

A poorly designed equipment redistribution policy can result in inefficient fleet utilization, and excessive fleet requirements. Du and Hall (1997) presented an alternative approach for fleet sizing and empty vehicle redistribution problem by compounding inventory and queuing theories. They developed decentralized stock control policy for empty vehicle distribution. Firstly, they modeled stochastic process representing various variables and defined stock-out probabilities as a function of the fleet size, then compared analytical results to monte-carlo simulations. Authors

emphasized that the model was robust, simple to understand and control parameters could be determine with off-line computation.

In another study, multi-location inventory model was used to handle the allocation and redistribution problem at the same time with fleet sizing problem by Köchel (1997). Proposed model was an approximate model for fleet sizing and redistribution namely optimal fleet size and optimal redistribution policy. Redistribution problem arose when a demand in a given location could be served by vehicle transferred from another terminal. In this study, single mode transportation and single type vehicle (homogenous fleet) were considered and initially one period model was investigated. A two-location case was solved and solutions were discussed for different value of parameters. They offered to use genetic algorithm for cost function which was non-linear in reality.

Redmer et al. (2000) developed a mathematical model which formulated feet sizing problem in a road freight transportation company with heterogeneous fleet, in terms of multi objective, non-linear and integer programming. The developed model was based on queuing theory, basically; it consisted of a two-stage solution process. In the first step, a set of efficient solutions (Pareto-optimal) were generated. In the second step, three different MCDA methods, LBS, ELECTRE, UTA were used to support decision maker while finally select the most satisfactory solution among a quite large solutions set. The objective functions of the developed model were i) maximizing utilization rate for each vehicle group, ii) minimizing total sales of subcontracted transportation orders, iii) maximizing average utilization rate of back-up facilities.

Chackroborty et al. (2001) expressed that optimal fleet size distribution and scheduling problem was a difficult optimization problem. They proposed a GA to minimize total waiting and transit time of passengers in an urban transit system since traditional non-linear mixed integer programming models fail to provide optimal solution to this problem. Zhao et al., (2001) presented a multi-period dynamic programming model for vehicle composition problem on fixed routes with

transshipment points. It was aimed at determining number of owned and hired vehicle in order to meet transportation demands on each period by minimizing total transportation cost of the vehicle transportation system. Also, inventory cost derived from continuous transportation in multi period was considered in this study. In this study, dynamic two phase solution was proposed by researchers because of multi period and NP hard attributes of the problem. In the first phase vehicle composition problem was formulated as mix-integer linear programming model in order to find optimal transport arrangement for one period. Multi period problem was divided into sub problems and solved by dynamic programming. By this way, optimal solution was obtained by minimizing total transportation, inventory and hiring costs.

Köchel et al. (2003) provided realistic solutions for fleet sizing and allocation problem by taking dynamic and uncertain characteristic of the transportation network into consideration. In the study, which was carried out for car rental company, the time period was taken continuously and interval of the orders was fitted to Poisson distribution. There was no restriction about location, time and duration of the hired vehicles by clients. Also, hired vehicles would be used for a random time, returned at random location and all these randomness were independent. However, it was assumed that all vehicles in the fleet were homogenous, ageless and perfect in addition to the number of transporters by which vehicle was transported between locations were infinite. At first, they developed queering network model for the movement of units through the location without any control in order to find out significant imbalance between inflow of the vehicle and demand. Then it was tried to maximize profit by applying different repositioning scenarios owing to eliminate imbalance. In this context, they developed a simulation optimization method based on genetic algorithm. The mathematical and simulation models developed for the system based on four elements that were location, vehicles, clients and transporters. Decision variables were stated as fleet size, number of the vehicles and reallocation policy. The idle waiting cost of the vehicles, waiting and rejection cost of the client were considered with fixed cost arising from fleet size and repositioning policy. Nearly optimal solutions were obtained due to lack of analytical calculation of fixed cost mentioned before.

It is so important determining appropriate fleet size for companies due to transportation vehicles are quite expensive capital items. Small fleet size reduces investment but increases penalties costs stemmed from lack of resources. Similarly, large fleet reduces penalties costs but increase investment and operational costs. List et al. (2003) stood on this issue in their study, and developed a formulation and solution procedure to find optimal fleet size under uncertain demand and operational conditions. They proposed a two-stage solution procedure (stochastic formulation and analysis) can be applied to different risk level. Basically, the optimization based on installing balance between vehicle purchasing costs and the risk costs caused by insufficient recourses. Vehicles are used in different demand and requirements during their lifetime, because they are generally long-lived assets. Therefore, demand and operational conditions are uncertain parameters of fleet sizing problem. Yet, these parameters were considered deterministic in most of the studies. This study combining the of uncertainty and optimization models focused on two basic resource of uncertainty; the first was the uncertainty of the future demands; the efficiency of each vehicle was the latter. Risks taken by investing in the fleet were compared in a clear manner and optimal fleet size was determined which allows remaining in top condition even in a variety conditions. Three different cost elements was involved to model which were ownership costs, fleet operating costs and service quality penalties costs derived from postponed shipments. Postponed shipments were examined in two categories as delays stemmed from transport and delays stemmed from lack of resources. A mathematical model was generated to ensure a balance between investment and penalties costs by researchers. The model had two objectives; total cost was minimized by the first objective function, then service quality penalties cost minimized by the second objective function. In this way, customer satisfaction was incorporated in the model. Although other studies that dealt with stochastic conditions and demands, they had been working mostly on repositioning problem which was operational problem. This study was different from other studies because of using stochastic parameters to determine strategic fleet size. Different scenarios were reflected in the mathematical model by using simulation so that optimal fleet size that minimized total expected cost was determined. At the final step flexibility

was provided to company up to a certain cost value. In other words, sensitivity analysis was made to seeking solutions that reduced the risk.

Wu et al. (2005) handled fleet sizing problem in the context of the truck rental industry. The proposed mathematical model minimized the total cost. The total cost was equal to subtraction proceeds from vehicle cost containing operation, maintenance and purchase costs. The fleet in question was heterogeneous since it was composed of different vehicles that had different age, capacity and operating cost. Also, the model included capital decisions such as purchases and sales of vehicles during the planning period. It was taken into account that transportation times between locations consisting some uncertainties, so transportation times were considered as stochastic parameters in this study. However, the demands between locations were assumed exactly known and authors mentioned that uncertainties about demand would be subject of further studies. Two-stage solution approach was proposed to solve large-scale real life fleet sizing problem by researchers. In the first stage, problem divided into sub problems and customer demands were allocated to different resources by using Benders decomposition. Then the initial bound obtained from first stage was used to improve the solution through Lagrangian relaxiation.

Papier and Thonemann (2008) carried out a study to deal with fleet optimization problem for a European rail cargo company. They tackled fleet optimization problem in three decision problems as fleet size, fleet structure (composition) and fleet leasing optimization. Fleet size refers to the total number of cars the company operates; fleet structure refers to what types of cars the company operates; fleet leasing is an option whereby rail cars can be leased on medium term basis. They modeled rental process as a queuing loss system. First of all, mathematical formulation developed to determine optimal fleet size by considering seasonal (stochastic) feature of demand and uncertain rental time which maximize expected profit. At first stage they assumed that the mixture of car types in the fleet was given. In the next step they analyzed of the merging fleets for different types of cars. As a last step, they determined optimal number of leased cars for fleet size found in the previous step.

Transport capacity, size and structure are one of the most important issues in logistic distribution systems. Fleet sizing literature mostly concerned total fleet needed to meet transport demands. However, transport managers can use their own transport fleet, carriers/logistics provider or both of these options. Stanajovic et al. (2011) modified classical make or buy decision making to determine optimal fleet size in non-logistic enterprises (manufacturers, merchandisers). They presented a formulation to minimize transport cost by considering stochastic demand, homogeneous fleet, average distance and fixed costs. Briefly they investigated make and buy decision in strategic and tactical level by evaluate all sourcing options such as in-house transport fleet and outsourcing.

There are important interactions between utilization and fleet sizing. The occurrence of imbalance in supply and demand of freight cars between different locations requires considering utilization of the freight cars when the empty freight cars are distributed along the railway. Sayarshad and Ghoseiri (2009) introduced a new solution procedure and mathematical model for optimizing the fleet size and freight car allocation. They assumed car demands and travel times were deterministic and they proposed simulated annealing approach for medium and large size multi periodic fleet sizing problem. Proposed model provided information about yard capacity, unmet demands, number of loaded and empty rail-car at any given time and location.

Fleet sizing problem is closely related to practical decision-making problems such as how empty and full vehicles will be positioned along transportation network. Most of the detailed and realistic study on this subject belongs to Sayarshad and Moghaddam (2010). They proposed a two-stage optimization model to solve multi period and stochastic railcar fleet sizing problem. They dealt with fleet sizing and repositioning problem, under uncertain demand conditions and different time periods since there is an important interaction between the fleet size and utilization of the fleet. First of all, a mathematical model was developed and profit maximization was aimed by considering gains and costs acquired as a result of transportation operations. The decisions variables were the number of loaded and empty vehicles on

each location. At a later stage, stochastic optimization was done. Stochastic optimization enabled to modeling of uncertainty thanks to scenarios created by using probability distribution. Stochastic optimization was used to determine the number of loaded vehicles under uncertain demand conditions because of the NP hard characteristic of the problem. Then acceptable final solution was obtained in a reasonable time by using simulated annealing even though the solution obtained was not optimal. However, the model provided information such as unmet demand, yard capacity, and number of loaded and empty vehicles at any given time and location, which helps the managers during making decision. Even though model had these important information, ignoring transportation, loading and unloading times were significant shortcomings of the model.

Redmer et al. (2012) dealt with the fleet composition problem which takes consideration of 2 echelon (warehouse and stations) fuel distribution system. They presented 2 different formulations to minimized total daily distribution cost which consist fixed and variable operational costs. It was aimed at determine the optimal type of tankers and optimal number of each tankers. Both of the formulations were single objective mathematical programming models. The difference between these mathematical programming models based on the definition of the problem. In the first model, customers' orders were assigned to specific vehicle types; in the second model, vehicles were assigned to transportation tasks. It was taken into account different customers' orders and different vehicles that had different capacities, fixed and variable costs in the both mathematical programming model. Local search, evolutionary algorithms and hybrid of these algorithms were used for solving the problem. Experimental results of the study showed that first formulation in which the customers' orders were assigned to the specific vehicles gave better solution in terms of quality of the solution and computational time.

Cheon et al. (2012) handled a railcar fleet optimization problem in which railcars were not used only as a means of transportation but also a storage space, thus, the problem covered inventory problem too. The model they developed consisted three parts: the first part computed amount of railcar by considering product demand, production schedule and transit time as well as seasonality impact. The second part

deals with operation and car utilization. The last part was the fleet mix optimization that tackles long-term capacity expansion planning problem which required the consideration of numerous economic factors. They generate a mixed-integer programming model to find out an optimal fleet procurement plan. This model determined fleet size that is a strategic decision by looking at operational requirements. Briefly, proposed model decided to appropriate fleet size, appropriate railcar type and finally optimal procurement strategy. However uncertainty in production and demand rates, transit times, uncertainty due to market fluctuation were not taken into consideration in this study.

Carbajal et al. (2013) developed an optimization model to analyze the tradeoff between fleet size cost and repositioning cost. In the study, it was analyzed if fixed cost stemming from purchase or leasing could be reduced during the planning period especially by extra tractor repositioning in addition to repositioning required for balancing resource. Network flow optimization model was established to determine fleet size by using different repositioning strategies. Then, optimal costs of 4 different repositioning strategies were compared. The results obtained by using national real data showed that appropriate repositioning reduce fleet size and provide savings to the companies.

Roy et al. (2013) emphasized that whether large or small-scale fleet has a lot of operational costs in addition to direct purchase costs. Thus, they underlined the need to decide the right fleet size. In this context, they developed quick and approximately way to address fleet sizing problem under non-stationary (stochastic) demand and uncertain transportation times. They used markow chain for modeling non-stationary demand and queuing theory for modeling variable fleet size just as Parikh (1977).

Koç et al. (2014) developed an integer linear programming model for fleet size and mix pollution routing problem. The objective of the proposed model was to minimize the sum of vehicle fixed costs, and routing cost where can be defined with respect to the cost of fuel, CO2 emissions, and driver costs. Main purpose of the study was to investigate the trade-offs between various cost indicators such as vehicle fixed cost, distance fuel emissions, diver cost, and total cost. Authors

proposed a hybrid evolutionary meta-heuristic for sizing and routing of heterogonous vehicle fleet. Computational results showed that optimizing the size and vehicle speed in a heterogeneous fleet is more meaningful and useful than homogeneous one.

Koo et al. (2005) proposed a solution procedure to find minimum fleet size and travel route for each vehicle that are used to transport containers at ports. It was assumed that transportation system was under the static environment and all transportation requirements were predetermined at the beginning of the planning horizon. Proposed procedure consisted of two phases. At the first stage, an optimization model was developed to obtain a lower bound on the fleet size which ensures minimum vehicle travel time. Loaded and empty vehicle travel time was taken into account while determining minimum fleet size. At the second stage, a tabu search based procedure was used to obtain vehicle routing with the least number of vehicles. Then, authors compared their some other meta-heuristics and observed that tabu search also produce vehicle routing with the least total vehicle travel time.

A similar study was carried out by Vis et al. (2005) to determine vehicle requirements while transporting containers under time-window constraints. They presented an integer linear programming model to solve fleet size problem. They considered single planning horizon and deterministic parameter in their study as Koo et al. (2005). Also, an assignment of vehicles to containers was made by solving this model. Some numerical experiments were performed to test ability of the developed model under various conditions. Authors concluded that results of the proposed model were close to results of the simulation model.

In the last few decades, ever-expanding global economy leads to rapid growth of container shipping. Container availability is essential for shipping lines to meet customer demands. However, the management of container fleets is complicated and requires intelligent trade-off among many activities. For example, smaller container fleet sizes would save capital investment and inventory costs, but this may increase risk of losing customer demands due to unavailability. Repositioning empty containers from one port to another is an essential mechanism to overcome the trade imbalance arising from most of the geographical locations (Dong, & Song, 2009).

In the broad context of general vehicle fleet sizing and empty vehicle allocation, a rich literature exists. As mentioned previously, only a few papers considered the joint fleet sizing and empty allocation problem and these are significantly different from container fleet management in liner shipping industry. There is very limited number of study tackling container fleet sizing and empty container repositioning even though there is relatively large number of studies managing empty container allocation. Imai and Rivera (2001) developed an analytical model to determine the optimal strategic fleet size of a refrigerated container fleet. Developed model consisted operational task as loaded and empty container dispatching and strategic investment decisions in case of extremely unbalanced trade. Finally a simulation model was developed to analyze optimal composition of leased and owned containers under the various scenarios.

Similar study carried out by Lagoudis, Litinas, and Fragkos (2006) in consideration of improving operations relevant to fleet size, vessel capacity utilization, scheduling and frequency of service. An analytical model was proposed to minimize container idle time by taking into account loaded and empty container movements that derives from unbalanced demand between ports. Optimum routes of vessels and optimum container fleet size are examined by taking into account different scenarios via simulation.

An extended study about container fleet sizing was made by Dong and Song (2009) by considering joint container fleet sizing and empty container repositioning with dynamic, uncertain and imbalanced customer demands. They developed a simulation based optimization model in order to optimize fleet size and parameterized empty repositioning policy in a liner system simultaneously. Although there were some assumption similarly previous studies as fixed and homogenous fleet, this study differed from other studies in terms of dynamic and uncertain characteristics. The objective was to minimize expected total cost including inventory holding costs, loading/unloading costs, transportation and repositioning costs, and lost sale penalty costs. It was difficult to find optimal fleet size and repositioning policy analytically because of the multi vessel, multi port and multi voyage shipping system. Thus, Authors presented optimization procedure which

combined Genetic Algorithm and Evolutionary Strategy. Loaded and empty containers movements, constraints of vessel routes and capacities were modeled to determine optimal container fleet size and repositioning policy in a stochastic and dynamic liner shipping system. After some numerical examples, results showed that cost reduction from non-repositioning policy to evolutionary algorithm-based (EAP) policy ranged from 26% to 69% when heuristic repositioning policy to EAP ranged from 4% to 38% under different cost parameters.

Finally, all mentioned studies that concern fleet sizing problem in unimodal transportation systems and their features are summarized in Table 3.1.

Table 3.1 An overview of approaches in the literature on fleet sizing problem in unimodal

Reviewed Studies	Planned Resource	Fleet Structure	Fleet Problem	*Load Allocation	**Fleet Allocation	Empty Reallocation	Vehicle Routing	Outsourcing	Fleet Extension/ Reduction	Multi Objective	Multi Period	Problem Characteristics	Solution Methodology
Kirby (1959)	Wagon	Homogeneous	FSP	-	-	-	-	-	-	-	-	Continuous Deterministic	Analytical Modeling
Wyatt (1961)	Wagon	Homogeneous	FSP	-	-	-	-	-	-	-	-	Continuous Deterministic	Analytical Modeling
Golud (1969)	Tanker	Heterogeneous	FCP	✓	-	-	-	✓	-	-	✓	Dynamic Deterministic	Linear Programming
Mole (1975)	Vehicle	Homogeneous	FSP	✓	-	-	-	✓	✓	-	✓	Dynamic Deterministic	Dynamic Programming
New (1975)	Aircraft	Heterogeneous	FCP	-	✓	-	-	-	✓	-	✓	Dynamic Deterministic	Linear Programming
Parikh (1977)	Vehicle	Homogeneous	FSP	-	✓	-	-	-	-	-	-	Continuous Stochastic	Analytical Modeling
Williams &Fowler (1980)	Vehicle	Homogeneous	FSP	-	-	-	-	-	✓	-	-	Static Stochastic	Simulation Modelling
Etezadi &Beasley (1983)	Vehicle	Heterogeneous	FCP	-	✓	-	✓	-	✓	-	✓	Dynamic Deterministic	Mixed-Integer Programming
Gheysens et al. (1984)	Vehicle	Heterogeneous	FCP	-	✓	-	✓	-	-	-	-	Static Deterministic	Heuristic Algorithm
Turnquist & Jordan (1986)	Container	Homogeneous	FSP	-	✓	✓	-	-	✓	-	-	Continuous Stochastic	Analytical Modeling
Avramovich et al. (1982)	Truck	Heterogeneous	FCP	-	-	-	-	-	✓	-	✓	Dynamic Deterministic	Linear Programming
Couillard & Martel (1990)	Truck	Heterogeneous	FCP	-	-	-	-	✓	✓	-	✓	Dynamic Stochastic	Heuristic Algorithm

FSP: Fleet Sizing Problem; FCP: Fleet Composition Problem

*Load Allocation: Loads are allocated to the routes or vehicles.
**Fleet Allocation: Vehicles are allocated to the routes and/or exact point on the network.

Table 3.1 An overview of approaches in the literature on fleet sizing problem in unimodal (continue)

Reviewed Studies	Planned Resource	Fleet Structure	Fleet Problem	*Load Allocation	**Fleet Allocation	Empty Reallocation	Vehicle Routing	Outsourcing	Fleet Extension/ Reduction	Multi Objective	Multi Period	Problem Characteristics	Solution Methodology
Klincewicz et al. (1990)	Vehicle	Homogeneous	FSP	-	✓	-	✓	✓	✓	-	✓	Dynamic Stochastic	Heuristic Algorithm
Beaujon & Turnquist (1991)	Vehicle	Homogeneous	FSP	-	✓	✓	-	✓	-	-	✓	Dynamic Stochastic	Stochastic Programming
Du & Hall (1997)	Vehicle	Homogeneous	FSP	-	✓	✓	-	-	-	-	✓	Dynamic Stochastic	Analitical Modeling
Köchel (1997)	Vehicle	Homogeneous	FSP	-	✓	✓	-	-	-	-	-	Static Deterministic	Analitical Modeling
Redmer et al. (2000)	Vehicle	Heterogeneous	FCP	-	-	-	-	-	-	✓	-	Continuous Stochastic	Analitical Modeling
Zhao et al. (2001)	Vehicle	Heterogeneous	FCP	✓	✓	-	-	✓	-	-	✓	Dynamic Deterministic	Dynamic Programming
Köchel et al. (2003)	Vehicle	Homogeneous	FSP	-	✓	✓	-	-	-	-	-	Static Deterministic	Simulation Optimization
List et al. (2003)	Vehicle	Heterogeneous	FCP	-	✓	-	-	-	✓	✓	✓	Dynamic Stochastic	Stochastic Programming
Wu et al. (2005)	Truck	Heterogeneous	FCP	✓	✓	✓	-	-	✓	-	✓	Dynamic Stochastic	Linear Programming
Papier & Thonemann (2008)	Vehicle	Heterogeneous	FCP	-	-	-	-	✓	-	-	-	Static Stochastic	Meta-Heuristic Algorithm

FSP: Fleet Sizing Problem; FCP: Fleet Composition Problem

*Load Allocation: Loads are allocated to the routes or vehicles.

**Fleet Allocation: Vehicles are allocated to the routes and/or exact point on the network.

Table 3.1 An overview of approaches in the literature on fleet sizing problem in unimodal (continue)

Reviewed Studies	Planned Resource	Fleet Structure	Fleet Problem	*Load Allocation	**Fleet Allocation	Empty Reallocation	Vehicle Routing	Outsourcing	Fleet Extension/ Reduction	Multi Objective	Multi Period	Problem Characteristics	Solution Methodology
Sayarshad &Ghoseiri, (2009)	Rail-Car	Homogeneous	FSP	-	✓	✓	-	-	✓	-	✓	Dynamic Deterministic	Meta-Heuristic Algorithm
Sayarshad &Moghaddam, (2010)	Rail-Car	Homogeneous	FSP	-	✓	✓	-	-	✓	-	✓	Dynamic Stochastic	Meta-Heuristic Algorithm
Cheon et al. (2012)	Rail-Car	Heterogeneous	FCP	-	-	-	-	✓	✓		✓	Dynamic Deterministic	Mixed-Integer Programming
Redmer et al. (2012)	Tanker	Heterogeneous	FCP	✓	✓	-	-	-	-	-	-	Static Deterministic	Meta-Heuristic Algorithm
Carbajal et al. (2013)	Truck	Homogeneous	FSP	-	✓	✓	-	✓	-	-	-	Static Deterministic	Non-Linear Integer Prog.
Roy et al. (2013)	Truck	Homogeneous	FSP	-	-	-	-	-	-	-	-	Continuous Stochastic	Analitical Modeling
Koç et al. (2014)	Vehicle	Heterogeneous	FCP	-	-	-	✓	-	-	-	-	Static Deterministic	Meta-Heuristic Algoritm
Koo et al. (2004)	Vehicle	Homogeneous	FSP	-	✓	✓	✓	-	-	-	-	Static Deterministic	Meta-Heuristic Alghorithm
Vis et al. (2005)	Vehicle	Homogeneous	FSP	-	✓	✓	-	-	-	-	-	Static Deterministic	Integer Linear Programming
Imai and Rivera (2001)	Container	Homogeneous	FSP	-	✓	✓	-	✓	-	-	-	Continuous Deterministic	Simulation Modeling
Dong & Song (2009)	Container	Homogeneous	FSP	-	✓	✓	-		-	-	✓	Dynamic Stochastic	Simulation Optimization
Qiuping et al., 2009	Ship	Heterogeneous	FCP	-	✓	-	✓		✓	-	✓	Dynamic Deterministic	Mixed-Integer Programming

FSP: Fleet Sizing Problem; FCP: Fleet Composition Problem

*Load Allocation: Loads are allocated to the routes or vehicles.

**Fleet Allocation: Vehicles are allocated to the routes and/or exact point on the network.

3.2.2 Fleet Sizing in Intermodal/Multimodal Transport Systems

Intermodal and intermodalism practices are relatively new. Although the term of intermodalism is being absent in 1980, the concept that is used and implemented in present days emerged by the early 1990s. Intermodal and multi-modal transportation are mostly confused and used interchangeable in the literature as well as in daily life. However, as mentioned in chapter two, multimodal is the broadest definition and includes all other combined and integrated transportation chains. United Nations Economic Commission for Europe exactly defined intermodal freight transportation as multimodal transport of goods in one and same intermodal transport unit by successive modes of transport without handling goods themselves when changing modes (UNECE, 2009).

Intermodal transport is considered as a competitive alternative to single mode (unimodal) transport system. The first scientific studies on the intermodalism have been done by Mahoney (1985), Hayuth (1987), Muller (1989), McKenzie, North, & Smith (1989), and De Boer (1992). Intermodal philosophy, especially in the world of logistics industry has become an important transport policy in the 1990s. Intermodal freight transportation is receiving increasing attention in last couple decades since it increase traffic safety, reduced road congestion and air pollution but especially because of providing total efficiency by using different transportation modes.

Bontekoning et al. (2004), referring to the limited number of studies on this issue, stressed only the light of the new information could bring about solutions to real-life applications due to the highly complex structure of intermodal transport. Similarly, Caris et al. (2008) mentioned that there has been no study yet conducted on intermodal transportation planning activities, which concerned resource allocation, capacity planning, and fleet sizing. Nonetheless, most of the studies concerning intermodal transportation focus on service, network design, load planning, mode selection, etc. (Guelat et al. 1990; Bierwirth et al., 2012; Meisel et al., 2013).

Guelat et al. (1990), proposed a multimode multiproduct network assignment model for strategic planning of freight flow by using network representation for the first time. They describe the mode as a means of transportation that has its own characteristics such as vehicle type and capacity as well as a specific cost functions. The network consists of the nodes, links and modes that represent all the physical movements possible on the available infrastructure. They define a link as (i, j, m); where i is the origin node, j is the destination node and m is the mode allowed on the arc. Also the model they proposed is flexible in the specification of the intermodal movements. The multimodal network that they used for the formulation of the multiproduct assignment model contains transfer cost. Therefore, the shortest path algorithm is used to minimize total cost in order to planning freight flows at a strategic level. Researchers performed the proposed model on Brazilian transportation network and results show that the proposed model is extremely good in terms of network utilization and total cost of the system.

Bierwirth, Kirschstein and Meisel (2012) introduced a tactical planning of mode and service selection for intermodal transportation problems. They investigated service selection problem in intermodal rail/road distribution network where road mode was used for short-distance haulage to intermodal terminals (rail terminal) and for direct shipments to customer. Also the problem included decision of either booking train capacity or chartering block train completely. It was assumed that all input data was known and deterministic, truck, train and load capacity was given by one transportation unit, demand of goods and transport flow considered a single type of commodity in this study. However, schedules for truck and train travels as well as travel times were not taken into consideration. A mathematical optimization model was presented to decide transport mode, transport service and intermodal terminals by using realistic cost functions and freight consolidation effects. They investigated impact of cost and structure of optimal decisions for small problem instance. Moreover they investigated if the company's distribution system would be modeled as an intermodal transportation system and solved to optimality under various parameters on a real-word case study. However, the capacity planning problem in question was still unsolved since this study did not concern a fleet size optimization

even though it considered mode and service selection on rail/road freight transportation.

Similarly, Meisel, Kirschstein and Bierwirth (2013) presented a model and solution approach for combining production and intermodal transportation planning in a supply network. Although this study filled the gap about integration both decision fields, capacity planning and fleet sizing problem was still unsolved since the problem was not considered in terms of carriers. Besides, schedules for truck and train travels as well as travel times were not taken into consideration. After all they provided 6%-cost saving in a case study from the integrated planning.

There are a few study considering fleet size and load planning problem in an integrated manner. Lin and Ma (1999) developed a model to determine appropriate integrated fleet size and load routes for a freight carrier company that uses both air and road transport. An integer programming model was developed to minimize total transportation cost while meeting the service commitment. Additionally, because of the numerous combination of routes and time constrains minimum spanning tree subproblem was developed for the problem. This study utilized for the largest delivery carrier in Taiwan and the results showed that handling fleet size and load routing in an integrated manner provided a gain of about 16 %.

In the last few decades, ever-expanding global economy leads to rapid growth of container shipping due to the increase intermodal transportation. Container availability is essential for shipping lines to meet customer demands. Typically, logistic managers' main concern is the transportation of loaded containers. They commonly ignore empty containers, but real-world containers networks usually require empties to account for imbalanced loaded flows. If these empty flows are not managed carefully, the entire shipping network will operate inefficiently. However, the number of studies deal with empty container repositioning by take into consideration intermodal network is very limited. In these studies, intermodal (multimodal) transportation is used to transport empty container (Choong et al., 2002; Bin & Zhongchen, 2007).

The management of container fleets is complicated and requires intelligent trade-off among many activities. For example, smaller container fleet sizes would save capital investment and inventory costs, but this may increase risk of losing customer demands due to unavailability. Repositioning empty containers from one port to another is an essential mechanism to overcome the trade imbalance arising from most of the geographical locations. While already very limited number of study tackles simultaneously container fleet sizing and empty container repositioning, only one study consider intermodal network system (Dong & Song, 2012).

Container fleet sizing relates with amounts of containers which has to purchase and hired in long-term. Dong and Song (2012) extended their study, which handles container fleet size and repositioning empty container (Dong & Song, 2009) by take into account inland container movements. They developed a simulation optimization approach to solve container fleet sizing problem, which consists uncertainties about demand and stochastic inland transportation times. They aimed to understand effects of inland transport times and their variability on container fleet size. For this reason, they improved the two algorithms (genetic algorithm and simulated annealing) and compared solutions of deterministic and stochastic case for transportation times.

Fazi et al. (2013) developed a mixed integer linear programming model to allocate and schedule heterogeneous container fleet. The model decided to best allocation for containers while minimizing the transportation cost and guaranteeing a high service level. Because of the model complexity, Markow Chain Monte Carlo heuristic was developed to solve problem. Also the authors investigated trade-off between cheap but slow modes and faster but costly modes. Actually, they developed a decision support system for this operational problem by implementing proposed model. The authors emphasized that the decision support system provided cost and time efficient plan for logistic planners.

Drayage operations constitute a relatively large proportion of total costs of intermodal transport. The development of efficient drayage operations can encourage its attractiveness. However, little research has been conducted on intermodal drayage

operations. Jansen et al. (2004) developed a decision support system to daily transport average 4000 containers daily for the one of the most important logistic company of Germany. This study carried out to make improvements regarding cost and quality of service. It was aimed to make a plan which ensures cost efficiency by repositioning trucks at the right place at the right time while returning their original place within a few days. Transportation of orders is planned with various approaches by dividing into sub-problems. Then, it was decided whether orders should be transported by road or by rail, transported at once or by transshipment. Developed system was designed to allow the addition of new constraints also it included constraints encountered in practice. Although difficult to measure savings, it was estimated that the system provided a 5 % savings in cost of the company. This means millions of dollars per year for such a company. The planning problem handled in this study was the operational dimension of the fleet planning problem and give an idea about complexity of the problem and contribution that can be provided.

Nossack and Pesch (2013) addressed truck scheduling problem that arises in pre- and end-haulage (between shippers and revivers) of intermodal container transportation. Additionally empty container transportation was considered. Briefly, this study carried out to determine optimal truck routing with loaded and empty container assignment to trucks. The homogenous fixed truck fleet was routed and scheduled to minimize total truck operating time under hard time windows constraints. A mixed integer programming model was developed to solve scheduling problem. However, because of the NP hard structure of the problem, authors proposed two-stage heuristic solution approach. At the first stage, route construction heuristic was used which consisted pairing pickup and delivery requests, sequencing pickup and delivery pairs, assignment of start and end depots to sequences and assignment of start and end times to routes. At the second stage, a route improvement heuristic was used. Authors emphasized that the results indicated that the two-stage heuristic outperformed the window partitioning approach that previously proposed in the literature.

Finally, all mentioned studies that concern fleet sizing problem in multimodal transportation systems and their features are summarized in Table 3.2.

Table 3.2 An overview of approaches in the literature on fleet sizing problem in intermodal

Reviewed Studies	Planned Resource	Fleet Structure	Fleet Problem	*Freight Planning	Fleet Allocation	Empty Reallocation	Vehicle Routing	Outsourcing	Fleet Extension/ Reduction	Multi Objective	Multi Period	Problem Characteristics	Solution Methodology
Guelat et al. (1990)	Train	Homogeneous	-	✓	-	-	-	-	-	-	-	Static Deterministic	Heuristic Algorithm
Bierwirth et al. (2012)	Train	Homogeneous	-	✓	-	-	-	-	-	-	-	Static Deterministic	Mixed-Integer Programming
Meisel et al. (2013)	Train	Homogeneous	-	✓	-	-	-	-	-	✓	-	Static Deterministic	Heuristic Algorithm
Choong et al. (2002)	Container	Homogeneous	-	-	-	✓	-	✓	✓	-	-	Static Deterministic	Integer Programming
Bin & Zhongchen (2007)	Container	Homogeneous	-	✓	-	✓	-	-	-	-	✓	Static Deterministic	Integer Programming
Dong & Song (2012)	Container	Homogeneous	FSP	-	-	✓	-	-	✓	-	-	Dynamic Stochastic	Simulation Optimization
Fazi et al. (2013)	Container	Heterogeneous	-	✓	✓	-	✓	-	-	-	-	Static Deterministic	Heuristic Algorithm
Jansen et al. 2004	Truck	Heterogeneous	-	✓	✓	✓	-	-	-	-	-	Static Deterministic	Heuristic Algorithms
Nossack & Pesch (2013)	Truck	Homogeneous	FSP	-	✓	✓	✓	-	-	-	-	Static Deterministic	Heuristic Algorithms
Lin ve Ma (1999)	Aircraft, Truck	Homogeneous	FSP	✓	✓	-	-	-	-	-	-	Static Deterministic	Integer Programming

FSP: Fleet Sizing Problem; FCP: Fleet Composition Problem

*Freight Planning: Freights are allocated to the modes and/or routes.

3.3 Future Prospects

Operational Research mostly focuses on unimodal freight transportation problems as indicated in the previous sections. Relatively, there are quite a few studies which concern multimodal, especially intermodal transport systems (Table 3.1 vs. Table 3.2). Nevertheless, intermodal transportation has become important issue for executers and researchers because of environmental sensitivity as well as the overall efficiency due to using different transportation modes.

Intermodal planning problems are more complex due to the inclusion of multiple transport modes, multiple decision makers and multiple types of load units. Two strategic planning problems, terminal design and infrastructure network configuration, have received increased attention in recent years. Yet the number of scientific publications on other intermodal planning problems remains limited or nonexistent. Topics such as the allocation of resources to jobs in an intermodal terminal or the determination of truck and trailer fleet size in intermodal drayage operations still need to be tackled (Caris et al., 2008).

Drayage operations constitute a relatively large proportion of total costs of intermodal transport. The development of efficient drayage operations can encourage its attractiveness. Nevertheless, little research has been conducted on intermodal drayage operations. Moreover, the main attention until now has been given to intermodal transport by rail. However, intermodal transport including maritime is quite important too, and its operations should be integrated to the inland transport in order to improve intermodal transportation operations.

Crainic and Kim (2007) stated that this largely unexplored research field offers multiple opportunities and challenges, such as the coordination of plans and operations of independent actors and the modeling of uncertainty of operations in each element of the intermodal transport chain. Furthermore, developing intermodal planning models in dynamic context supports decision makers and may be important enabler to provide adequate, correct information to decision makers.

Another issue is cooperation between actors in the intermodal transport chain. Still there is a few study that consider multiple decision maker, although an increased level of coordination is required to improve the performance of intermodal freight transport. Also more integration should be achieved between planning problems at different decision levels since all decision problems are interdependent and linked economically.

The freight transportation industry must achieve high performance level in terms of economic efficiency and quality of service. A tactical planning problem that requires more research attention is the design of the intermodal service network and in particular the determination of optimal freight routes. Especially, there is a need for solution methods for intermodal routing models taking into account multiple objectives such as minimization total costs, maximization utilization and service quality. Besides, the impact on the environment plays a key role in policy making for intermodal transport. One of the trends appearing in several models at multiple planning levels is the introduction of environmental concerns as secondary objective.

Caris et al. (2013) mentioned that the inclusion of all the actors in the decision support tools is still an issue. Only looking at the problems from one point of view creates suboptimal solutions. A better understanding of all involved actors, and their objectives, will enable to integrate them in the decision support systems. Authors also hoped that these models would be more and more relied on by the policy makers, and would not be left in the scientific world.

All mentioned prospects could be summarized in seven main heading:

1. Integration of different decision makers (actors) and problems in the intermodal network (freight planning, fleet planning, etc.).
2. Integration of the different decision levels interrelated with fleet size (mode and route selection, fleet allocation, empty vehicle repositioning, etc).
3. Integration of different resource while constructing a plan (train, trailer, truck, etc.).

4. Integration more transportation mode to widespread rail-road intermodal transportation (maritime, inland waterway, etc. in addition to rail and road).
5. Taking into account the dynamic nature of the problems, (periodic planning for long-term).
6. Taking into account the uncertainties related to each element of intermodal system (stochastic demand, uncertain transport times, etc.).
7. Constructing multi-objective models (concerning cost, service quality, environmental etc. purposes)

As mentioned, fleet sizing is highly related with empty vehicle repositioning and freight flows. A poorly designed repositioning policy can result in inefficient fleet utilization, and excessive fleet requirements. Therefore, a decision support systems based on mathematical modeling is required for real-world intermodal planning problems. By solving these problems in an integrated and simultaneous way, effective freight plan and efficient fleet plan can be obtained for an intermodal transportation network.

CHAPTER FOUR
A REAL-WORLD FLEET SIZING PROBLEM AND DEVELOPMENT OF MIXED INTEGER LINEAR PROGRAMMING MODEL

4.1 Problem Definition

The fleet-sizing problem dealt with in this section belongs to Ekol Logistics Company. Ekol Logistics Inc. offers transportation services to its high number (around 5,000) customers mostly located in Europe by using different transport modes (road, rail, maritime and different combination of them) and service types. The company carries about 20,000 load demands between Turkey and Europe (on both directions) with 7,000 positions corresponding to one transportation unit (TU-one trailer) per month via intermodal transportation system. A featured intermodal transportation service brings many advantages to the company such as timely delivery, cost-effectiveness and environmental awareness.

Ekol Logistics Inc., having largest and most modern fleet in Turkey even in Europe, serves its customers with three different transportation modes. Transport process begins with determining most appropriate routes according to the preferred service type. These routes are located on three main lines which are used i) road; ii)marine and road; iii) marine, rail, and road transport modes. The company provides transport service in both direction between Turkey and Europe. Freight transport from Turkey to Europe is called as importation and opposite is called as exportation in this study. In the meantime, different transportation modes are used to serve customers by taking into consideration a number of criteria. Transportation modes in question can be summarized as follows and demonstrated in Figure 4.1.

i) Road transportation is a pure transport mode in which freight is transported from Turkey to hubs in Europe and delivered to the destination points only by road. Vice versa is valid for freight transportation from Europe to Turkey. Freights are transported from order points to hubs in Europe and from there to ports in Turkey.

ii) Marine and road transportation is developed as an alternative to the road transport due to high costs and various constraints of road transport. It is based on freight transportation by Ro-Ro vessels from ports in Turkey to ports in Europe, then from there to the related hubs in Europe by road. The opposite route is valid as road then Ro-Ro transport for freights transported from Europe to Turkey.

iii) Marine, rail and road transportation is combined these three transport modes as intermodal transportation system. Freights are transported respectively by Ro-Ro vessels from Turkey to Europe, by trains in Europe and by road to the hubs before final moving to the customers. The opposite route is valid as road, rail, and marine transport for freights transported from Europe to Turkey.

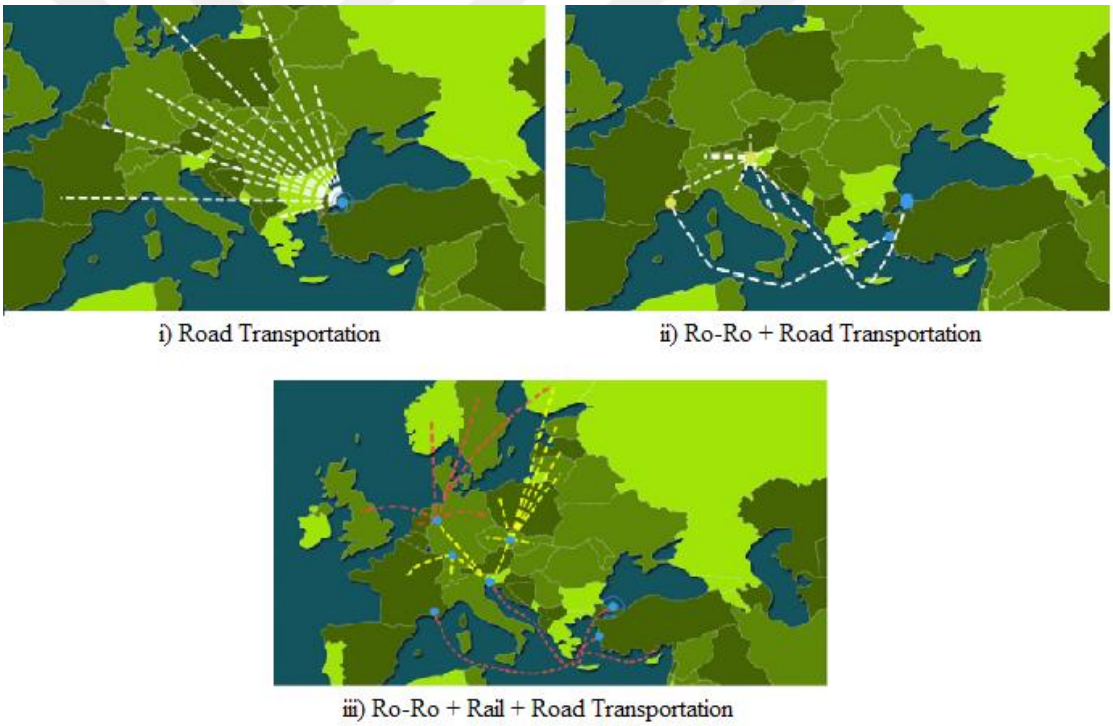


Figure 4.1 Transportation modes and routes used by Ekol Logistics (Ekol, 2015)

One of the important problem encountered by company, while realizing intermodal transportation services, is to determine appropriate number of different kind of resources, and allocate them in the right place, at the right time in order to meet changing customer demands while balancing own resources and outsourcing. The problem in general definition is resource planning problem including fleet

sizing, allocation, reallocation problems. Resources at issue are trucks, trailer, and trains. The optimal number of owned trucks and trailer should be determined while determining optimal train times per month. In addition to all, the balance between own resources and outsourcing should be established. However, freight planning needs to be done correctly for accurate resource planning. This means that freight and fleet planning problems should be addressed in an integrated and simultaneous way. Consequently, fleet sizing problem gathers different decision problems at different decision levels; fleet allocation and reallocation, outsourcing, mode and route selection problems.

4.1.1 Specifications of the Intermodal Transportation Network

As mentioned in the previous section, Ekol Logistics uses three different transportation modes and three main transportation routes in order to meet transport demand of its customers. Company integrates marine, rail and road operations and carries all operations simultaneously. Marine and rail transportation provide advantages in term of both cost and environmental impact since they are based just on the movement of trailers. However, road transportation is inevitable in freight transportation even in intermodal systems. Pre-haulage and end-haulage are carried out by road transportation. Thus, road transportation should be carefully integrated with all other modes.

The system is based on the transportation of freights from İstanbul, İzmir, and Mersin marine ports to the ports of Trieste or Sete via owned Ro-Ro vessels. The trailers/containers are loaded to the block trains at Trieste port and forwarded to Ostrava, Cologne or Ludwigshafen train terminals. The arrived trailers/containers are unloaded from the block trains and transported to the Ostrava, Cologne or Ludwigshafen consolidation centers and the final destinations by trucks. In same manner, the freights are brought to Ludwigshafen or Cologne terminals by trucks and consolidated there for transportation to Trieste port via railways; and then brought into Turkish ports through the owned Ro-Ro vessels in case of exportation.

Intermodal transportation network of the company with main maritime and rail routes can be seen in Figure 4.2.



Figure 4.2 Detailed intermodal transportation network of Ekol Logistics (Ekol, 2015)

Ekol Logistics Inc. uses İstanbul, İzmir and Mersin ports in Turkey, Lavrion (Greece), Trieste (Italy), Sete (Italy), and Toulon (France) ports in Europe, to transport freight by marine. Company has five Ro-Ro vessels and four of them take trips between İstanbul-Trieste. Lavrion port is visited a few times during these trips in that Lavrion port is transshipment port on İstanbul-Trieste line. One of the vessels takes trips between İzmir-Sete. Briefly, company schedules their vessels between İstanbul-Trieste, İstanbul-Lavrion-Trieste at certain times, and İzmir-Sete. Freights are transported through other logistics providers among the remaining ports. The ports used by company and their transportation features are summarized in Table 4.1.

Table 4.1 Ekol Logistics marine transportation lines and features

	Lavrion	**Trieste**	**Sete**	**Toulon**
İstanbul	O	O + LP	-	LP
İzmir	-	LP	O	-
Mersin	-	LP	-	-

O: Owned vessels; LP: Other logistics providers

There are four round trips between İstanbul-Trieste ports and one round trip between İzmir-Sete every week. One-way each trip takes about 60 hours between

İstanbul-Trieste and 48 hours between İzmir-Sete. The average capacity of Ro-Ro vessels is 240 mega-trailers or 45 ft. containers. Detailed information about navigation times and capacities for each Ro-Ro lines and vessels will take place on the following sections. Detailed timetable of company's Ro-Ro vessels can be seen in Table 4.2.

Table 4.2 Timetable of Ro-Ro vessels belongs to Ekol Logistics (Ekol, 2015)

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Trieste Departure		05:59		00:59		02:59	03:59
Lavrion Arrival(NS)*		00:59		02:59			
Lavrion Departure(NS)*		03:59		05:59			
Haydarpaşa Arrival	17:59	20:59		22:59		15:59	
Haydarpaşa Departure		05:59		02:59		04:59	03:59
Lavrion Arrival(SN)**							20:59
Lavrion Departure(SN)**							23:59
Trieste Arrival	17:59	20:59		20:59		15:59	

*NS : Trieste-Lavrion-Haydarpaşa Route
**SN : Haydarpaşa-Lavrion-Trieste Route

Hatche Qezban Paqize Fadiq

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
İzmir Departure	20:00						
Sete Arrival			20:00				
Sete Departure						10:00	
İzmir Arrival	13:00						

Ayshe

After arriving to the ports in Europe, freights are transported by road to the nearby hubs. However, some of the freights are transferred to rail terminal and continues to transport by railway. Trailers are unloaded from RoRo's and loaded to the trains with cranes only at Trieste port. As can be seen on Figures 4.1 and 4.2, Trieste is a transshipment port for railway. Three different block train lines, Cologne, Ludwigshafen and Ostrava, and one public (flexible and high-speed) train line Munich, are used to provide transport services to various countries in Europe. Cologne terminal is a transshipment terminal for Malmo and Gothenburg terminals. Feature of port-terminal and terminal-terminal railway lines that are used in intermodal transportation network of Ekol Logistics are in Table 4.3.

Table 4.3 Ekol Logistics Rail transportation lines and feutures

Port/Terminal	Ostrava	Munich	Ludwigshafen	Cologne
Trieste	B	P	B	B
Terminal/Terminal	Malmo	Gothenburg		
Cologne	P	P		
B: Block trains line; P: Public trains line				

Rail transportation times takes about 24 hours for direct connected terminals and 46 hours for connecting terminals (Malmo, Gothenburg). Block train capacities mostly 32 trailers. Detailed information about capacities and transportation times etc. for each train lines will take place on the next chapter.

4.1.2 General Structure and Assumptions of the Model

Road transportation is still backbone of transportation systems and inevitable in freight transportation even in intermodal transportation. This dissertation is conducted to determine optimal fleet size needed on an intermodal transportation network with the perspective of drayage operators. Thus, network design, Ro-Ro vessel and train schedules, etc strategic decisions are not considered in scope of this study. This information is used as constraints of the intermodal network. On the other hand, freight flow (mode and route selection), required number of train, truck and trailer are determined. Appropriate number of trucks and trailers are allocated on the routes and nodes in order to minimize empty vehicle movements so as to minimize total cost of the transportation network. However, we should point out that this study carried out to obtain an aggregated plan, which allows the company to conduct the right strategies and polices for one-year planning horizon. Thus, operations management is not dealing in detail only in aggregated manner. Already, a detailed operations planning could be made only in light of the aggregated plan.

Developed model is based on the following situation and assumptions. These assumptions are made with experts of the company and based on working conditions, agreements, contracts, customs clearance etc. Actually, these assumptions constitute the general structure of the problem handled in this study.

1. All operations, decisions and plans are conducted in aggregated manner since planning horizon of the company is 12 month/1 year.
2. Freights are shipped between specific origin-destination points in Turkey and Europe as import and export transportation.
3. Freights can be transported by all modes to all customers. There is no restriction about freight routes.
4. It is not allowed to delayed or deferred customer demands. All transport demand is met within the relevant period.
5. Consolidation and distribution of freights to end customers are not considered since an aggregated plan constructed.
6. Freights are not consolidated or stored on the ports and terminals.
7. Pre/end haulage in Turkey is not considered.
8. One transportation unit (TU) is one trailer.
9. Less than Truck loaded ((LTL) is not allowed.
10. Trailer requirements occur only at ports in Turkey and hubs in Europe because they do not go through any process meanwhile transportation.
11. Truck requirements occur at ports, terminals and hubs in order to transport trailers while transport mode of trailer changing.
12. All trucks are same, and all trailers are same (homogenous fleets).
13. Owned and other logistics providers' Ro-Ro vessels are used for marine transportation. Ro-Ro vessels have a fixed schedule and cannot be change.
14. Block and public trains are used for rail transportation.
15. There is upper bound about the number of trips of owned vessels/block trains per month. Additionally, each vessel and train has their own capacities.
16. There is no restriction about outsourcing.
17. Fleet size of vehicles is determined in each period by considering loaded and empty vehicle movements (repositioning), transportation times and length of the period, and vehicle availability.
18. Vehicles are optimally allocated to the different lines and nodes at the beginning of each period so as to minimize empty vehicle movements (repositioning).

19. Company has two different truck types as European and Turkish plated when one type trailer is available. Generally, only European plated trucks serve in Europe because of legal obligations.
20. Transportation times between nodes on network include loading and unloading times.
21. Transportation costs are per TU except for block trains. Transportation cost by block train is independent of unit cost.
22. Transportation times and costs are symmetric (same for both directions).
23. Total cost contains all transportation, outsourcing (variable costs) and vehicle costs (fixed costs) such as holding, maintenance costs.
24. Vehicle allocation to the lines and repositioning on the same line during each period is concerned. However, reallocation of the vehicles to different routes/nodes between different time periods is not concerned.
25. It is not allowed to fleet extension or reduction throughout the planning horizon. It is just aimed that to determine optimal number of vehicles required in each period.
26. It is assumed that customer demands, transportation times and all cost are exactly known and constant.

4.2 Network Representation and Notation of the Model

A generic network representation of the intermodal transportation network of Ekol Logistics is shown in Figure 4.3 with transportation nodes and arcs. Specifications of the ports, terminals used in the intermodal network are detailed in the section 4.1.1 and 4.1.2. There are 4 different node sets as origins, destinations (changeable according to transportation direction), ports, and terminals while three different arc sets correspond to transport modes; road, rail, and marine transport on the intermodal transportation network. Sets and indices of the transportation network are shown in the Table 4.4.

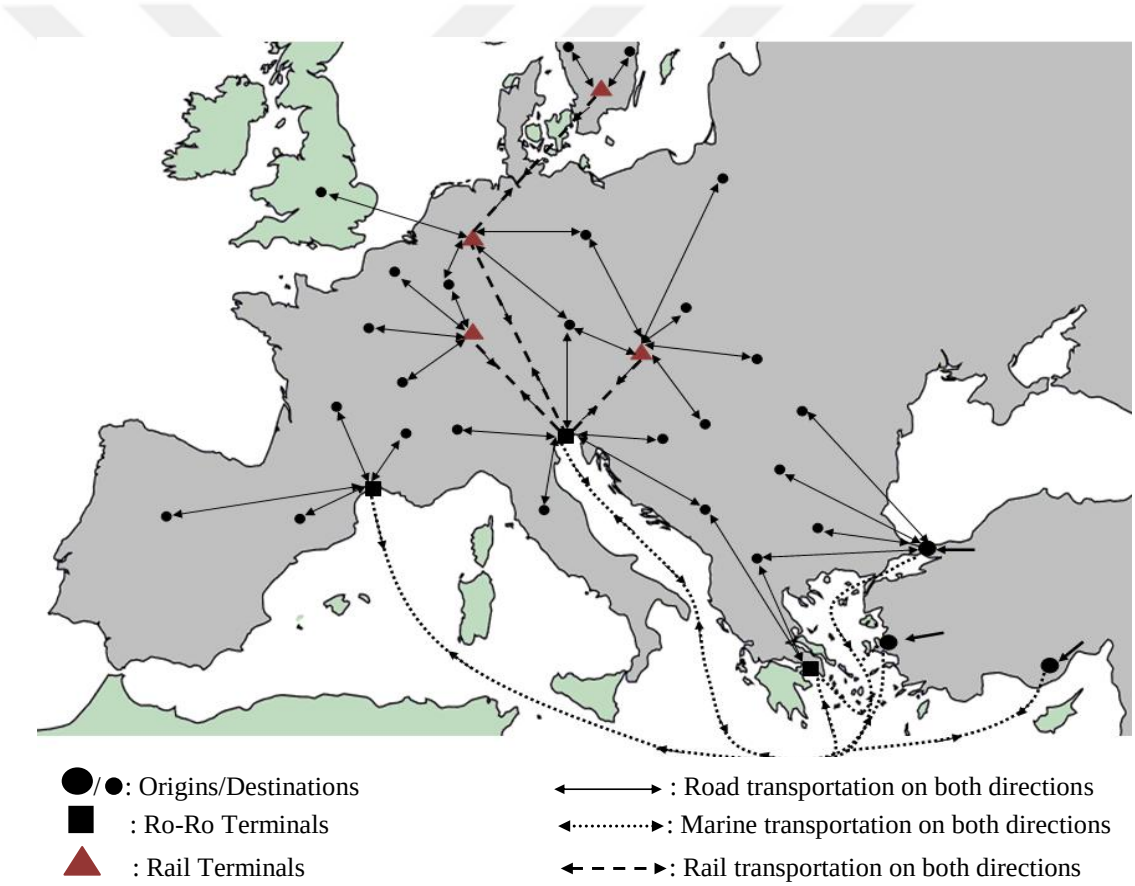


Figure 4.3 Network representation of the intermodal transportation of Ekol Logistics

4.2.1 Sets and Indices

Table 4.4 Notation of the Network

Sets:	
I	Set of ports in Turkey, additionally origin point for import freight transportation and destination point for export freight transportation
L	Set of hubs in Europe, additionally destination point for import freight transportation and origin point for export freight transportation
J	Set of vessels ports in Europe
K	Set of train terminals in Europe
T	Set of periods in planning horizon
Indices:	
i	the ith ports in Turkey for both transport direction, $i \in I$
j	the jth ports in Europe for both transport direction, $j \in J$
k	the kth terminals in Europe for both transport direction, $k \in K$
l	the lth hubs in Europe for both transport direction, $l \in L$
t	monthly time periods, $t \in T$
Sub-sets of maritime transportation:	
C_{ij}	Set of (i,j) marine line providing service only with owned Ro-Ro vessels, $i \in I, j \in J$.
L_{ij}	Set of (i,j) marine line providing service only with other service providers, $i \in I, j \in J$.
B_{ij}	Set of (i,j) marine line providing service with both owned vessels and other service providers, $i \in I, j \in J$.
γ_j	Set of all ports connecting with transshipment ports (including transshipment port), $j \in J$.
T_j	Set of transshipment ports meanwhile marine transportation, $j \in J$.
D_j	Set of ports connecting directly with train terminal, $j \in J$.
Sub-sets of railway transportation:	
C_{jk}	Set of (j,k) railway line providing service only with block trains, $j \in D_j, k \in D_k$.
L_{jk}	Set of (j,k) railway line providing service only with public trains, $j \in D_j, k \in D_k$.
B_{jk}	Set of (j,k) marine line providing service with block and public trains, $j \in D_j, k \in D_k$.
D_k	Set of terminals connecting directly with ports, $k \in K$.
T_k	Set of terminals connecting with other terminals (transshipment terminals), $k \in K$.
G_k	Set of all terminals connecting with transshipment terminals, $k \in K$.
G_l	Set of hubs served by transshipment train terminals, $l \in L$.

* Here, just sub-sets related to import transportation are given, however analogue sub-sets exist for export direction to.

4.2.2 Parameters

Table 4.5 Parameters of the model

Cost parameters:	
Co_{ij}^{imp}	Marine transportation cost per TU by owned Ro-Ro vessels on marine line $(i,j) \in C_{ij}$.
Cp_{ij}^{imp}	Marine transportation cost per TU by other logistics providers on marine line $(i,j) \in L_{ij}$.
Cb_{jk}^{imp}	Railway transportation cost per booked train by block trains on railway line $(j,k) \in C_{jk}$.
Cp_{jk}^{imp}	Railway transportation cost per TU by public trains on railway line $(j,k) \in L_{jk}$.
Cp_{sk}^{imp}	Railway transportation cost per TU by public trains on railway line $(s,k) \mid s \in T_k;\ k \in G_k$.
SC_{ilt}^{imp}	Spot transportation cost per TU by other service providers between $i \in I$ and $l \in L$.
Cr	Cost of loaded vehicle (truck+trailer) movements per TU-km for both directions (import and export)
RC^{v}	Cost of empty truck movements per TU-km for both directions (import and export).
RC^{Tr}	Cost of empty trailer movements per TU-km for both directions (import and export).
FC^{v}	Fixed cost of owning a truck for one month.
FC^{T}	Fixed cost of owning a trailer for one month.
Distances:	
d_{ij}	Distance between port $i \in I$ in Turkey and port $j \in J$ in Europe.
d_{jk}	Distance between port $j \in J$ and terminal $k \in K$ in Europe.
d_{sk}	Distance between terminal $s \in T_k$ and terminal $k \in G_k$ in Europe.
d_{jl}	Distance between port $j \in J$ and hub $l \in L$ in Europe.
d_{kl}	Distance between terminal $k \in K$ and hub $l \in L$ in Europe.
d_{il}	Distance between port $i \in I$ in Turkey and hub $l \in L$ in Europe.
Transportation Times (including transfer, waiting, loading and unloading times):	
TM_{ij}^{imp}	Transportation time between port $i \in I$ in Turkey and port $j \in J$ in Europe.
TR_{jk}^{imp}	Transportation time between port $j \in J$ in Europe and terminal $k \in K$ in Europe.
TR_{sk}^{imp}	Transportation time between terminal $s \in T_k$ in Europe and terminal $k \in G_k$ in Europe.
T_{il}^{imp}	Transportation time between port $i \in I$ in Turkey and hub $l \in L$ in Europe.
T_{jl}^{imp}	Transportation time between port $j \in J$ in Europe and hub $l \in L$ in Europe.
T_{kl}^{imp}	Transportation time between terminal $k \in K$ in Europe and hub $l \in L$ in Europe.

Table 4.5 Parameters of the model (continue)

Transportation demands:

De_{ilt}^{imp} Import transportation demand between port $i \in I$ in Turkey and hub $l \in L$ in Europe, in period $t \in T$

De_{lit}^{exp} Export transportation demand between hub $l \in L$ in Europe and port $i \in I$ in Turkey, in period $t \in T$

Capacities of Ro-Ro vessels and block trains:

Cap_{ij}^{imp} Loading capacity of the owned Ro-Ro vessels on marine line $(i,j) \in C_{ij}$.

Cap_{jk}^{imp} Loading capacity of the block trains on railway line $(j,k) \in C_{jk}$.

Limitation about Ro-Ro vessels and block train :

N_{ijt}^{imp} Maximum number of Ro-Ro trips on marine line $(i,j) \in C_{ij}$ in period $t \in T$.

UB_{ijt}^{imp} Maximum service level of Ro-Ro trips on marine line $(i,j) \in C_{ij}$ in period $t \in T$.

LB_{ijt}^{imp} Minimum service level of Ro-Ro trips on marine line $(i,j) \in C_{ij}$ in period $t \in T$.

UB_{jkt}^{imp} Maximum number of block trains could be hired on railway line $(j,k) \in C_{jk}$ in period $t \in T$.

LB_{jkt}^{imp} Minimum number of block trains could be hired on railway line $(j,k) \in C_{jk}$ in period $t \in T$.

Other network parameters :

φ_{lt} The number of working days per month in country of hub $l \in L$ in period $t \in T$.

Γ The length of the period (in hours)

α Trucks availability

β Trailers availability

*Here, parameters related to import transportation are given, however analogue parameters exist for export direction to.

*It should be noted that all lines and parameters are symmetric on whole network. Parameter values are same for both directions on the same line.

4.2.3 Decision Variables

Table 4.6 Decision variables

Outsourcing:	
O_{ilt}^{imp}	Amount of freight transported (TU) by spot (outsourced) from port $i \in I$ to hub $l \in L$ in period $t \in T$.
O_{lit}^{exp}	Amount of freight transported (TU) by spot (outsourced) from hub $l \in L$ to port $i \in I$ in period $t \in T$.
Amount of freight transported by road:	
X_{ilt}^{imp}	Amount of freight transported (TU) directly by road from port $i \in I$ to hub $l \in L$ in period $t \in T$.
X_{lit}^{exp}	Amount of freight transported (TU) directly by road from hub $l \in L$ to port $i \in I$ in period $t \in T$.
Amount of freight transported by marine & road:	
Y_{ijlt}^{imp}	Amount of freight transported (TU) from port $i \in I$ to hub $l \in L$, through port $j \in J$ in period $t \in T$.
Y_{ljit}^{exp}	Amount of freight transported (TU) from hub $l \in L$ *to* port $i \in I$, through port $j \in J$ in period $t \in T$.
Amount of freight transported by marine & rail & road:	
Z_{ijklt}^{imp}	Amount of freight transported (TU) from port $i \in I$ to hub $l \in L$, through port $j \in D_j$ and terminal $k \in D_k$ in period $t \in T$.
Z_{lkjit}^{exp}	Amount of freight transported (TU) from hub $l \in L$ to port $i \in I$, through terminal $k \in D_k$ and port $j \in D_j$ in period $t \in T$.
Decision variables related to marine transportation:	
R_{ijt}^{imp}	Amount of freight (TU) transported by owned Ro-Ro on marine line $(i,j) \in C_{ij}$ in period $t \in T$.
R_{jit}^{exp}	Amount of freight (TU) transported by owned Ro-Ro on marine line $(j,i) \in C_{ji}$ in period $t \in T$.
P_{ijt}^{imp}	Amount of freight transported (TU) by other logistics providers on marine line $(i,j) \in L_{ij}$ in period $t \in T$.
P_{jit}^{exp}	Amount of freight transported (TU) by other logistics providers on marine line $(j,i) \in L_{ji}$ in period $t \in T$.
S_{ijt}^{imp}	Number of owned Ro-Ro trips on marine line $(i,j) \in C_{ij}$ in period $t \in T$.
S_{jit}^{exp}	Number of owned Ro-Ro trips on marine line $(j,i) \in C_{ji}$ in period $t \in T$.

Table 4.6 Decision variables (continue)

U_{ijt}^{imp}	Utilization of owned Ro-Ro vessels on marine line $(i,j) \in C_{ij}$ in period $t \in T$.
U_{jit}^{exp}	Utilization of owned Ro-Ro vessels on marine line $(j,i) \in C_{ji}$ in period $t \in T$.
Decision variables related to railway transportation:	
P_{jkt}^{imp}	Amount of freight transported (TU) by public trains on railway line $(j,k) \in C_{jk}$ in period $t \in T$.
P_{kjt}^{exp}	Amount of freight transported (TU) by public trains on railway line $(k,j) \in C_{kj}$ in period $t \in T$.
P_{skt}^{imp}	Amount of freight transported (TU) by public trains on railway line $(s,k) \mid s \in T_k; k \in G_k$ in period $t \in T$.
P_{kst}^{exp}	Amount of freight transported (TU) by public trains on railway line $(k,s) \mid s \in T_k; k \in G_k$ in period $t \in T$.
S_{jkt}^{imp}	Number of block train trips on railway line $(j,k) \in C_{jk}$ in period $t \in T$.
S_{kjt}^{exp}	Number of block train trips on railway line $(k,j) \in C_{kj}$ in period $t \in T$.
Decision variables related to loaded vehicle movements:	
V_{jlt}^{imp}	Number of loaded movements (TU) of European plated vehicles from port $j \in J$ to hub $l \in L$, in period $t \in T$.
V_{ljt}^{exp}	Number of loaded movements (TU) of European plated vehicles from hub $l \in L$ to port $j \in J$, in period $t \in T$.
V_{klt}^{imp}	Number of loaded movements (TU) of European plated vehicles from terminal $k \in K$ to hub $l \in L$, in period $t \in T$.
V_{lkt}^{exp}	Number of loaded movements (TU) of European plated vehicles from hub $l \in L$ to terminal $k \in K$, in period $t \in T$.
VE_{ilt}^{imp}	Number of loaded movements (TU) of European plated vehicles from port $i \in I$ to hub $l \in L$, in period $t \in T$.
VE_{lit}^{exp}	Number of loaded movements (TU) of European plated vehicles from hub $l \in L$ to port $i \in I$, in period $t \in T$.
VT_{ilt}^{imp}	Number of loaded movements (TU) of Turkish plated vehicles from port $i \in I$ to hub $l \in L$, in period $t \in T$.
VT_{lit}^{exp}	Number of loaded movements (TU) of Turkish plated vehicles from hub $l \in L$ to port $i \in I$, in period $t \in T$.

Table 4.6 Decision variables (continue)

Repositioning (empty vehicle movements):

V_{jlt}^{rep}	Number of empty European plated trucks' movements from port $j \in J$ to hub $l \in L$, in period $t \in T$.
V_{ljt}^{rep}	Number of empty European plated trucks' movements from hub $l \in L$ to port $j \in J$, in period $t \in T$.
V_{klt}^{rep}	Number of empty European plated trucks' movements from terminal $k \in K$ to hub $l \in L$, in period $t \in T$.
V_{lkt}^{rep}	Number of empty European plated trucks' movements from hub $l \in L$ to terminal $k \in K$, in period $t \in T$.
VE_{ilt}^{rep}	Number of empty European plated trucks' movements from port $i \in I$ to hub $l \in L$, in period $t \in T$.
VE_{lit}^{rep}	Number of empty European plated trucks' movements from hub $l \in L$ to port $i \in I$, in period $t \in T$.
VT_{ilt}^{rep}	Number of empty Turkish plated trucks' movements from port $i \in I$ to hub $l \in L$, in period $t \in T$.
VT_{lit}^{rep}	Number of empty Turkish plated trucks' movements from hub $l \in L$ to port $i \in I$, in period *t.*
TR_{ilt}^{rep}	Number of empty movements of trailers from port $i \in I$ to hub $l \in L$, in period $t \in T$.
TR_{lit}^{rep}	Number of empty movements of trailers from hub $l \in L$ to port $i \in I$, in period $t \in T$.

Fleet sizing and allocation decisions :

VS_{jlt}^{imp}	Number of European plated trucks allocated on road line (j, l) in period $t \in T$.
VS_{ljt}^{exp}	Number of European plated trucks allocated on road line (l, j) in period $t \in T$
VS_{klt}^{imp}	Number of European plated trucks allocated on road line (k, l) in period $t \in T$.
VS_{lkt}^{exp}	Number of European plated trucks allocated on road line (l, k) in period $t \in T$
EP_{ilt}^{imp}	Number of European plated trucks allocated on road line (i, l) in period $t \in T$.
EP_{lit}^{exp}	Number of European plated trucks allocated on road line (l, i) in period $t \in T$
TP_{ilt}^{imp}	Number of Turkish plated trucks allocated on road line (i, l) in period $t \in T$.
TP_{lit}^{exp}	Number of Turkish plated trucks allocated on road line (l, i) in period $t \in T$
TS_{ilt}^{imp}	Number of trailers (for all modes) allocated on road line (i, l) in period $t \in T$.
TS_{lit}^{exp}	Number of trailers (for all modes) trucks allocated on road line (l, i) in period $t \in T$

Table 4.6 Decision variables (continue)

Number of vehicles required on each node :	
VJ_{jt}	Number of European plated trucks needed in port $j \in J$ at the beginning of period $t \in T$.
VK_{kt}	Number of European plated trucks needed in terminals $k \in K$ at the beginning of period $t \in T$.
VL_{lt}^{E}	Number of European plated trucks needed in hub $l \in L$ at the beginning of period $t \in T$.
VL_{lt}^{T}	Number of Turkish plated trucks needed in hub $l \in L$ at the beginning of period $t \in T$.
VI_{it}^{E}	Number of European plated trucks needed in port $i \in I$ at the beginning of period $t \in T$.
VI_{it}^{T}	Number of Turkish plated trucks needed in port $i \in I$ at the beginning of period $t \in T$.
TL_{lt}	Number of trailers needed in port $i \in I$ at the beginning of period $t \in T$.
TI_{it}	Number of trailers needed in port $i \in I$ at the beginning of period $t \in T$.
Total number of vehicle required at the beginning of each period :	
VFS_{t}^{E}	Total number of European plated trucks needed at the beginning of each period.
VFS_{t}^{T}	Total number of Turkish plated trucks needed at the beginning of each period.
TFS_{t}	Total number of trailers needed at the beginning of each period.

4.3 The Developed Mixed-Integer Linear Programming Model

4.3.1 Objective Function

In light of this information, a mixed integer mathematical model is developed to solve integrated freight and fleet planning problem simultaneously. Objective function of the developed model is minimizing total transportation costs, which consist of marine, rail, spot (outsourcing) costs and road transportation cost related with loaded and empty movements (repositioning) costs. In addition, there is fixed vehicle cost derives from owning a vehicle for one month. Equation (4.1) represents total cost including all cost items that mentioned above.

$$Min\ Z_{total} = Z_{marine} + Z_{rail} + Z_{spot} + Z_{road_loaded} + Z_{road_empty} + Z_{owned} \quad (4.1)$$

Marine transportation can be realized in two ways having different cost: by owned Ro-Ro vessels or/and by other logistics providers. Naturally shipping freights with own vessels is cheaper than getting service from other logistics providers. However, sometimes using other logistics services may be more efficient than owned ships, because of time and capacity constraints. All costs are defined per TU and total marine transport cost formulized in Equation (4.2).

$$Z_{marine} = \sum_{(i,j)\in C_{ij}} \sum_{l\in L} \sum_{t\in T} R_{ijt}^{imp}.Co_{ij}^{imp} + \sum_{(i,j)\in C_{ij}} \sum_{l\in L} \sum_{t\in T} R_{jit}^{exp}.Co_{ji}^{exp} + \sum_{(i,j)\in L_{ij}} \sum_{t\in T} P_{ijt}^{imp}.Cp_{ij}^{imp} + \sum_{(i,j)\in L_{ij}} \sum_{t\in T} P_{jit}^{exp}.Cp_{ji}^{exp} \quad (4.2)$$

In the same way, railway transportation can be realized in two way having different transport agreements and costs. Freights could be transported on port-terminal lines by block trains or flexible public trains. Transportation cost of block trains is fixed and defined per train independently from units. Transportation between railway terminals is carried out only by public trains and their costs are defined per TU. Total railway transport cost is given in Equation (4.3).

$$Z_{rail} = \sum_{(j,k)\in C_{jk}} \sum_{t\in T} S_{jkt}^{imp}.Cb_{jk}^{imp} + \sum_{(j,k)\in C_{jk}} \sum_{t\in T} S_{kjt}^{exp}.Cb_{kj}^{exp} + \sum_{(j,k)\in L_{jk}} \sum_{t\in T} P_{jkt}^{imp}.Cp_{jk}^{imp}$$
$$+ \sum_{(j,k)\in L_{jk}} \sum_{t\in T} P_{kjt}^{exp}.Cp_{kj}^{exp} + \sum_{s\in T_k} \sum_{k\in G_k} \sum_{t\in T} P_{skt}^{imp}.Cp_{sk}^{imp}$$
$$+ \sum_{s\in T_k} \sum_{k\in G_k} \sum_{t\in T} P_{kst}^{exp}.Cp_{ks}^{exp} \quad (4.3)$$

Occasionally, outsourcing can be more profitable. In such cases, company could assign all transportation operations to the other logistics providers namely get transportation services from other companies as a customer. Mostly this solution is an effective way to overcome imbalances between import and export transportation demands. The company pays per TU to transport its freights and total spot cost deriving from outsourced transportation is given in Equation (4.4).

$$Z_{spot} = \sum_{i\in I} \sum_{l\in L} \sum_{t\in T} O_{ilt}^{imp}.SC_{ilt}^{imp} + \sum_{i\in I} \sum_{l\in L} \sum_{t\in T} O_{lit}^{exp}.SC_{lit}^{exp} \quad (4.4)$$

Road transportation is still backbone of transportation systems even in intermodal transportation and it is the highest cost item in total transportation cost. Road transportation cost mainly results from the i) loaded (full) and ii) empty (repositioning) vehicle movements. Both loaded and empty vehicle movements' costs are defined per TU-km. There are three main lines, where road transportation is carried out. These lines are actually pre and end haulage between i) ports in Turkey and hubs in Europe , ii) ports and hubs in Europe, iii) terminals and hubs in Europe. Turkish plated vehicles only operate on the first line (ports in Turkey - hubs in Europe), when European plated vehicles can operate on all lines but especially on the lines within Europe. Total road transport cost of loaded vehicles with plate features is formulated in Equation (4.5).

$$Z_{road_loaded} = \sum_{j\in J} \sum_{l\in L} \sum_{t\in T} V_{jlt}^{imp}.d_{jl}.Cr + \sum_{j\in J} \sum_{l\in L} \sum_{t\in T} V_{ljt}^{exp}.d_{lj}.Cr + \sum_{k\in K} \sum_{l\in L} \sum_{t\in T} V_{klt}^{imp}.d_{kl}.Cr$$
$$+ \sum_{k\in K} \sum_{l\in L} \sum_{t\in T} V_{lkt}^{exp}.d_{lk}.Cr + \sum_{i\in I} \sum_{l\in L} \sum_{t\in T} \left(VE_{ilt}^{imp} + VT_{ilt}^{imp}\right).d_{il}.Cr$$
$$+ \sum_{i\in I} \sum_{l\in L} \sum_{t\in T} \left(VE_{lit}^{exp} + VT_{lit}^{exp}\right).d_{li}.Cr \quad (4.5)$$

Empty vehicle movements namely repositioning of vehicles are non value added movements but unavoidable due to imbalances between import and export transportation demand. Even though it could be reduced by proper freight and fleet allocation, could not be avoided completely. Thus, costs arising from repositioning should be considered. Additionally, trucks and trailers are separated from each other so they could reposition separately according to requirements. In this sense, total repositioning cost related with empty truck and trailers is given in Equation (4.6).

$$\begin{aligned} Z_{road_empty} = & \sum_{j\in J}\sum_{l\in L}\sum_{t\in T} V_{jlt}^{rep}.d_{jl}.RC^{v} + \sum_{j\in J}\sum_{l\in L}\sum_{t\in T} V_{ljt}^{rep}.d_{lj}.RC^{v} + \sum_{k\in K}\sum_{l\in L}\sum_{t\in T} V_{klt}^{rep}.d_{kl}.RC^{v} \\ & + \sum_{k\in K}\sum_{l\in L}\sum_{t\in T} V_{lkt}^{rep}.d_{lk}.RC^{v} + \sum_{i\in I}\sum_{l\in L}\sum_{t\in T}\left(VE_{ilt}^{rep} + VT_{ilt}^{rep}\right).d_{il}.RC^{v} \\ & + \sum_{i\in I}\sum_{l\in L}\sum_{t\in T}\left(VE_{lit}^{rep} + VT_{lit}^{rep}\right).d_{li}.RC^{v} \\ & + \sum_{i\in I}\sum_{l\in L}\sum_{t\in T} TR_{ilt}^{rep}.d_{il}.RC^{Tr} + \sum_{i\in I}\sum_{l\in L}\sum_{t\in T} TR_{lit}^{rep}.d_{li}.RC^{Tr} \end{aligned} \quad (4.6)$$

We should note that repositioning of vehicles are possible only on the line (arc) that they are allocated. This means that the vehicles cannot be assigned to another line/route. Vehicle should be reallocated to different lines in order to reposition empty vehicles between different lines/routes. Such a reallocation concept is not considered in scope of this dissertation, and vehicle repositioning on the same line/route are taken into account. However, reallocation is one of the most important issues for fleet planning and needs more attention in future studies.

$$Z_{owned} = \sum_{t\in T} VFS_{t}^{E}.FC^{v} + \sum_{t\in T} VFS_{t}^{T}.FC^{v} + \sum_{t\in T} TFS_{t}.FC^{T} \quad (4.7)$$

Finally as given in Equation (4.7), fixed cost of vehicles arising from owning vehicles has to be considered when optimizing fleet size. Because optimal fleet size balances fixed cost arising from having excess vehicle and operating vehicle under the particular utilization rate.

4.3.2 Constraints Related to Freight Planning

Constrains of the developed mathematical model can be grouped into two main sections. These are i) constraints related to freight planning and ii) constraints related to fleet planning which includes loaded and empty vehicle movements and optimal allocation of total number of required vehicles. In addition, constraints related to freight constraints (4.8 - 4.45) are divided into three constraint groups: transport demands, marine transportation and rail transportation restrictions for both directions.

$$X_{ilt}^{imp} + \sum_{j \in J} Y_{ijlt}^{imp} + \sum_{j \in D_j} \sum_{k \in D_k} Z_{ijklt}^{imp} + O_{ilt}^{imp} \geq De_{ilt}^{imp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.8)$$

$$X_{lit}^{exp} + \sum_{j \in J} Y_{ljit}^{exp} + \sum_{j \in D_j} \sum_{k \in D_k} Z_{lkjit}^{exp} + O_{lit}^{exp} \geq De_{lit}^{exp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.9)$$

Constraints (4.8) and (4.9) ensure that monthly import and export transportation demands are met by using different combination of transport modes (pure road, integrated road and marine, integrated road, rail, and marine transport) and outsourcing option. Similar to these constraints, analogue constraints are written within entire proposed model for both import and export direction.

4.3.2.1 Marine Transportation

$$\sum_{l \in L} Y_{ijlt}^{imp} \leq N_{ij^*t}^{imp} . Cap_{ij^*}^{imp} - \sum_{l \in L} Y_{ij^*lt}^{imp} - \sum_{l \in L} \sum_{k \in K} Z_{ij^*klt}^{imp} \qquad \forall (i,j) \in C_{ij} \wedge j \in T_j, j^* \in \gamma_j, \forall t \in T \qquad (4.10)$$

$$\sum_{l \in L} Y_{ljit}^{exp} \leq N_{j^*it}^{exp} . Cap_{j^*i}^{exp} - \sum_{l \in L} Y_{lj^*it}^{exp} - \sum_{l \in L} \sum_{k \in K} Z_{lkj^*it}^{exp} \qquad \forall (j,i) \in C_{ji} \wedge j \in T_j, j^* \in \gamma_j, \forall t \in T \qquad (4.11)$$

$$\sum_{l \in L} Y_{ijlt}^{imp} \leq N_{ijt}^{imp} . Cap_{ij}^{imp} \qquad \forall (i,j) \in C_{ij} \wedge \{j \notin D_j\}, \forall t \in T \qquad (4.12)$$

$$\sum_{l \in L} Y_{ljit}^{exp} \leq N_{jit}^{exp} . Cap_{ji}^{exp} \qquad \forall (j,i) \in C_{ji} \wedge \{j \notin D_j\}, \forall t \in T \qquad (4.13)$$

$$\sum_{l \in L} Y_{ijlt}^{imp} \leq N_{ijt}^{imp} . Cap_{ij}^{imp} + P_{ijt}^{imp} \qquad \forall (i,j) \in B_{ij} \wedge j \notin D_j, \forall t \in T \qquad (4.14)$$

$$\sum_{l\in L} Y_{ljit}^{exp} \le N_{jit}^{exp}.Cap_{ji}^{exp} + P_{jit}^{exp} \qquad \forall(i,j)\in B_{ij}\wedge j\notin D_j, \forall t\in T \qquad (4.15)$$

$$\sum_{l\in L} Y_{ijlt}^{imp} = R_{ijt}^{imp} \qquad \{\forall(i,j)\in C_{ij}\vee B_{ij}\}\wedge\{j\in T_j\vee j\notin D_j\}, \forall t\in T \qquad (4.16)$$

$$\sum_{l\in L} Y_{ljit}^{exp} = R_{jit}^{exp} \qquad \{\forall(j,i)\in C_{ji}\vee B_{ji}\}\wedge\{j\in T_j\vee j\notin D_j\}, \forall t\in T \qquad (4.17)$$

$$\sum_{l\in L} Y_{ijlt}^{imp} + \sum_{k\in D_k}\sum_{l\in L} Z_{ijklt}^{imp} \le N_{ijt}^{imp}.Cap_{ij}^{imp} - \sum_{l\in L} Y_{ij'lt}^{imp} + P_{ijt}^{imp}$$
$$\forall(i,j)\in C_{ij}, j\in D_j, j'\in T_j, \forall t\in T \qquad (4.18)$$

$$\sum_{l\in L} Y_{ljit}^{exp} + \sum_{k\in D_k}\sum_{l\in l} Z_{lkjit}^{exp} \le N_{jit}^{exp}.Cap_{ji}^{exp} - \sum_{l\in L} Y_{lj'it}^{exp} + P_{jit}^{exp}$$
$$\forall(j,i)\in C_{ji}, j\in D_j, j'\in T_j, \forall t\in T \qquad (4.19)$$

$$\sum_{l\in L} Y_{ijlt}^{imp} + \sum_{k\in D_k}\sum_{l\in L} Z_{ijklt}^{imp} = R_{ijt}^{imp} + P_{ijt}^{imp} \qquad \{\forall(i,j)\in B_{ij}\vee C_{ij}\}, j\in D_j, \forall t\in T \qquad (4.20)$$

$$\sum_{l\in L} Y_{ljit}^{exp} + \sum_{k\in D_k}\sum_{l\in l} Z_{lkjit}^{exp} = R_{jit}^{exp} + P_{jit}^{exp} \qquad \{\forall(j,i)\in B_{ji}\vee C_{ij}\}, j\in D_j, \forall t\in T \qquad (4.21)$$

$$\sum_{l\in L} Y_{ijlt}^{imp} + \sum_{k\in D_k}\sum_{l\in L} Z_{ijklt}^{imp} \le P_{ijt}^{imp} \qquad \forall(i,j)\in L_{ij}, j\in D_j, \forall t\in T \qquad (4.22)$$

$$\sum_{l\in L} Y_{ljit}^{exp} + \sum_{k\in D_k}\sum_{l\in L} Z_{lkjit}^{exp} \le P_{jit}^{exp} \qquad \forall(j,i)\in L_{ji}, j\in D_j, \forall t\in T \qquad (4.23)$$

$$\sum_{l\in L} Y_{ijlt}^{imp} \le P_{ijt}^{imp} \qquad \forall(i,j)\in L_{ij}, j\notin D_j, \forall t\in T \qquad (4.24)$$

$$\sum_{l\in L} Y_{ljit}^{exp} \le P_{jit}^{exp} \qquad \forall(j,i)\in L_{ji}, j\notin D_j \forall t\in T \qquad (4.25)$$

$$R_{ijt}^{imp}/Cap_{ij}^{imp} = MS_{ijt}^{imp} \qquad \forall(i,j)\in C_{ij}, \forall t\in T \qquad (4.26)$$

$$R_{jit}^{exp}/Cap_{ji}^{exp} = MS_{jit}^{exp} \qquad \forall(j,i)\in C_{ji}, \forall t\in T \qquad (4.27)$$

$$U_{ijt}^{imp} = R_{ijt}^{imp}/\left(Cap_{ijt}^{imp}.Cap_{ij}^{imp}\right) \qquad \forall(i,j)\in C_{ij}, \forall t\in T \qquad (4.28)$$

$$U_{jit}^{exp} = R_{jit}^{exp}/\left(N_{jit}^{exp}.Cap_{ji}^{exp}\right) \qquad \forall(j,i)\in C_{ji}, \forall t\in T \qquad (4.29)$$

$$LB_{ijt}^{imp} \le U_{ijt}^{imp} \qquad \forall(i,j)\in C_{ij}, \forall t\in T \qquad (4.30)$$

$$LB_{jit}^{exp} \le U_{jit}^{exp} \qquad \forall(j,i)\in C_{ji}, \forall t\in T \qquad (4.31)$$

Constraints (4.10) and (4.11) are capacity constraints related to marine lines including transshipment ports (Lavrion) which is only operated by owned Ro- Ro vessels of the company for both direction. It is assumed that the transshipment ports

have no railway connections. Constraints (4.12) and (4.13) are about capacities of marine lines, which are operated only by owned Ro-Ro vessels and have no rail connections (Sete). In addition, constraints (4.14) and (4.15) are about line capacities, which are operated by owned Ro-Ro vessels and other logistics providers' ships and have no rail connections. The total amount of freight transported by owned Ro-Ro to ports that have no rail connection (Lavrion, Sete) is calculated by Equations (4.16) and (4.17). Constrains (4.18) and (4.19) are related to capacity of marine lines which have at least one transshipment port (Lavrion) and final ports have rail connections (Trieste). Total freight transported by owned and other logistics providers' ships to ports having rail connections (Trieste) is obtained by Equations (4.20) and (4.21). Also, amount of freight could be transported only via other logistics providers to the ports having rail connections is obtained by equations (4.22) and (4.23). Amount of freight transported via other logistics providers to the ports having no rail connections is calculated by equations (4.24) and (4.25). The required trip numbers of owned vessels, operated between ports in Turkey and ports in Europe, can be calculated by equations (4.26) and (4.27), when utilization of these vessels can be calculated by equations (4.28) and (4.29). The lower bound related to utilization is defined by constrains (4.30) and (4.31). In other words, preferred minimum utilization rate of the lines is added by these constraints.

4.3.2.2 Railway Transportation

$$\sum_{i\in I}\sum_{l\in L} Z_{ijklt}^{imp} = S_{jkt}^{imp}.Cap_{jk}^{imp} \qquad (j,k)\in C_{jk}\backslash\{T_k\}, \forall\in T \qquad (4.32)$$

$$\sum_{i\in I}\sum_{l\in L} Z_{lkjit}^{exp} = S_{kjt}^{exp}.Cap_{kj}^{exp} \qquad (k,j)\in C_{kj}\backslash\{T_k\}, \forall\in T \qquad (4.33)$$

$$\sum_{i\in I}\sum_{l\in L} Z_{ijklt}^{imp} \le P_{jkt}^{imp} \qquad (j,k)\in L_{jk}\backslash\{T_k\}, \forall t\in T \qquad (4.34)$$

$$\sum_{i\in I}\sum_{l\in L} Z_{lkjit}^{exp} \le P_{kjt}^{exp} \qquad (k,j)\in L_{kj}\backslash\{T_k\}, \forall t\in T \qquad (4.35)$$

$$\sum_{i\in I}\sum_{l\in L} Z_{ijklt}^{imp} \le S_{jkt}^{imp}.Cap_{jk}^{imp} + P_{jkt}^{imp} \qquad (j,k)\in B_{jk}\backslash\{T_k\}, \forall t\in T \qquad (4.36)$$

$$\sum_{i\in I}\sum_{l\in L} Z_{lkjit}^{exp} \le S_{kjt}^{exp}.Cap_{kj}^{exp} + P_{kjt}^{exp} \qquad (k,j)\in B_{kj}\backslash\{T_k\}, \forall t\in T \qquad (4.37)$$

$$\sum_{i\in I}\sum_{l\in L} Z^{imp}_{ijklt} + \sum_{i\in I}\sum_{l\in G_l}\sum_{k\in G_k} Z^{imp}_{ijklt} = S^{imp}_{jkt}.Cap^{imp}_{jk} \quad \forall j \in D_j, \forall k \in T_k \cap (j,k) \in C_{jk}, \forall t \in T \quad (4.38)$$

$$\sum_{i\in I}\sum_{l\in L} Z^{exp}_{lkjit} + \sum_{i\in I}\sum_{l\in G_l}\sum_{k\in G_k} Z^{exp}_{lkjit} = S^{exp}_{kjt}.Cap^{exp}_{kj} \quad \forall j \in D_j, \forall k \in T_k \cap (k,j) \in C_{kj}, \forall t \in T \quad (4.39)$$

$$\sum_{i\in I}\sum_{j\in D_j}\sum_{l\in G_l} Z^{imp}_{ijklt} \le P^{imp}_{skt} \qquad \forall s \in T_k, \forall k \in G_k \cap (s,k) \in L_{sk}, \forall t \in T \quad (4.40)$$

$$\sum_{i\in I}\sum_{j\in D_j}\sum_{l\in G_l} Z^{exp}_{lkjit} \le P^{exp}_{kst} \qquad \forall s \in T_k, \forall k \in G_k \cap (k,s) \in L_{ks}, \forall t \in T \quad (4.41)$$

$$LB^{imp}_{jkt} \le S^{imp}_{jkt} \le UB^{imp}_{jkt} \qquad \forall (j,k) \in C_{jk}, \forall t \in T \quad (4.42)$$

$$LB^{exp}_{kjt} \le S^{exp}_{kjt} \le UB^{exp}_{kjt} \qquad \forall (k,j) \in C_{kj}, \forall t \in T \quad (4.43)$$

$$\left|S^{imp}_{jkt} - S^{exp}_{kjt}\right| \le 1 \qquad \forall (j,k) \in C_{jk}, \forall t \in T \quad (4.44)$$

$$\left|\sum_{t\in T}\left(S^{imp}_{jkt} - S^{exp}_{kjt}\right)\right| \le 1 \qquad \forall (j,k) \in C_{jk} \quad (4.45)$$

Constraints (4.32) and (4.33) are lines capacities related to block trains lines having fixed schedules (Ludwigshafen, Ostrova). Amount of freight transported on flexible public train lines (Munich) is calculated by equations (4.34) and (4.35). Similarly, (4.36) and (4.37) constraints are related to capacity of lines operated by both bock and public trains. Constrains (4.38) and (4.39) are related to capacity of transshipment terminal lines which are operated by block trains (Cologne). Some of the freights are distributed by road at transshipment terminals and some of them transported by public trains to the final terminals (Malmo, Gothenburg). The freights at issue are transported from final terminals to their destinations by road. Transportation between final terminals and transshipment terminals are realized only by public trains and the capacity constraints of these lines are represented by (4.40) and (4.41). Constrains (4.42) and (4.43) keep the trip number of the block trains within lower and upper bound for both direction. Furthermore, there should be a balance between the import and export trip number of block trains each month. In detail, the difference between the import and export trip number of block trains should not be more than one, and constraint (4.44) ensures that. Also this balance should be provided annually and this constraint is ensured by Equation (4.45).

4.3.3 Constraints Related to Fleet Planning

4.3.3.1 Vehicle Movement and Fleet Sizing

$$X_{ilt}^{imp} = VE_{ilt}^{imp} + VT_{ilt}^{imp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.46}$$

$$X_{lit}^{exp} = VE_{lit}^{exp} + VT_{lit}^{exp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.47}$$

$$\sum_{i \in I} Y_{ijlt}^{imp} = V_{jlt}^{imp} \qquad \forall j \in J, \forall l \in L, \forall t \in T \tag{4.48}$$

$$\sum_{i \in I} Y_{ljit}^{exp} = V_{ljt}^{exp} \qquad \forall j \in J, \forall l \in L, \forall t \in T \tag{4.49}$$

$$\sum_{i \in I} \sum_{j \in J} Z_{ijklt}^{imp} = V_{klt}^{imp} \qquad \forall k \in K, \forall l \in L, \forall t \in T \tag{4.50}$$

$$\sum_{i \in I} \sum_{j \in J} Z_{lkjit}^{exp} = V_{lkt}^{exp} \qquad \forall k \in K, \forall l \in L, \forall t \in T \tag{4.51}$$

$$V_{jlt}^{imp}.T_{jl} + V_{ljt}^{exp}.T_{lj} + \left|V_{jlt}^{imp}.T_{jl} - V_{ljt}^{exp}.T_{lj}\right| \leq \left(VS_{jlt}^{imp} + VS_{ljt}^{exp}\right).\varphi_{lt}.\Gamma.\alpha \qquad \forall j \in J, \forall l \in L, \forall t \in T \tag{4.52}$$

$$V_{klt}^{imp}.T_{kl} + V_{lkt}^{exp}.T_{lk} + \left|V_{klt}^{imp}.T_{kl} - V_{lkt}^{exp}.T_{lk}\right| \leq \left(VS_{klt}^{imp} + VS_{lkt}^{exp}\right).\varphi_{lt}.\Gamma.\alpha \qquad \forall k \in K, \forall l \in L, \forall t \in T \tag{4.53}$$

$$VE_{ilt}^{imp}.T_{il} + VE_{lit}^{exp}.T_{li} + \left|VE_{ilt}^{imp}.T_{il} - VE_{lit}^{exp}.T_{li}\right| \leq \left(EP_{ilt}^{imp} + EP_{lit}^{exp}\right).\varphi_{lt}.\Gamma.\alpha \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.54}$$

$$VT_{ilt}^{imp}.T_{il} + VT_{lit}^{exp}.T_{li} + \left|VT_{ilt}^{imp}.T_{il} - VT_{lit}^{exp}.T_{li}\right| \leq \left(TP_{ilt}^{imp} + TP_{lit}^{exp}\right).\varphi_{lt}.\Gamma.\alpha \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.55}$$

$$VS_{jlt}^{imp} \leq V_{jlt}^{imp} \qquad \forall j \in J, \forall l \in L, \forall t \in T \tag{4.56}$$

$$VS_{ljt}^{exp} \leq V_{ljt}^{exp} \qquad \forall j \in J, \forall l \in L, \forall t \in T \tag{4.57}$$

$$VS_{klt}^{imp} \leq V_{klt}^{imp} \qquad \forall k \in K, \forall l \in L, \forall t \in T \tag{4.58}$$

$$VS_{lkt}^{exp} \leq V_{lkt}^{exp} \qquad \forall k \in K, \forall l \in L, \forall t \in T \tag{4.59}$$

$$EP_{ilt}^{imp} \leq VE_{ilt}^{imp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.60}$$

$$EP_{lit}^{exp} \leq VE_{lit}^{exp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.61}$$

$$TP_{ilt}^{imp} \leq VT_{ilt}^{imp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.62}$$

$$TP_{lit}^{exp} \leq VT_{lit}^{exp} \qquad \forall i \in I, \forall l \in L, \forall t \in T \tag{4.63}$$

$$X_{ilt}^{imp}.T_{il}+\sum_{j\in J}Y_{ijlt}^{imp}.\left(TM_{ij}+T_{jl}\right)+\sum_{j\in D_j}\sum_{k\in K}Z_{ijklt}^{imp}.\left(TM_{ij}+TR_{jk}+T_{kl}\right)+X_{lit}^{exp}.T_{li}+$$

$$\sum_{j\in J}Y_{ljit}^{exp}.\left(T_{lj}+TM_{ji}\right)+\sum_{j\in D_j}\sum_{k\in K}Z_{lkjit}^{exp}.\left(T_{lk}+TR_{kj}+TM_{ji}\right)+\left|X_{ilt}^{imp}.T_{il}+\sum_{j\in J}Y_{ijlt}^{imp}.\left(TM_{ij}+T_{jl}\right)\right.$$

$$+$$

$$\sum_{j\in D_j}\sum_{k\in K}Z_{ijklt}^{imp}.\left(TM_{ij}+TR_{jk}+T_{kl}\right)-X_{lit}^{exp}.T_{li}-\sum_{j\in J}Y_{ljit}^{exp}.\left(T_{lj}+TM_{ji}\right)$$

$$\left.-\sum_{j\in D_j}\sum_{k\in K}Z_{lkjit}^{exp}.\left(T_{lk}+TR_{kj}+TM_{ji}\right)\right|\leq\left(TS_{ilt}^{imp}+TS_{lit}^{exp}\right).\varphi_{lt}.\Gamma.\beta$$

$$\forall i\in I,\forall l\in L,\forall t\in T \qquad (4.64)$$

$$TS_{ilt}^{imp}\leq X_{ilt}^{imp}+\sum_{j\in J}Y_{ijlt}^{imp}+\sum_{j\in J}\sum_{k\in K}Z_{ijklt}^{imp} \qquad \forall i\in I,\forall l\in L,\forall t\in T \qquad (4.65)$$

$$TS_{lit}^{exp}\leq X_{lit}^{exp}+\sum_{j\in J}Y_{ljit}^{exp}+\sum_{j\in J}\sum_{k\in K}Z_{lkjit}^{exp} \qquad \forall i\in I,\forall l\in L,\forall t\in T \qquad (4.66)$$

Constraints (4.46)-(4.51) can be defined as transition constraints from freight planning to vehicle position (one vehicle movement) number. In other word, the connection and relationship between the transported freight and loaded vehicle movements are ensured by these constraints. (4.46) and (4.47) constraints represent the position number should be done by Turkish and European plated trucks between ports in Turkey and hubs in Europe for both direction. Constraints (4.48) and (4.49) are written for the position number of European plated trucks that operated on port-hub lines in Europe for both directions. Similarly, (4.50) and (4.51) constraints are written for terminal-hub lines in Europe for both directions. Constraints (4.52)-(4.55) are so crucial since fleet size (the minimum number of required vehicles) is determined by these equations by taking into account the number of vehicle positions, transportation times, length of the periods, number of the working days in order countries and vehicle availabilities. Besides, incoming and outgoing movements of loaded and empty vehicles are taken into account when calculating minimum number of required vehicles on each arc. Constraints (4.52) and (4.53) are written respectively for the number of required European plated truck on port-hub and terminal-hub lines in Europe for both transport direction. Constraint (4.54) represents the number of required Turkish plated trucks between ports in Turkey and

hubs in Europe for both transport direction, when (4.55) represents European plated trucks. As mentioned, the obtained truck number includes not only loaded vehicle movements but also empty vehicle movements (repositioning). Trailer requirement occurs only at ports in Turkey and hubs in Europe because they do not go through any process meanwhile transportation. Therefore, Equation (4.64) is written in order to calculate trailer requirement by considering all transportation modes that used to transport trailers. Constraints (4.529 - (4.55) and (4.64) are non-linear constraints hence these constraints must be converted to the linear form in the solution phase. (4.56) - (4.63) constraints ensure that assigned truck number would not exceed the position number on the relevant routes for both transport direction. Similarly, constraints (4.65) and (4.66) are written for trailers transported by all modes. Already, the most important difference between trucks and trailers is that the trucks are used only for road transportation while trailers are used in all modes.

4.3.3.2 Vehicle Allocation and Repositioning

$$VJ_{jt} = \sum_{l \in L} VS_{jlt}^{imp} \qquad \forall j \in J, \forall t \in T \qquad (4.67)$$

$$VK_{kt} = \sum_{l \in L} VS_{klt}^{imp} \qquad \forall k \in K, \forall t \in T \qquad (4.68)$$

$$VL_{lt}^{E} = \sum_{j \in J} VS_{ljt}^{exp} + \sum_{k \in K} VS_{lkt}^{exp} + \sum_{i \in I} EP_{lit}^{exp} \qquad \forall l \in L, \forall t \in T \qquad (4.69)$$

$$VL_{lt}^{T} = \sum_{i \in I} TP_{lit}^{exp} \qquad \forall l \in L, \forall t \in T \qquad (4.70)$$

$$VI_{it}^{E} = \sum_{l \in L} EP_{ilt}^{imp} \qquad \forall i \in I, \forall t \in T \qquad (4.71)$$

$$VI_{it}^{T} = \sum_{l \in L} TP_{ilt}^{imp} \qquad \forall i \in I, \forall t \in T \qquad (4.72)$$

$$TL_{lt} = \sum_{i \in I} TS_{lit}^{exp} \qquad \forall l \in L, \forall t \in T \qquad (4.73)$$

$$TI_{it} = \sum_{i \in I} TS_{ilt}^{imp} \qquad \forall i \in I, \forall t \in T \qquad (4.74)$$

Constraints (4.67) - (4.72) represent the total truck number, which have to be located on the different points of intermodal logistics network (ports in Turkey, ports, terminals, and hubs in Europe.) at the beginning of the each period. Inventories of these trucks are kept separately at ports in Turkey and hubs in Europe because both of Turkish and European plated trucks operate on these lines. On the other hand, only European plated trucks are kept in inventory at ports, and terminals in Europe. The number of European plated trucks at the beginning of each period is represented by constraints (4.67) and (4.68) respectively for ports, and terminals in Europe. Requirement of European and Turkish plated trucks at hubs in Europe and ports in Turkey can be obtained respectively by constraints (4.69) - (4.70) and (4.71) - (4.72). Equations (4.73) and (4.74) are trailer constraints that represent the number of trailers to be presented at the end of each period respectively at ports in Turkey and hubs in Europe. Also these constraints are formulated by considering loaded and empty trailers transported by all modes. Loaded trailers can be transported by owned Ro-Ro or/and other logistics providers' vessels, block or/and public train, and by trucks in road transport. However, empty trailer repositioning is solely realized by trucks, namely empty trailer transported only by road.

$$\sum_{l\in L} V_{jlt}^{imp} - \sum_{l\in L} V_{ljt}^{exp} - VS_{jlt}^{imp} \leq \sum_{l\in L} V_{ljt}^{rep} \qquad \forall j \in J, \forall l \in L, \forall t \in T \qquad (4.75)$$

$$\sum_{l\in L} V_{klt}^{imp} - \sum_{l\in L} V_{lkt}^{exp} - VS_{klt}^{imp} \leq \sum_{l\in L} V_{lkt}^{rep} \qquad \forall k \in K, \forall l \in L, \forall t \in T \qquad (4.76)$$

$$\sum_{j\in J} V_{ljt}^{exp} - \sum_{j\in J} V_{jlt}^{imp} - VS_{ljt}^{exp} \leq \sum_{j\in J} V_{jlt}^{rep} \qquad \forall j \in J, \forall l \in L, \forall t \in T \qquad (4.77)$$

$$\sum_{k\in K} V_{lkt}^{exp} - \sum_{k\in K} V_{klt}^{imp} - VS_{lkt}^{exp} \leq \sum_{k\in K} V_{klt}^{rep} \qquad \forall k \in K, \forall l \in L, \forall t \in T \qquad (4.78)$$

$$\sum_{l\in L} VE_{ilt}^{imp} - \sum_{l\in L} VE_{lit}^{exp} - EP_{ilt}^{imp} \leq \sum_{l\in L} VE_{lit}^{rep} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.79)$$

$$\sum_{l\in L} VT_{ilt}^{imp} - \sum_{l\in L} VT_{lit}^{exp} - TP_{ilt}^{imp} \leq \sum_{l\in L} VT_{lit}^{rep} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.80)$$

$$\sum_{i\in I} VE_{lit}^{exp} - \sum_{i\in I} VE_{ilt}^{imp} - EP_{lit}^{exp} \leq \sum_{i\in I} VE_{ilt}^{rep} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.81)$$

$$\sum_{i\in I} VT_{lit}^{exp} - \sum_{i\in I} VT_{ilt}^{imp} - TP_{lit}^{exp} \leq \sum_{i\in I} VT_{ilt}^{rep} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.82)$$

$$\sum_{l\in L} X_{ilt}^{imp} + \sum_{l\in L}\sum_{j\in J} Y_{ijlt}^{imp} + \sum_{l\in L}\sum_{j\in J}\sum_{k\in K} Z_{ijklt}^{imp} - \sum_{l\in L} X_{lit}^{exp} - \sum_{l\in L}\sum_{j\in J} Y_{ljit}^{exp} - \sum_{l\in L}\sum_{j\in J}\sum_{k\in K} Z_{lkjit}^{exp} - TS_{ilt}^{imp} \leq TR_{lit}^{rep} \qquad \forall i \in I, \forall t \in T \qquad (4.83)$$

$$\sum_{i\in I} X_{lit}^{exp} + \sum_{i\in I}\sum_{j\in J} Y_{ljit}^{exp} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} Z_{lkjit}^{exp} - \sum_{i\in I} X_{ilt}^{imp} - \sum_{i\in I}\sum_{j\in J} Y_{ijlt}^{imp} - \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} Z_{ijklt}^{imp} - TS_{lit}^{exp} \leq TR_{ilt}^{rep} \qquad \forall l \in L, \forall t \in T \qquad (4.84)$$

$$VE_{ilt}^{rep} + VT_{ilt}^{rep} \geq TR_{ilt}^{rep} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.85)$$

$$VE_{lit}^{rep} + VT_{lit}^{rep} \geq TR_{lit}^{rep} \qquad \forall i \in I, \forall l \in L, \forall t \in T \qquad (4.86)$$

Constraints (4.75)-(4.82) are related to vehicle repositioning. Requirement of empty truck reposition is stem from the differences between import and export freight transportation, in the same period between two nodes on the same line. Additionally, to be able to transfer empty vehicle between two nodes, there should be freight transportation on the relevant line whether import or export direction. Because repositioning is aimed that to meet vehicle requirement arising from the imbalance between import and export freight transportation on the same line. Constraint (4.75) gives the number of empty trucks should be transferred from hubs to ports in Europe during relevant period. The number of reposition is obtained by loaded incoming minus loaded outgoing minus the number of vehicle allocated to line. Constraint (4.76) is similarly written for repositions from hubs to train terminals. Constraints (4.77) and (4.78) give the number of repositions realized from ports/terminals to hubs, which require trucks in order to transport trailers to ports/terminals. Constraints (4.79) and (4.81) represent the number of repositions handled by European plated trucks between ports in Turkey and hubs in Europe. Similar constrains are written in (4.80) and (4.82) in order to determine the number of positions realized by Turkish plated trucks. Trailer repositions are made only between origin and destination points, because trailer requirement occurs solely on this line, namely between ports in Turkey and hubs in Europe. (4.83) and (4.84) constraints are related to number of trailer would repositioned between these points. As mentioned before, trailer repositions are only realized by road. Hence, the relation between repositioned trucks and trailers is ensured by constraints (4.85) and (4.86).

According these constraints, the number of repositioned trucks could not be less than the number of repositioned trailers since trailers should be repositioned by empty trucks.

4.3.3.3 Total Required Vehicle Number

$$VFS_t^E = \sum_{j \in J} VJ_{jt} + \sum_{k \in K} VK_{kt} + \sum_{l \in L} VL_{lt}^E + \sum_{i \in I} VI_{it}^E \qquad \forall t \in T \qquad (4.87)$$

$$VFS_t^T = \sum_{l \in L} VL_{lt}^T + \sum_{i \in I} VI_{lt}^T \qquad \forall t \in T \qquad (4.88)$$

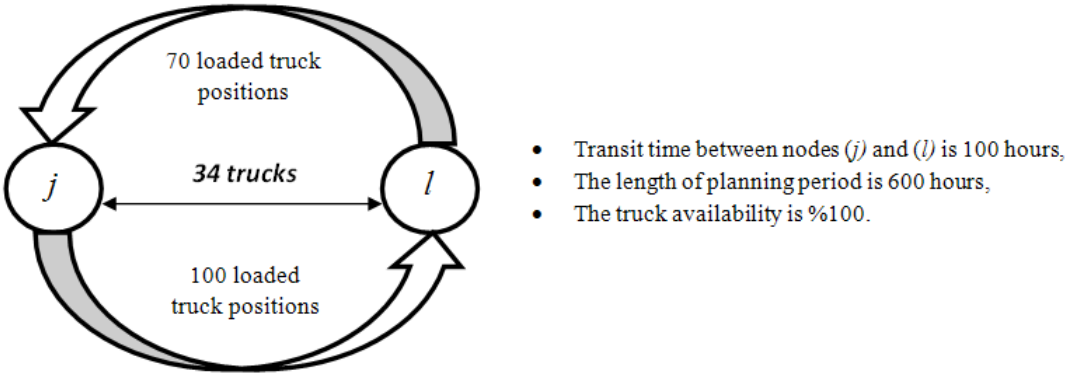
$$TFS_t = \sum_{l \in L} TL_{lt} + \sum_{i \in I} TI_{it} \qquad \forall t \in T \qquad (4.89)$$

Optimal number of vehicle should the company has each period from each type can be calculated by constraints (4.87)-(4.89). Constraints (4.87) and (4.88) give respectively total number of required European and Turkish plated trucks when constraint (4.89) gives optimal number of trailers, which the company should has. Finally, we remind that all decision variables are non-negative and decision variables related with resources and movements are integer except for truck and trailer numbers, since a certain portion of their capacity can be used on different routes each month.

4.4 An Illustrative Example for Fleet Sizing and Allocation of Vehicles

For better understanding, an illustrative numerical example is given in this section. The developed mixed integer linear programming model provides solution simultaneously for freight planning, truck and trailer fleet sizing, vehicle allocation (trucks and trailers) and repositioning problems by taking into account many aspects of intermodal transportation network.

Parameters such as transportation times, length of the period and availability of vehicles are substantial as well as position number of the vehicles while determining optimal fleet size. For instance, 100 TU freight should be transported from port (*j*) to hub (*l*) and 70 TU freight in opposite way according to the conducted freight plan. Assume that transit time between these nodes is 100 hours, length of the period is 600 hours and truck availability is 100 % as can be seen in the Figure 4.4. The required truck number will change in case of variation in freight plan or parameters. The total number of required truck size on line *(j-l)* can be obtained by Equation (4.52).



$$(100 * 100 + 70 * 100 + |70 * 100 - 100 * 100|) \leq (Truck_i + Truck_j) * 600 * 1.0 \approx 34$$

Figure 4.4 An numerical example for fleet size determination

Minimum 34 trucks should be allocated to line *(j-l)* in order to transport planned freight between node *j* and node *l*. Each truck could make 6 (600/100=6) trips during each period between these two nodes. However, allocation of these trucks so vital in terms of solution quality. Especially, amount of repositioned truck number is directly related with initial position of the trucks. Constraints (4.75)-(4.76) represent the

mathematical relationship between allocation and reposition. Moreover, physical impact of the appropriate allocation can be clarified by following cases.

Case 1: A poor allocation that causes repositioning: 0 trucks at node *j* and 34 trucks at node *l* (Figure 4.5)

$(100 - 70) - 0 = 30 \leq Rep_{lj}$ *(Namely 30);*

Node *j*	Trip 0 - # of Loads	Node *l*
0	100	0
0	70	34

Node *j*	Trip 1 - # of Loads	Node *l*
0	100	0
34	36	0

Node *j*	Trip 2 - # of Loads	Node *l*
0	66	0
0	36	34

Node *j*	Trip 3 - # of Loads	Node *l*
0	66	0
34	2	0

$(70 - 100) - 34 = -64 \leq Rep_{lj}$ *(Namely 0)*

Node *j*	Trip 4 - # of Loads	Node *l*
0	32	0
0	2	34

Node *j*	Trip 5 - # of Loads	Node *l*
0	32	0
2+**30**	0	2

Node *j*	Trip 6 - # of Loads	Node *l*
0	0	0
0	0	34

Figure 4.5 An example of poor allocation

Case 2: A comparatively better truck allocation with less truck repositions: 20 trucks at node *i* and 14 trucks at node *j* (Figure 4.6)

$(100 - 70) - 20 = 30 \leq Rep_{lj}$ *(Namely 10);*

Node *j*	Trip 0 - # of Loads	Node *l*
20	100	0
0	70	14

Node *j*	Trip 1 - # of Loads	Node *l*
0	80	20
14	56	0

Node *j*	Trip 2 - # of Loads	Node *l*
20	66	0
0	36	14

Node *j*	Trip 3 - # of Loads	Node *l*
0	46	20
14	22	0

$(70 - 100) - 14 = -44 \leq Rep_{lj}$ *(Namely 0)*

Node *j*	Trip 4 - # of Loads	Node *l*
20	32	0
0	2	14

Node *j*	Trip 5 - # of Loads	Node *l*
0	12	20
2+**10**	0	2

Node *j*	Trip 6 - # of Loads	Node *l*
0	0	30
0	0	14

Figure 4.6 An example of better allocation

Case 3: A perfect allocation without any repositioning: 30 trucks at node j and 4 trucks at node (Figure 4.7).

$(100 - 70) - 30 = 0 \leq Rep_{lj}$ *(Namely 0);*

Node j	Trip 0 - # of Loads	Node l
30	100	0
0	70	4

Node j	Trip 1 - # of Loads	Node l
0	70	30
4	66	0

Node j	Trip 2 - # of Loads	Node l
30	66	0
0	36	4

Node j	Trip 3 - # of Loads	Node l
0	36	30
4	32	0

$(70 - 100) - 4 = -34 \leq Rep_{lj}$ *(Namely 0)*

Node jj	Trip 4 - # of Loads	Node l
30	32	0
0	2	4

Node j	Trip 5 - # of Loads	Node l
0	2	30
2	0	2

Node j	Trip 6 - # of Loads	Node l
0	0	30
0	0	4

Figure 4.7 An example of perfect allocation

Now assumed that the node j at issue has connection with 3 hubs, namely freights transported between this node j and 3 hubs towards import and export direction. The optimal number of truck for each line (arc) is determined as 34, 20, and 30. Besides, optimal allocation that minimizes empty vehicle repositioning is shown in Figure 4.8.

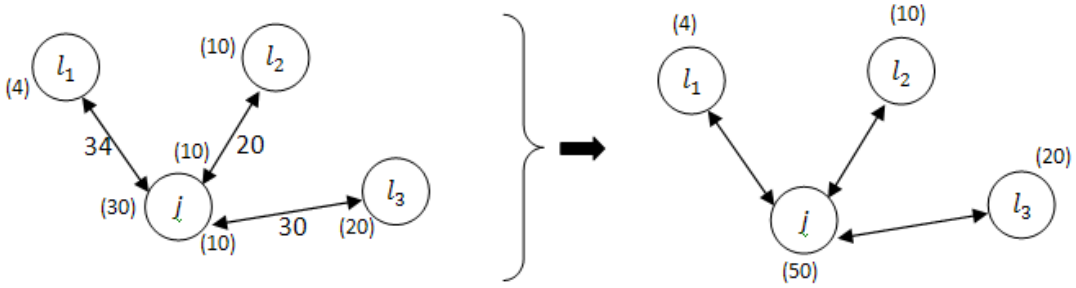


Figure 4.8 An example for truck allocation to nodes

As a result of optimal allocation, total truck requirement will be 50 at node j at the beginning of the period when it will be 4 at l_1, 10 at l_2, and 20 at l_3. Of course, a real transportation network is larger and more complicated than this simple example. Almost all nodes have connection with each other in an actual network, consequently this makes the fleet sizing and allocation problem difficult to solve owing to NP hard structure of the problem.

CHAPTER FIVE
IMPLEMENTATION OF THE PROPOSED MILP MODEL AND ANALYSIS OF VARIOUS SCENARIOS

In this section, in order to illustrate the usefulness, validity, and practicality of the proposed MILP model, we evaluated the computational results obtained from a real-life application in Ekol Logistics Inc., which is a large-sized logistics company in Turkey. The company provides various transportation models and services to its customers including road freight transport, the combined marine & road transport, and marine & rail & road transport.

The developed model is implemented to the real intermodal transportation network belonging to Ekol Logistics Company. The ideal solution that obtained after executing MILP model is presented in this chapter. The results, which are obtained under different conditions and scenarios, are discussed and analyzed. Primarily, effects of implementing some strategic decisions are investigated in terms of total cost, freight and fleet plan. Later, the more general cases are discussed to find out effects of using different transportation policies such as shipment without rail and marine transport. Moreover, modality effect on total costs, freight transportation and fleet structure are revealed by analysis.

5.1 Implementation of the Developed MILP Model

In our application, the intermodal logistics network is composed of 4 seaports in Europe with a single transshipment seaport, 3 seaports in Turkey, 3 railway terminals with a single transshipment point for block trains and finally 3 railway terminals for public train services. There are also 49 order points in Europe, which correspond to the aggregated customers and require both import/export transportation operations from/to Turkey. The planning horizon is set to one year composed of 12 monthly periods. Monthly transport demand is given for import and export direction in Table 5.1.

Table 5.1 Monthly transport demand (TU)

Month	Import	Export	Total
January	3023	2832	5855
February	3313	2818	6131
March	3670	3138	6808
April	3594	3124	6718
May	3827	3088	6915
June	3612	3233	6845
July	3571	3192	6763
August	3214	2405	5619
September	4010	3218	7228
October	3426	2885	6311
November	3858	2996	6854
December	3169	2807	5976
Total	42,287	35,736	78,023

Maximum number of Ro-Ro navigations and capacity of each vessel are given in Table 5.2. There are four round trips between İstanbul-Trieste ports and one round trip between İzmir-Sete every week. Each one-way trip takes about 62 hours between İstanbul-Trieste and 48 hours between İzmir-Sete. The average capacity of Ro-Ro vessels is 240 mega-trailers or 45 ft. containers apart from vessel operating on İzmir-Sete line.

Table 5.2 Data are related to maritime transport

	Max.Navigations (times/month)	Capacity (TU/Ro-Ro)	Transport time (hours/trip)
İstanbul --> Lavrion	4	240	19
İstanbul --> Trieste	13	240	62
İzmir --> Sete	4	165	48
Trieste --> Lavrion	9	240	42
Trieste--> İstanbul	14	240	63
Sete --> İzmir	5	165	52

Similarly, maximum train services related to block train line with capacity of each one can be seen in Table 5.3. Rail transport services takes about 24 hours from Trieste port to directly linked terminals (Ostrava, Cologne), and 46 hours to indirectly linked terminals (Malmo, Gothenburg).

Table 5.3 Data are related to railway transport

	Max. train service (times/month)	Capacity (TU/train)	Transport time (hours/trip)
Trieste --> Ostrava	14	28	24
Trieste --> Ludwigshafen	27	32	20
Trieste --> Cologne	39	32	24
Ostrava --> Trieste	14	28	24
Ludwigshafen --> Trieste	27	32	20
Cologne --> Trieste	40	32	24

In addition, there are a numerous data sets related to transportation and outsourcing costs, distances and transport times between nodes. Particularly data sets related to road transportation consist of too many nodes and links as the company has a large-scale intermodal transportation network. However, road transport comprises two main costs concerning loaded and empty movement of trucks. Repositioning cost of solely empty trucks between nodes is € 1.0 TU-km. Transferring trucks with empty trailer is costing € 1.1 when transferring trucks with loaded trailer is costing € 1.2 per TU-km.

In light of data's related to intermodal transportation system of the Ekol Logistics Inc., the MILP model is run through optimization software LINGO 14.0 on an Intel Core i7 2 GHz IBM in order to minimize total cost. The optimization model specifications are shown in Table 5.4.

Table 5.4 Specifications of the optimization model

Model class	MILP	**Total # of iteration**	329,779
Solver type	B&B	**Computational time (sec.)**	147.17
Total # of variables	101,263	**Objective value (€)**	168,341,100
Total # of integer variables	54,336	**Objective bound (€)**	168,280,600
Total # of constraints	92,126	**Optimality gap (≤)**	0.001

A freight and fleet plan is obtained by solving multi-mode and multi-period mathematical model, which minimize total annual cost of the company. The total cost contains variable costs (per TU) depending on transport, outsourcing cost and fixed vehicle owning cost.

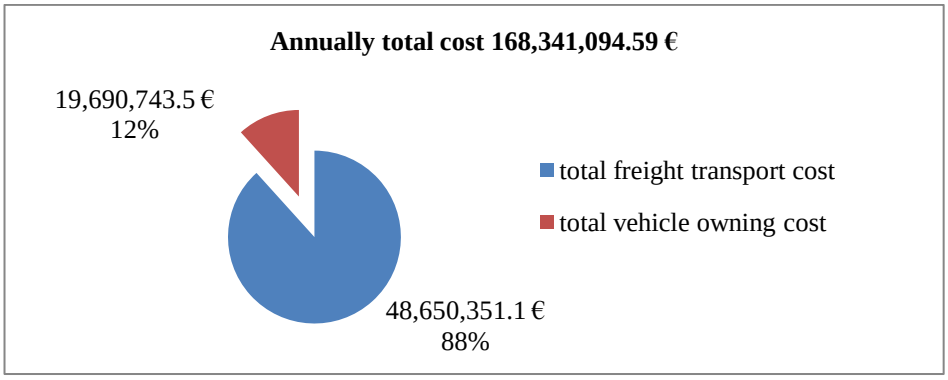


Figure 5.1 Total annual cost obtained by MILP model

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It can be seen in Figure 5.1 that the annual cost derived from transportation of freight and owning vehicles (trucks and trailers). Additionally, transportation cost belonging to each month is depicted in Figure 5.2.

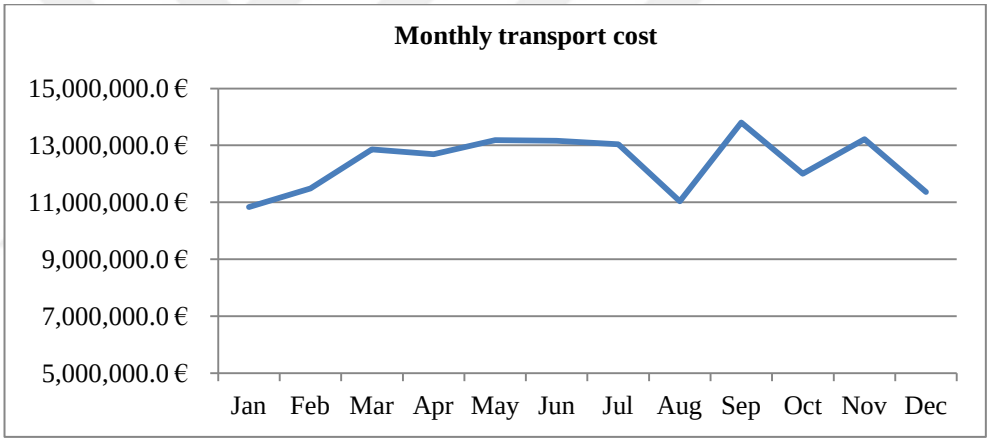


Figure 5.2 Transportation costs are related to each month

These results are obtained after the model run for 24 hours. By this way, a freight and fleet plan is obtained, in detail mode selection, and route selection for freight, fleet sizing, vehicle allocation and repositioning for resources of the company. We can divide and analyze exhaustive plan into two plan as freight and fleet plans in the next section.

5.1.1 Freight Plan

Obtained freight plan is indicated in Figure 5.3. Totally 78,023 TU freight should be transported between Turkey and Europe through different modes and combination of modes. Import transportation is realized by transferring total 42,287 TU freight in detail, 160 TU with road, 7,499 TU with marine & road, 25,315 TU with marine & rail & road transport and 9,313 TU by outsourcing. On the other hand, export transportation is carried out by transferring total 35,736 TU freight in detail, 135 TU with road, 7,030 TU with road & marine, 25,213 TU with road & rail & marine transport and 3,358 TU with outsourcing.

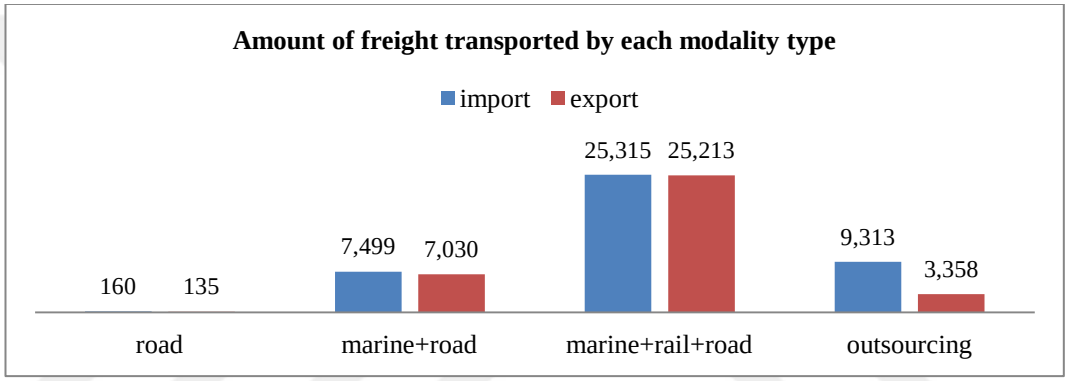


Figure 5.3 Amount of freight transported by each modality type for both directions

As can be seen clearly in Figure 5.3, amount of freight transported by owned resource almost equal for both directions due to minimize empty vehicle movements. Additionally, intermodal transportation involving marine & rail and road transport has the highest proportion within all alternatives as expected. The biggest change is emerged in outsourcing in terms of import and export transportation (Figure 5.4) because the outsourcing is used to balance freight transported by owned resources.

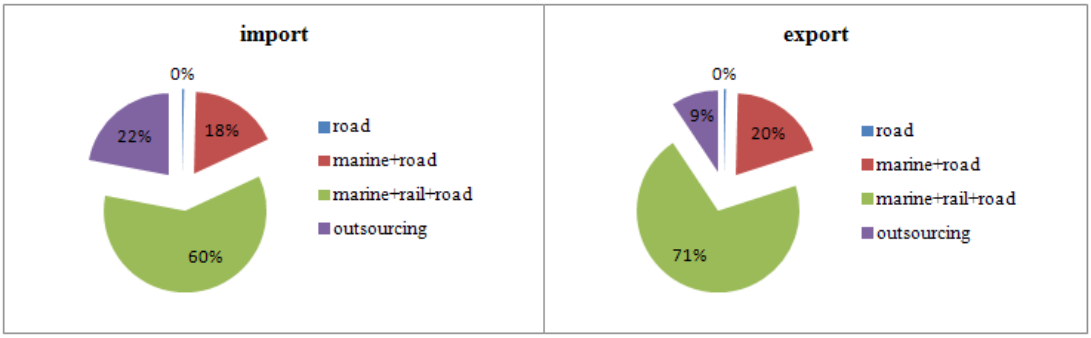


Figure 5.4 Percentage of freight transported by each modality type for both directions

Actually, routes of all freights namely which freight will transported by which mode and through which port and terminal (if it will be transported by multi-mode) are determined by the model. Even though there is detailed transport plan involving which freight should be transported through which port and terminal, only maritime and railway transport plans are summarized respectively in Table 5.5 and 5.6.

Table 5.5 Marine transport plan

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Amount of freight transported by owned Ro-Ro vessels												
Lavrion/İstanbul	35	36	38	37	35	38	36	36	36	47	40	34
İstanbul/Trieste	2028	1986	2182	2181	2247	2135	2168	1741	2438	2054	2170	1919
İzmir/Sete	74	92	104	97	118	114	114	105	126	96	101	70
Lavrion/İstanbul	13	12	13	13	14	13	14	12	13	13	13	11
Trieste/İstanbul	2178	2143	2361	2321	2263	2356	2318	1713	2452	2117	2179	2084
Sete/İzmir	86	107	119	111	134	126	131	104	126	95	101	82
Amount of freight transported by other logistics providers vessels												
İstanbul/Trieste	0	0	0	0	0	0	0	0	0	0	0	0
İstanbul/Toulon	71	93	110	128	125	114	107	98	114	89	108	92
İzmir/Trieste	305	319	360	349	359	356	341	281	368	322	335	316
Mersin/Trieste	52	49	57	56	57	56	57	44	58	53	56	51
Trieste/İstanbul	0	0	0	0	0	0	0	0	0	0	0	0
Toulon/İstanbul	60	75	87	91	100	82	94	80	89	72	84	74
Trieste/İzmir	26	28	32	33	34	36	31	13	31	26	26	24
Trieste/Mersin	6	6	7	7	7	7	7	5	8	6	6	6

Table 5.6 Railway transport plan

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Number of block trains booked												
Trieste/Ostrava	9	10	11	11	12	11	13	8	12	11	12	11
Trieste/Ludwigshafen	26	23	26	26	27	25	26	24	26	27	25	26
Trieste/Cologne	26	27	29	29	29	29	27	21	36	25	33	25
Ostrava/Trieste	10	10	12	11	11	12	12	8	11	11	11	11
Trieste/Ludwigshafen	27	24	26	26	26	26	27	23	25	27	24	27
Trieste/Cologne	26	28	30	30	28	30	28	20	35	24	32	26
Amount of freight transported by public trains												
Trieste/Munich	86	88	94	91	94	88	89	69	100	92	99	84
Cologne/Malmo	0	0	0	0	0	0	0	0	0	0	0	0
Cologne/Gothenburg	96	31	36	22	24	31	33	19	131	28	22	41
Munich/Trieste	87	85	90	96	84	103	92	57	92	85	83	88
Malmo/Cologne	0	0	0	0	0	0	0	0	0	0	0	0
Gothenburg/Cologne	78	14	17	17	18	18	16	13	110	16	16	22

As mentioned, very extensive transport plan is constituted by using proposed model. A majority of the freights are transported by intermodal because of the overall efficiency provided by using different transportation modes. Also, utilization of each mode (road, rail and marine separately) in planned freight transportation can be investigated in two way; i) how many TU freight transported by each mode, ii) how many TU freight how many km transported by each mode (Figure 5.5).

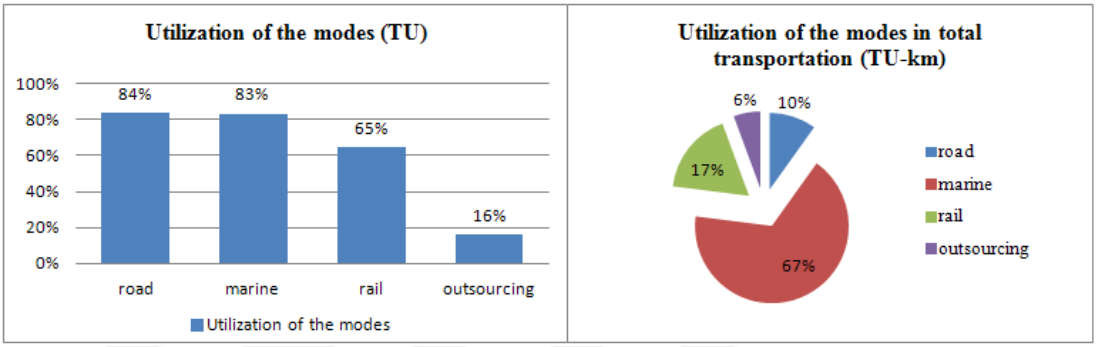


Figure 5.5 Utilization rate of each transport mode

Already road transportation is inevitable (excluding freights outsourced, 16 %), yet as expected almost all remain freights transported by marine (83 %) to take advantage of cheaper transport of a great number of freight. Even though rail transportation relatively less than road and marine, we have to take into consideration second chart to drawn a more accurate conclusion (Figure 5.5). As it can be seen in the second chart, the large part of the transport operations is actualized by marine, rail and road respectively. Finally, if we take a look at the share of the each mode in total cost (Figure 5.6), we can see the road transportation is most expensive transportation mode while comparing proportion of utilization rate and contribution to the total cost.

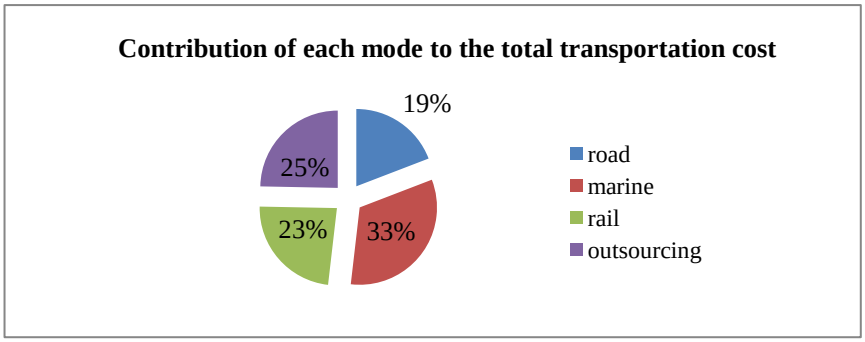


Figure 5.6 Contribution rates of the modes to the total transportation cost

5.1.2 Fleet Plan

In this section, we will analyze the obtained fleet plan in aspect of drayage operator since decisions and results related to network such as determination of optimal number of train and Ro-Ro service, mode and route selection discussed on the previous section. Optimum number of trailer and truck are acquired by solving MILP model. In other word, the optimum fleet size of the trailer/truck is determined, operation plan including allocation, loaded, and empty vehicle movements are expressed in aggregated manner. Additionally, note that the total numbers are rounded up or down owing to related decision variables are defined as continues numbers in the model.

First of all, trailer corresponds to one transportation unit (TU) of the system and freights transported by trailer from origin to destination point without handling; even though their transport mode is changed during transportation. Thus, trailer requirement arises only at ports in Turkey and hubs in Europe in our application. The optimum number of trailer required each month could be seen on Figure 5.7. However, fleet size optimization cannot be considered separately from optimal allocation of the trailers. Briefly, the number of trailers should be found in Turkey and Europe at the beginning of each period is demonstrated in Table 5.7.

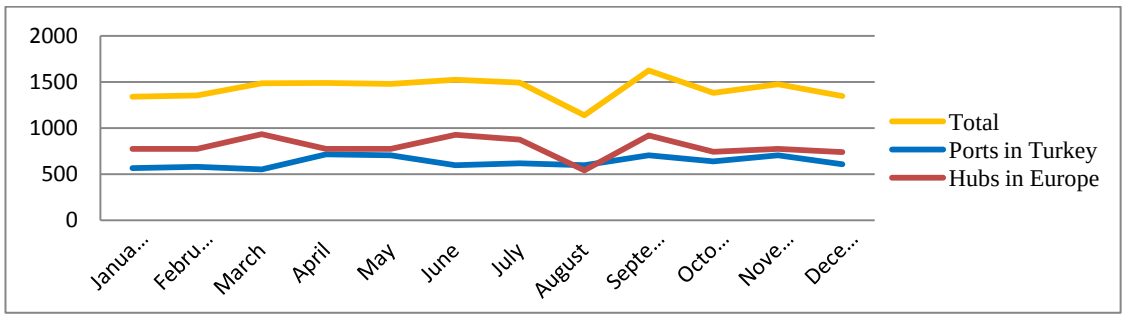


Figure 5.7 Optimum number of trailer related to each month

As it can be understood through the Table, there is substantial imbalance between resources located to origin and destination points, which is derived from the unbalanced freight carried between these nodes. Unfortunately, this situation is irrepressible as originate from customers' demand. Proposed model sets a balance

between required number of vehicle and repositioning number of empty vehicle to overcome the imbalanced transport demand. The optimal allocation of trailers, which minimizes the empty vehicle repositioning, is realized in Figure 5.7 and detailed in Table 5.7.

Table 5.7 Optimal allocation of trailers

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Ports in Turkey	566	580	554	717	706	599	619	598	705	639	705	608
Hubs in Europe	775	776	935	775	775	928	876	543	921	744	774	742
Total	1342	1356	1489	1491	1481	1527	1495	1141	1626	1383	1478	1350

According to the obtained results, Figure 5.8 represents the total number of loaded (65,353 positions) and empty (almost zero) trailer movements occur between Turkey and Europe. It can be seen that the number of empty trailer position number is quite few in comparison the loaded trailer number. When loaded and empty trailer movements are investigated separately in terms of transport direction (import/export), it is discovered that loaded and empty trailer movements nearly same for both directions.

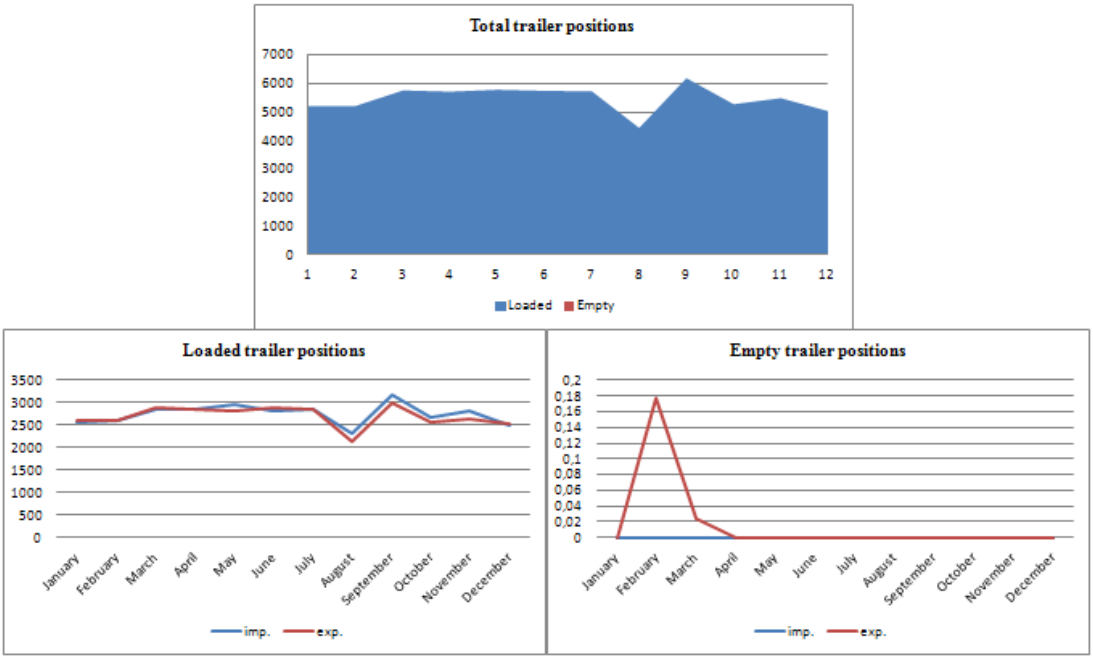


Figure 5.8 Loaded and empty trailer position numbers

Determination of the optimal size of the truck fleet is relatively troublesome since there are two type trucks as European and Turkish plated. The source of this difficulty stems from that each type of truck has different circulation agreements in Turkey and Europe. Details about the circulation right of each truck are given in the previous chapter. Under the all constraints at issue, optimal fleet size of trucks are obtained by proposed model and shown in Figure 5.9. European plated truck number is significantly higher than the Turkish plated trucks on the ground that road transport operations mostly take place in Europe due to intermodal transportation. Consequently European plated truck requirement is increase since laws restrict circulation of the Turkish plated truck in Europe.

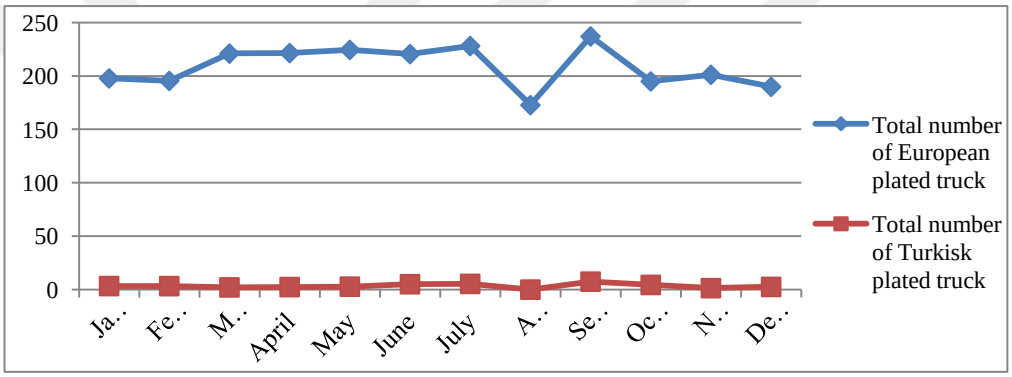


Figure 5.9 Optimum numbers of European and Turkish plated trucks related to each month

Apart from trailers, trucks are used in whole transportation network to carry out pre and end haulage operations. That means truck requirement arises within all transshipment nodes such as ports (in Turkey and Europe), terminals and hubs. However, Turkish plated trucks can be positioned only at ports in Turkey and hubs in Europe (Figure 5.10).

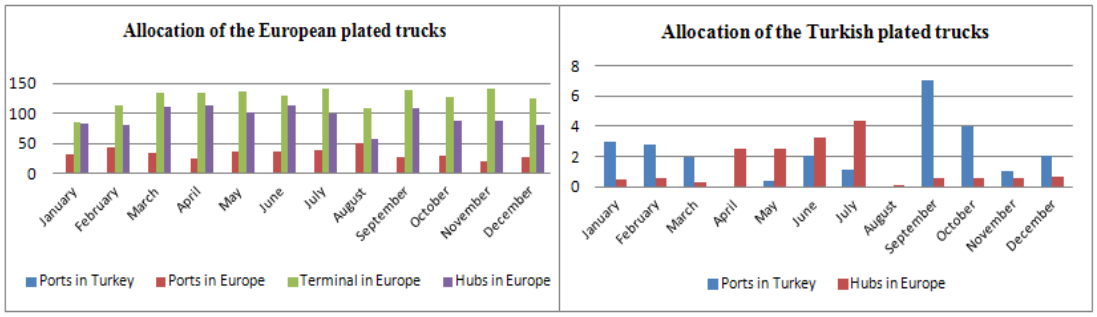


Figure 5.10 Allocation of the European and Turkish plated trucks

Total truck requirement for each month can be seen separately in Table 5.8, as a) for European and b) for Turkish plated truck size. In addition, optimal allocation of trucks can be seen in the Table for both European and Turkish plated trucks. However, this table gives aggregated information about total number of required trucks on set of nodes presented in the intermodal network, even though the number of trucks needed on each port/terminal/hub is already obtained.

Table 5.8 Allocation of the a) European, b) Turkish plated truck related to nodes

a) (European)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Ports (in Tu.)	0	0	0	0	0	0	0	0	0	0	0	0
Ports (in Eu.)	32	43	34	25	37	37	38	51	27	29	19	27
Terminals	84	114	135	133	137	130	142	109	139	126	141	125
Hubs	82	80	111	114	102	114	99	57	109	86	88	80
Total	198	237	280	272	277	281	280	217	274	241	248	233
b) (Turkish)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
İstanbul	3	3	2	0	0	2	1	0	7	4	1	2
Hubs	0	1	0	2	3	3	4	0	1	1	1	1
Total	3	3	2	2	3	5	5	0	8	5	2	3

Amount of loaded and empty truck movements are displayed in Figure 5.11, which is resulted from optimization of size and allocation of fleet. It can be seen that the empty truck position number is relatively lower than the loaded truck position number. Total 65,353 loaded truck positions consist of nearly 32,974 positions towards import and 32,378 positions towards export direction. Total 6,954 empty truck positions consist of nearly 3,371 positions towards import 3,584 positions towards export direction. Otherwise, it is seen that loaded position numbers are almost same for both direction in the chart. As a result, total empty trucks reposition numbers is constantly changing to maintain this balance.

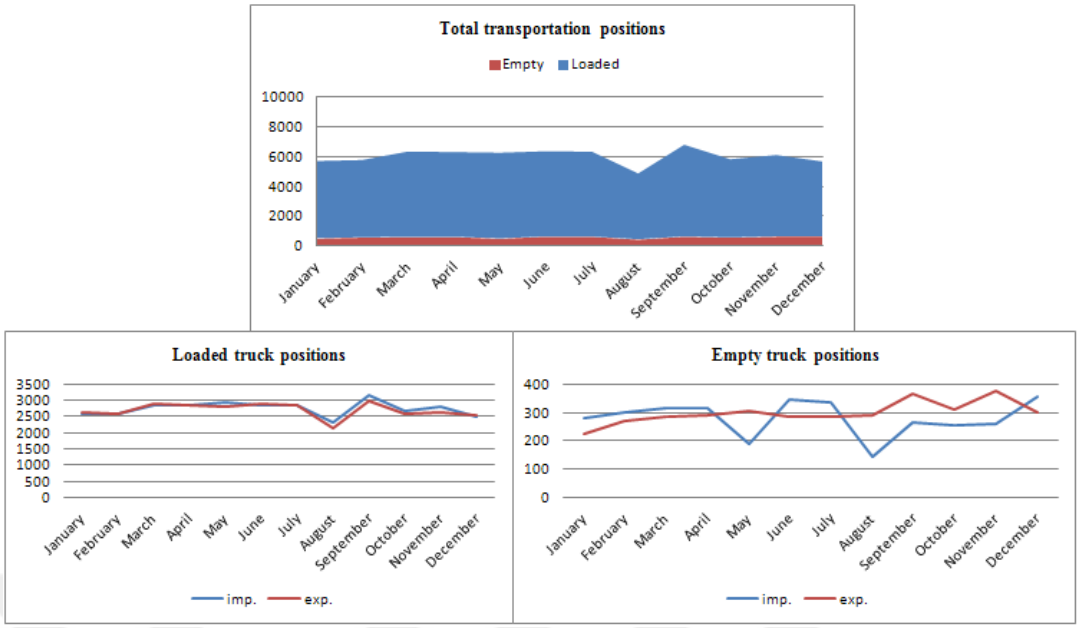


Figure 5.11 Total loaded and empty truck position numbers

Additionally, when we investigate main road lines (as in Figure 5.12) which are direct road (I-L), pre/end haulage of rail (K-L) and pre/end haulage of marine transport (J-L), it is clearly seen that terminal-hub line is most frequently used (50,528 of total 65,358 positions) as road line based on intermodal transportation. Consequentially, trucks repositioning takes place mostly on the terminal-hub (K-L) line as a result using intensively intermodal transportation consisting of rail transport.

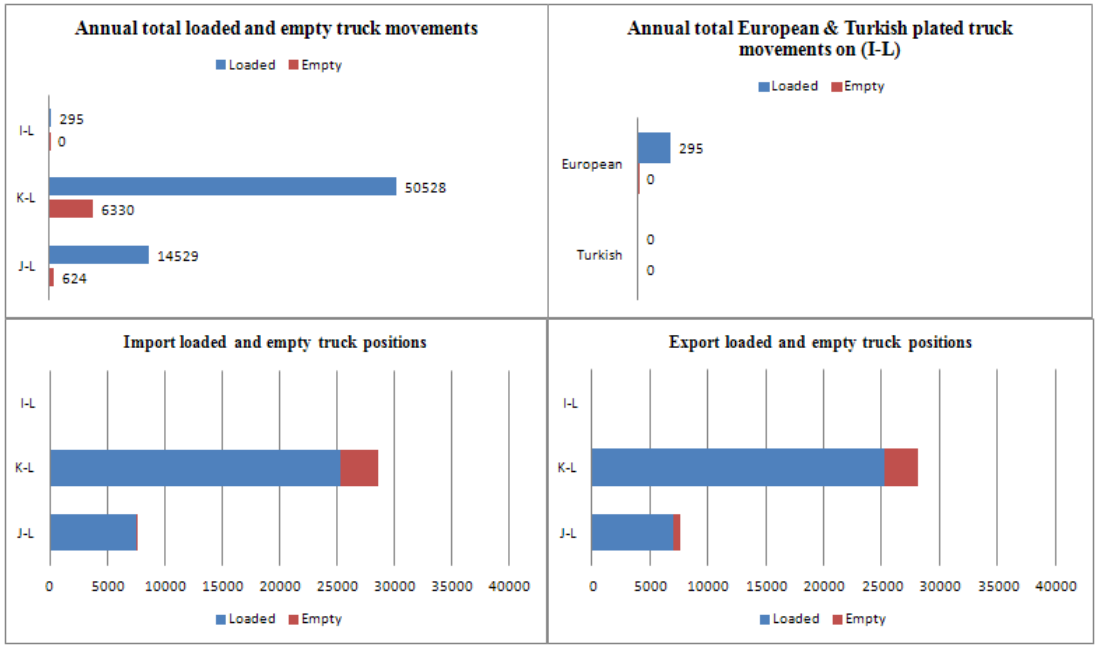


Figure 5.12 Loaded and empty truck position numbers related to each transport line

Other inference can be made, as repositioning towards export direction is higher than import for all transport lines during one-year planning horizon. When considering whole transportation network it is very sensible because there is imbalance in terms of import and export transportation and freights transported towards import direction are slightly higher than export direction. The company can resolve this imbalance and reduce reposition numbers by holding a large number of vehicles. However, this required very large capital investment to. The opposite situation also causes high reposition cost or inability to meet demand. Proposed model already sets a balance between, vehicle numbers and reposition costs.

5.2 Implementation and Analysis of Some Strategic Decisions

The results obtained in the previous section are ideal solution of the current situation of the company. On the other hand, there are some strategic issues considered by experts of the company in order to make use of opportunities will arise in the future. The first of these issues is about utilization of owned Ro-Ro vessels operated on specific marine lines. In the ideal solution, utilization of owned Ro-Ro ships that operate on İstanbul–Trieste marine line is change between nearly 55 % - 80 % through the planning horizon. Nevertheless, utilization of İzmir-Sete marine line is relatively very low, between nearly 10 % - 18 %.

Even though the owned Ro-Ro ships serve external customer, this ratio is still low. Actually, purpose of this line is to reach faster and easier into new markets in future periods. Nevertheless, the Company does not want to operate İzmir-Sete line below a certain efficiency level. Hence, a lower utilization bound is set for İzmir-Sete line. The second issue is about the rate of using road transportation. In the ideal solution, road transportation rate is nearly 0 % in total freight transportation. Although it is an expensive transport mode, the company wants to keep road transport rate above a certain level due to flexibility of the highway transportation. Therefore, a lower bound related to road usage is added to model. The developed model is run again with the strategic decisions included and specifications of the model are shown in Table 5.9.

Table 5.9 Model specifications related to strategic decision implementation

Computational time (sec.)	140.94	**Optimality gap (≤)**	0.001
Objective value (€)	176,402,200	**Objective bound (€)**	176,288,800

It can be reached to the desired goals with approximately € 8 million deviation (5 % increases) from the ideal solution. The change will be occurring in transport cost and vehicle cost can be seen in the Figure 5.13.

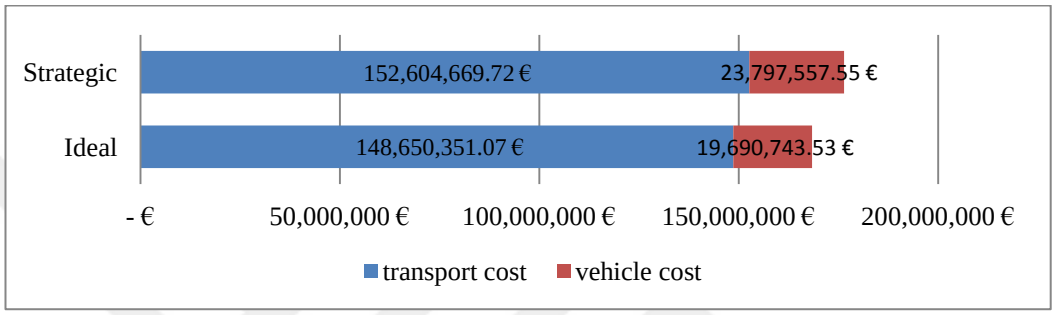


Figure 5.13 Comparison of ideal and strategic solutions in terms of costs

Naturally, there will be changes in freight and fleet plans to. For instance, rate of freight transported by highway increase from 0 % to 10 % as expected. Consequently, amount of freight transported by other modes is reduced. The changes that resulted in freight plan are shown in Figure 5.14, below.

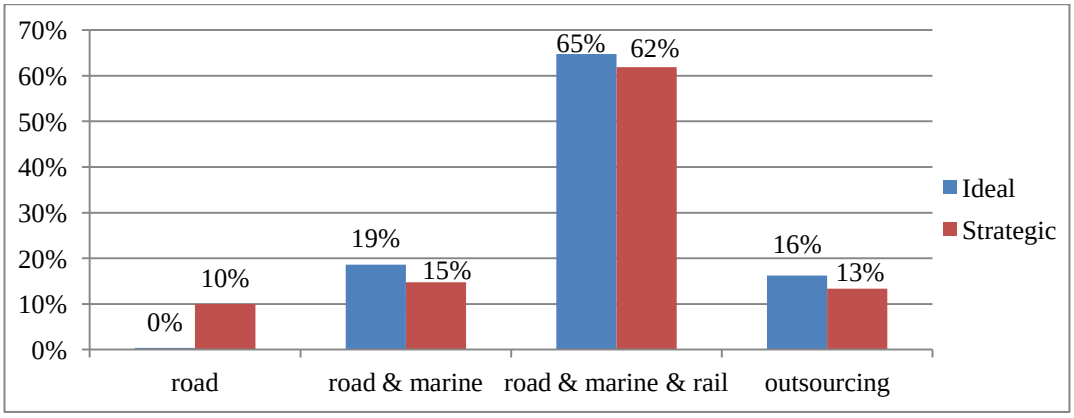


Figure 5.14 Comparison of ideal and strategic solutions in terms of transportation plan

Despite the reduction infreight transported by marine consequently by owned Ro-Ro ships, the amount of freight transported through İzmir-Sete line is increased.

Otherwise, desired changes on the utilization of same line and effects to the İstanbul-Trieste line can be seen in the Figure 5.15. The utilization rate of İstanbul-Trieste line is decreased when utilization rate of İzmir-Sete line is increased to the desired operation level.

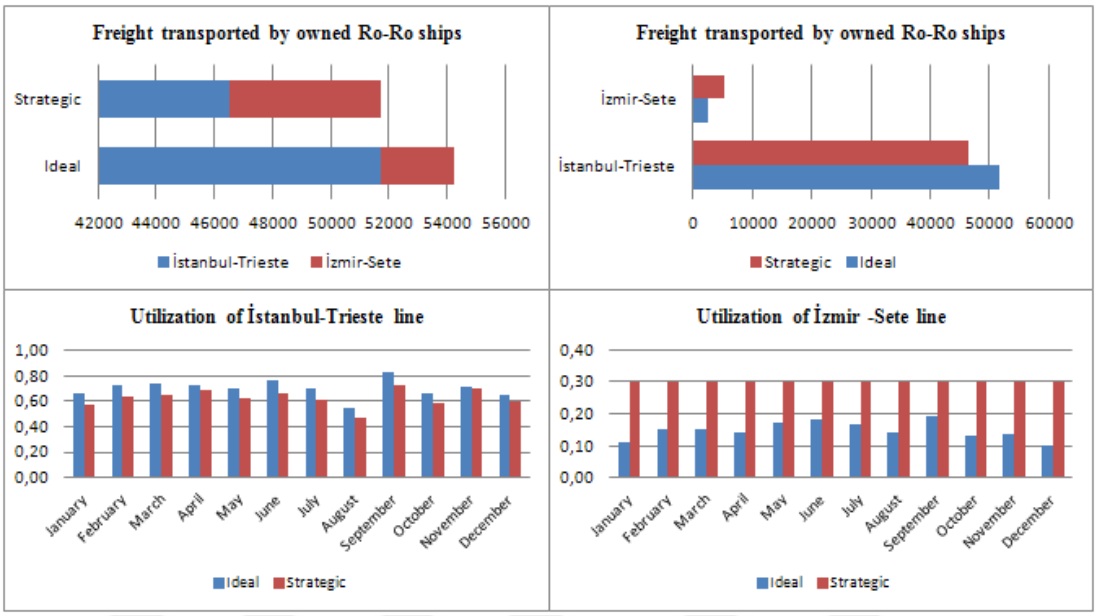


Figure 5.15 Comparison of ideal and strategic solutions in terms of marine transport

When we compare the total resource requirement for both situations, it is seen that there is reduction in requirements of train and European plated truck whereas, number of trailer and especially Turkish plated trucks is increased in consequence of increase in freight transportation by road from Turkey to Europe and vice versa. Figure 5.16 gives average number of required resources each month.

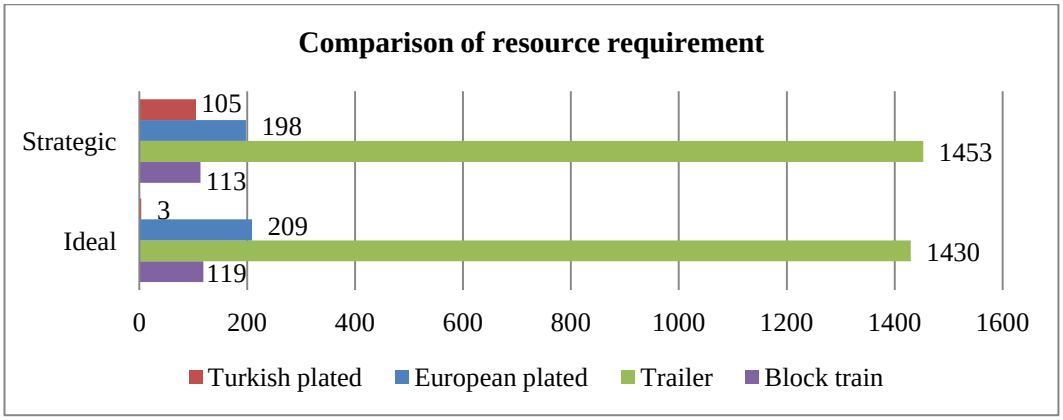


Figure 5.16 Comparison of ideal and strategic solutions in terms of total resource requirements

When Figure 5.17 is analyzed in detail, it is clearly seen that the total number of truck required on transshipment centers as ports and terminals (apart from origin and destination points) is decrease. However, the fleet allocated on the origin and destination points of the transportation (ports and hubs) is increased. Especially, dramatic increase is observed in the number of trucks required on ports in Turkey for both European and Turkish plated trucks.

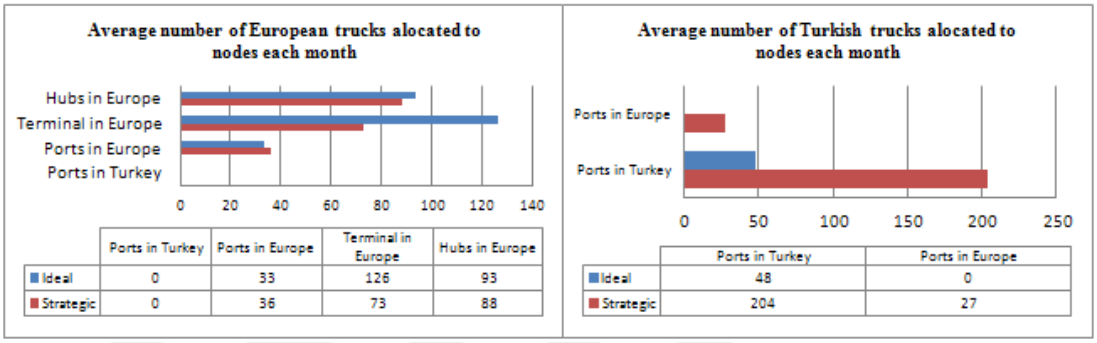


Figure 5.17 Comparison of ideal and strategic solutions in terms of truck allocation

This situation is a result of amount of freight transported on related lines. As it can be in Figure 5.18, loaded vehicle position numbers are decreased when empty vehicle reposition numbers are nearly same. As mentioned above, only amount of transportation on the line, between ports in Turkey and hubs in Europe, is dramatically increased by virtue of the policy of increasing highway transportation.

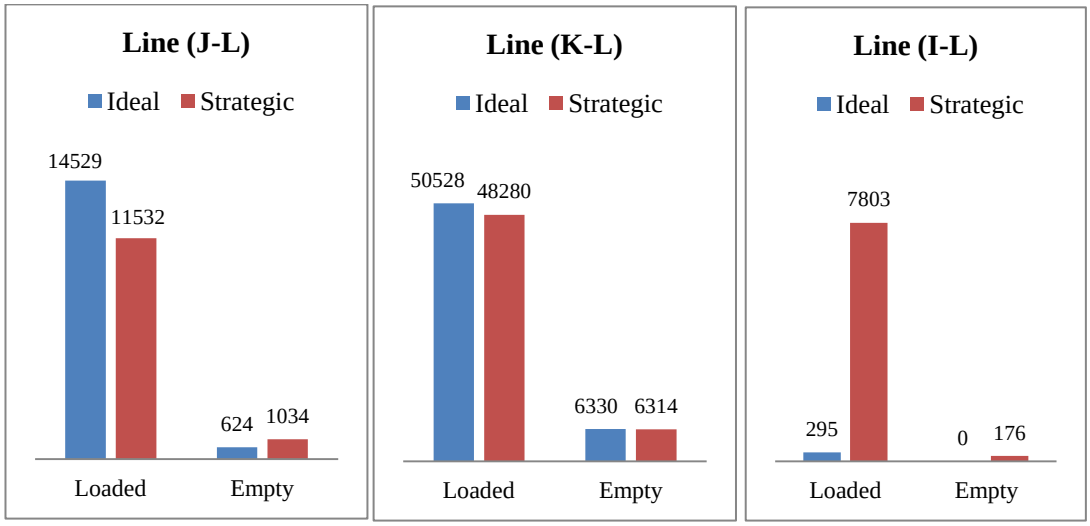


Figure 5.18 Comparison of ideal and strategic solutions in terms of loaded and empty truck position numbers on each line

A specific situation analysis is done at the request of the company in this section. A more general examination will do in the next section as effects of the modality choice on the transportation network.

5.3 Modality Type Analysis of the Intermodal Network

In this section, the more general cases are investigated so that analyze the effects of using various modalities consisting of different transport modes such as road, rail and marine. Existing transportation network of the company will compare with different transportation scenario in terms of total cost and fleet structure and size. Current state of the transportation network is an intermodal transportation consists of combination road, rail and marine transport, which can be named as full intermodal transportation. One of the scenarios is using only two-transportation mode as road and marine, which can be named as semi intermodal. The last situation is that only (pure) road transportation available in whole transportation network. First, we can see comparison of the modality types in term of total cost consisting transportation and vehicle costs in Figure 5.19.

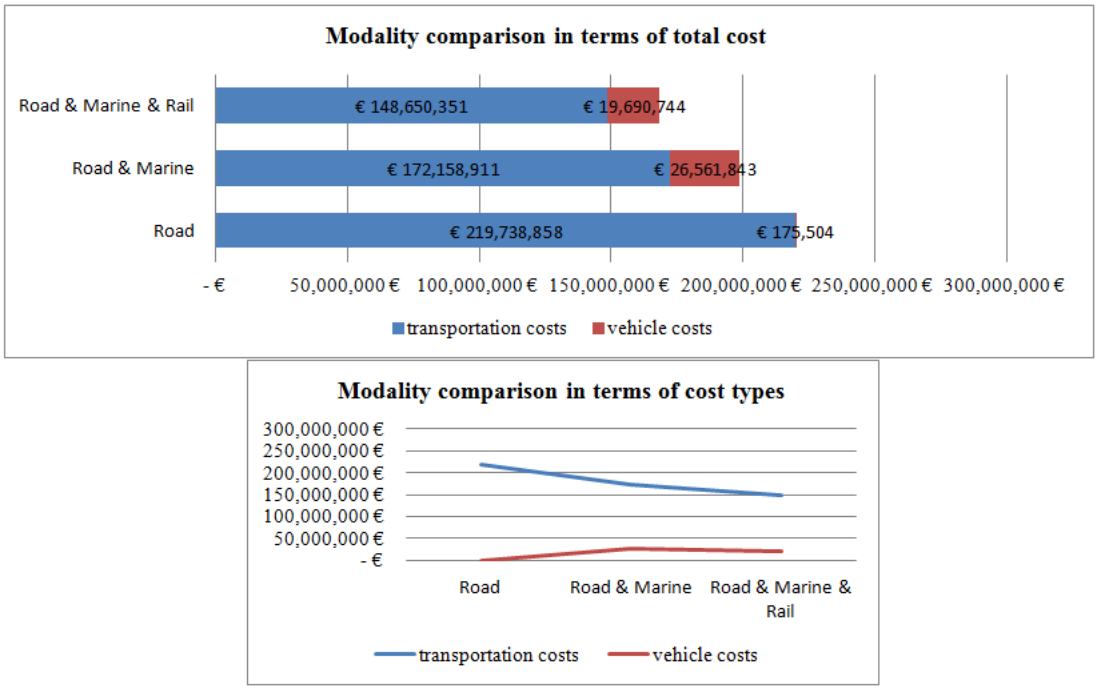


Figure 5.19 Comparison of the modality types in terms of total cost and cost types

We can see clearly cost effectiveness of the multi modal but especially intermodal transportation, which we dwell on whole dissertation. Actual costs are about € 220 million for pure road transport, € 198 million for combination of road and marine, finally, € 168 million for road, rail and marine combination. Additionally, we can see that the transport costs are decrease dramatically by using multi mode transport and this lead to actual decrease in total costs despite of the increase in vehicle costs. On the other hand, multimodal transportation increases utilization and efficiency in addition to reduce total cost. A significant reduction is observed in transportation costs whereas vehicle costs have fluctuation. The reason of increment in vehicle cost is revealed in the following analysis. In fact, there is no reduction in vehicle costs until including railway to the intermodal network as an alternative to road transportation. To summarize, marine transport reduces transportation costs when rail transport reduces vehicle costs derived from road transportation.

A change in the transport form certainly would affect entire freight transportation plan. Freight transportation tends to take advantages all transport modes. Each mode enables different advantages during transportation. Especially long haul freight transportation allows using all advantages, for instance maritime could be used for long distances, railway for aggregate land transport, and road transport for door-to-door services. Optimal freight plan for each modality type is shown in Figure 5.20.

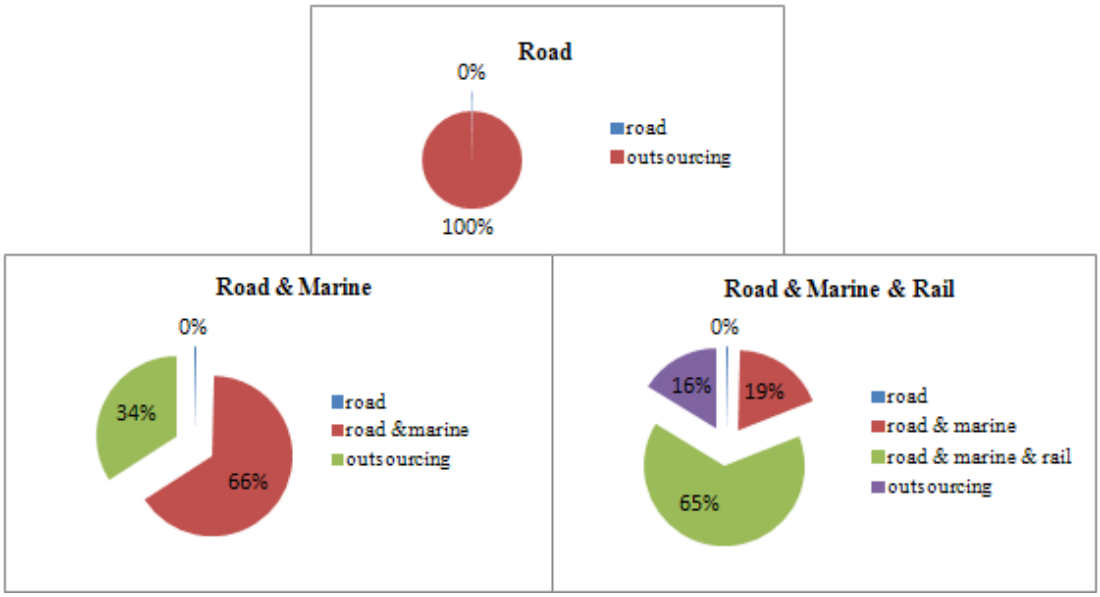


Figure 5.20 Comparison of optimal freight plan for each modality type

The interesting finding according to results (Figure 5.20) is that the other logistic companies transport freights at lower cost than the pure road transport options of the Ekol Logistics Company. Therefore, it is more cost effective way where the company has the other companies carry freights instead of own transport.

Similarly, fleet structure and size are varied depending on the modality type (Figure 5.21). As expected, obtained results show that there is no truck requirement while transport mode alternative is only road. An average of 212, 380 and 3 trucks are required for each month respectively for intermodal, semi intermodal and pure road transportation.

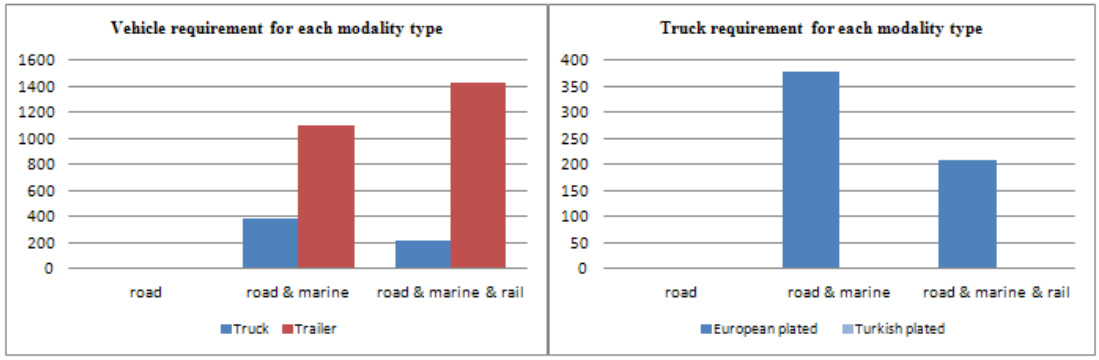


Figure 5.21 Vehicle requirement related to modality types

However, trailer requirements unlike trucks, is continuously increase when number of transport modes are increase (Figure 5.21). For instance, trailer fleet size is 3 for road, 1,098 for semi intermodal, and 1,430 trailers for intermodal transportation modality. There are two reasons cause that; the first one is decline in effectiveness of trailers. Trailers could be used only with trucks thus the number of trailers held is close to the truck number in road transportation. In fact, the second reason is the main reason and stem from greatly increased ratio of the outsourcing. Another important issue is about proportion of the European and Turkish plated trucks in the fleet. Turkish plated trucks only used while pure road transportation at issue. However, once intermodal transportation is started to use using of European plated trucks become inevitable due to restriction about circulation right in Europe.

Thus, number of the European plated trucks in fleet is increasing by increasing land transport in Europe owing to intermodal transportation.

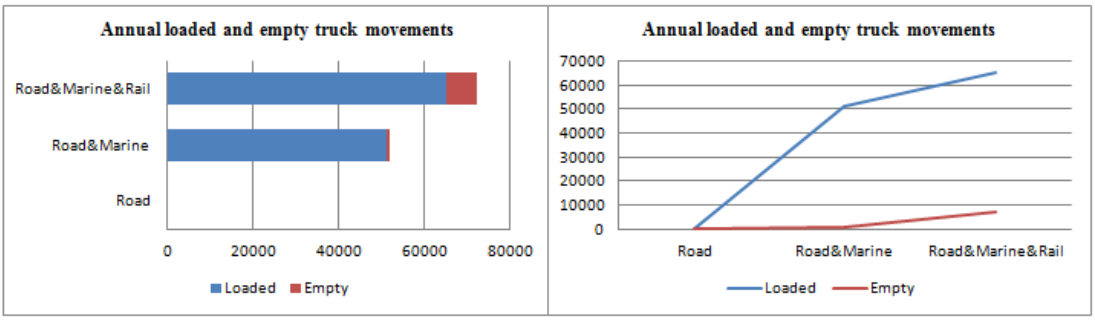


Figure 5.22 Loaded and empty truck position numbers related to modality type

Besides, changes in number of loaded vehicle positions are demonstrated in Figure 5.22. It is clear that the operation level and efficiency is increased by using multi-mode transport. On the other hand, empty vehicle reposition number is also increased in order to resolve growing imbalance derived from increase in freight flow. Although, there is imbalance derived from differences quantities of import and export transportation, it is kept at minimum due to existence of outsourcing alternative. The balance between own transportation and outsourcing let the company avoid not value added activities.

CHAPTER SIX
CONCLUSION

6.1 Summary

This dissertation is conducted to determine optimal fleet size needed on an intermodal transportation network with the perspective of drayage operators yet by taking into account all aspects related with fleet size. First of all, brief information about freight transportation and transportation models are given at beginning of the study. Fleet size optimization and related problems are discussed in detail in the next section. The extensive literature review shows that studies mostly concern unimodal transportation systems and there are quite a few studies concern multimodal, especially intermodal transportation systems. Besides, existing studies do not deal with freight and fleet planning simultaneously in an integrated manner. Thus, this study aimed to solve fleet sizing problem by considering structure of intermodal network, freight flow, allocation and reallocation of the vehicles.

Some strategic decisions such as network design, Ro-Ro and train schedules etc, are not considered in the scope of this study. Still, this information is taken into account and used as constraints of the intermodal network. On the other hand, freight flow (mode and route selection), number of required train, truck and trailer are determined. Appropriate number of trucks and trailers are allocated to the routes and nodes in order to minimize empty vehicle movements so as to minimize total cost of the transportation network. However, we should point out that this study carried out to obtain an aggregated plan, which allows the company to conduct the right strategies and polices for one-year planning horizon. Thus, operations management is not dealt in detail; only carried out in aggregated manner. Already, an aggregate plan should be constituted in able to construct a detailed operations plan.

We can summarize framework of the study as follow:

- A specific intermodal transportation network (belongs to Ekol Logistics Company) is considered in this study.
- It is aimed to model and solve the freight-planning problem (mode and route selection) and fleet-sizing problem (by considering allocation, repositioning, and outsourcing problem) in an integrated and simultaneous way.

Transportation mode combinations, which considered in the study, are:

1. Road Transportation
2. Marine + Road Transportation
3. Marine + Rail + Road Transportation

Briefly, this study is carried out to determine:

1. Optimum routes of freights
2. Optimum fleet size of the resources
3. Optimum allocation of the resources

For this purpose, a mixed-integer linear programming model is developed for intermodal network of Ekol Logistics Inc., which is the largest and most important logistics company in Turkey. Developed mathematical model determines optimal fleet size by constituting freight plan and fleet plan in which deciding to vehicle allocation, reallocation, loaded and empty vehicle movements. The ideal solution obtained after executing MILP model is presented.

Afterwards, the results, which are obtained under different conditions and scenarios are discussed and analyzed. Primarily, effects of implementing some strategic decisions are investigated in terms of total cost, freight and fleet plan. After that, the more general cases are discussed to find out effects of using different transportation policies such as shipment without rail or/and marine transport. Withal, modality effect on total costs, freight plan and fleet structure are revealed by analysis in the relevant sections.

6.2 Contribution of the Study

Operational Research mostly focuses on unimodal freight transportation problems as indicated in chapter three where literature is reviewed. Relatively, there are quite a few studies which concern multimodal, especially intermodal transport systems (Table 3.1 vs. Table 3.2). Nevertheless, intermodal transportation has become important issue for executers and researchers because of environmental sensitivity as well as the overall efficiency due to using different transportation modes.

Intermodal planning problems are more complex due to the inclusion of multiple transport modes, multiple decision makers and multiple types of load units. Two strategic planning problems, terminal design and infrastructure network configuration, have received increased attention in recent years. Yet the number of scientific publications on other intermodal planning problems remains limited or nonexistent. Topics such as the allocation of resources to jobs in an intermodal terminal or the determination of truck and trailer fleet size in intermodal drayage operations still need to be tackled (Caris et al., 2008).

Drayage operations constitute a relatively large proportion of total costs of intermodal transport. The development of efficient drayage operations can encourage its attractiveness. However, little research has been conducted on intermodal drayage operations. A tactical planning problem that requires more research attention is the design of the intermodal service network and in particular the determination of optimal freight routes. The main attention until now has been given to intermodal transport by rail. However, intermodal transportation including maritime is quite important too, and its operations should be integrated to the inland intermodal transportation.

Another issue is cooperation between actors in the intermodal transport chain. Still there are a few studies that consider multiple decision maker, although an increased level of coordination is required to improve the performance of intermodal freight transport. Also more integration should be achieved between planning

problems at different decision levels since all decision problems are interdependent and linked economically.

Caris et al. (2013) mentioned that the inclusion of all the actors in the decision support tools is still an issue. Only looking at the problems from one point of view creates suboptimal solutions. A better understanding of all involved actors, and their objectives, will enable to integrate them in the decision support systems. Also authors hoped that these models would be more and more relied on by the policy makers and would not be left in the scientific world.

This is exactly what we have done with this study. A mixed integer linear programming model is developed to determine optimum fleet size of multi resource by considering all intermodal transportation networks. Contributions of this study can be summarized in five main heading:

1. Integration of different decision makers (actors) and different planning problems (freight and fleet) in the intermodal network.
2. Integration of the different decision levels interrelated with fleet size (mode and route selection, fleet allocation, empty vehicle repositioning, etc).
3. Integration of different resource (train, trailer, truck).
4. Integration of three different transportation mode as intermodal transport (road, rail and maritime).
5. In addition to all, taking into account of dynamic aspects of the problems (multi-period planning for long-term).

As mentioned before, fleet sizing is highly related with empty vehicle repositioning and freight flows. A poorly designed repositioning policy and freight flows can result in inefficient fleet utilization and excessive fleet requirements. Therefore, a decision support systems based on mathematical modeling is developed for real-world intermodal planning problems. By solving these problems in an integrated and simultaneous way, effective freight plan and efficient fleet plan are obtained for real size of intermodal transportation network.

6.3 Future Works

First of all, there are two concepts which can be improved in the developed model. The first one is about inventory of vehicles kept between different time periods. In this dissertation, conservation of the vehicle inventories is not taken into consideration. The only purpose of the study is to determine amount of vehicle required independently in each period. However, considering this situation may cause changes in freight plan.

Moreover, once the vehicle inventories are taken into account, a new empty vehicle requirement will occur between periods. The empty resource repositioning strategy is considered in scope of this dissertation as so repositions are only realized on the same line and in the same period. However, empty resource requirement can be emerge between different lines in different periods, which arise from variations in freight transported between different time periods. Reallocation term is more suitable to define the reposition concept at issue.

In this case, two improvements, which should be made in the developed model, can be summarized as follows:

1. The integration of vehicle inventories to the model,
2. Taking into account reallocation of the vehicle between different routes/lines in different time periods.

In addition to contribution of this study, still there are some conceptional issues can be implemented to the developed model. The future prospects related to problems of intermodal transportation network is stated in detail in chapter three. Most of the mentioned headings are handled within scope of this dissertation. Just two issues remain from the mentioned prospects, which should be addressed. These are:

1. Taking into account the uncertainties related to each element of intermodal system (stochastic demand, uncertain transport times, etc.).
2. Constructing a multi-objective models (concerning cost, service quality, environmental etc. purposes)

Especially, the need of developing solution methods by taking into account multiple objectives such as minimization total costs, maximization utilization, service quality and environmental concerns is expressed several times whether in this dissertation or other studies. Furthermore, there is uncertainty about the demands and about the conditions under which they will operate since vehicles are generally long-lived assets. For instance, stochastic transport demands, uncertain travel times, unpredicted costs affect the robustness and quality of the solution. Therefore, modeling uncertainties by using stochastic or/and fuzzy optimization techniques is very substantial to provide adequate, correct information to decision makers.

REFERENCES

Avramovich, D., Cook, T. M., Langston, G. D., & Sutherland, F. (1982). A decision support system for fleet management: A linear programming approach. *Interfaces*, *12*(3), 1-9.

Beaujon, G. J., & Turnquist, M. A. (1991). A model for fleet sizing and vehicle allocation. *Transportation Science*, *25*(1), 19-45.

Bielli, M., Bielli, A., & Rossi, R. (2011). Trends in models and algorithms for fleet management. *Procedia-Social and Behavioral Sciences*, *20*, 4-18.

Bierwirth, C., Kirschstein, T., & Meisel, F. (2012). On transport service selection in intermodal rail/road distribution networks. *BuR-Business Research*,*5*(2), 198-219.

Bin, W. A. N. G., & Zhongchen, W. (2007). Research on the optimization of intermodal empty container reposition of land-carriage. *Journal of Transportation Systems Engineering and Information Technology*, *7*(3), 29-33.

Bontekoning, Y. M., Macharis, C., & Trip, J. J. (2004). Is a new applied transportation research field emerging?—A review of intermodal rail–truck freight transport literature. *Transportation Research Part A: Policy and Practice*, *38*(1), 1-34.

Çancı, M., & Erdal, M. (2003). *Lojistik yönetimi* (2nd Ed.). İstanbul: UTIKAD (Uluslararası Taşımacılık ve Hizmet Üretenler Derneği).

Carbajal, J. A., Erera, A., & Savelsbergh, M. (2013). Balancing fleet size and repositioning costs in LTL trucking. *Annals of Operations Research*, *203*(1), 235-254.

Caris, A., Macharis, C., & Janssens, G. K. (2008). Planning problems in intermodal freight transport: Accomplishments and prospects. *Transportation Planning and Technology*, *31*(3), 277-302.

Caris, A., Macharis, C., & Janssens, G. K. (2013). Decision support in intermodal transport: A new research agenda. *Computers in Industry*, *64*(2), 105-112.

Çetin, S., Özkütük, E., & Gencer, C. (2011). Heterojen araç filolu eş zamanlı dağıtım ve toplamalı araç rotalama problemi için bir karar destek sistemi. *International Journal of Research and Development*, *3*(1), 11-18.

Chakroborty, P., Deb, K., & Sharma, R. K. (2001). Optimal fleet size distribution and scheduling of transit systems using genetic algorithms. *Transportation Planning and Technology*, *24*(3), 209-225.

Cheon, M. S., Furman, K. C., & Shaffer, T. D. (2012). A modeling framework for railcar fleet sizing in the chemical industry. *Industrial & Engineering Chemistry Research*, *51*(29), 9825-834.

Choong, S. T., Cole, M. H., & Kutanoglu, E. (2002). Empty container management for intermodal transportation networks. *Transportation Research Part E: Logistics and Transportation Review*, *38*(6), 423-438.

Couillard, J., & Martel, A. (1990). Vehicle fleet planning the road transportation industry. *Engineering Management, IEEE Transactions on*, *37*(1), 31-36.

Crainic, T. G. (2003). Long-haul freight transportation. In *Handbook of transportation science* (2nd Ed.) (451-516). US: Springer.

Crainic, T. G., & Kim, K. H. (Eds). (2007). Intermodal transportation. In *Handbook in Operations Research and Management Science.* (vol. 14) (467-537). North-Holland: Elsevier.

Crainic, T. G., & Laporte, G. (1997). Planning models for freight transportation. *European Journal Of Operational Research, 97*(3), 409-438.

DeBoer, D.J. (1992). *Piggyback and Containers*: A history of rail intermodal on America's steel highway, San Marino, CA: Goden West Books.

Dejax, P. J., & Crainic, T. G. (1987). Survey paper-a review of empty flows and fleet management models in freight transportation. *Transportation Science, 21*(4), 227-248.

Dong, J. X., & Song, D. P. (2009). Container fleet sizing and empty repositioning in liner shipping systems. *Transportation Research Part E: Logistics and Transportation Review, 45*(6), 860-877.

Dong, J. X., & Song, D. P. (2012). Quantifying the impact of inland transport times on container fleet sizing in liner shipping services with uncertainties. *OR Spectrum, 34*(1), 155-180.

Du, Y., & Hall, R. (1997). Fleet sizing and empty equipment redistribution for center-terminal transportation networks. *Management Science, 43*(2), 145-157.

Ekol, (2015). *ULA ~ style citations of electronic resources.* Retrieved September 10, 2015, from http://www.ekol.com/en/freight/intermodal.

Etezadi, T., & Beasley, J. E. (1983). Vehicle fleet composition. *Journal of the Operational Research Society, 34*(1), 87-1.

Fazi, S., Van Woensel, T., & Fransoo, J. C. (2013). *Mode allocation and scheduling of inland container transportation: a case-study in the Netherlands*. Beta Working Paper Series 433.

Gheysens, F., Golden, B., & Assad, A. (1984). A comparison of techniques for solving the fleet size and mix vehicle routing problem. *Operations-Research-Spektrum, 6*(4), 207-216.

Gould, J. (1969). The size and composition of a road transport fleet. *Operational Research, 20*(1), 81-92.

Guelat, J., Florian, M., & Crainic, T. G. (1990). A multimode multiproduct network assignment model for strategic planning of freight flows. *Transportation Science, 24*(1), 25-39.

Hayuth Y. (1987). *Intermodality*: Concept and practice: Structural changes in the ocean freight transport industry. London: Lloyds of London Press.

Imai, A., & Rivera, F. (2001). Strategic fleet size planning for maritime refrigerated containers. *Maritime Policy & Management, 28*(4), 361-374.

Jansen, B., Swinkels, P. C., Teeuwen, G. J., de Fluiter, B. V. A., & Fleuren, H. A. (2004). Operational planning of a large-scale multi-modal transportation system. *European Journal of Operational Research, 156*(1), 41-53.

Kirby, D. (1959). Is your fleet the right size&quest. *Journal of the Operational Research Society, 10*(4), 252-252.

Klincewicz, J. G., Luss, H., & Pilcher, M. G. (1990). Fleet size planning when outside carrier services are available. *Transportation Science, 24*(3), 169-182.

Koç, Ç., Bektaş, T., Jabali, O., & Laporte, G. (2014). The fleet size and mix pollution-routing problem. *Transportation Research Part B: Methodological, 70*, 239-254.

Köchel, P. (1997). An approximate model for fleet sizing and redistribution. *Science in Traffic 9* (5-6), 195-200.

Köchel, P., Kunze, S., & Nieländer, U. (2003). Optimal control of a distributed service system with moving resources: Application to the fleet sizing and allocation problem. *International Journal of Production Economics, 81*, 443-459.

Köfteci, S. (2008). *Bir karayolu ulaştırma koridorunda yük taşımacılığı tür seçiminin lojistik maliyete göre modellenmesi.* Ph.D Thesis, Yıldız Technical University, İstanbul, Turkey.

Koo, P. H., Lee, W. S., & Jang, D. W. (2005). Fleet sizing and vehicle routing for container transportation in a static environment. In *Container Terminals and Automated Transport Systems* (123-139). Berlin, Heidelberg: Springer.

Lagoudis, I.N., Litinas, N.A., & Fragkos, S. (2006). Modelling container fleet size: the case of a medium size container shipping company. In *Proceedings of the International Conference in Honour of Prof. Basil Metaxas, Argostoli*, Cephalonia (14-16).

Lin, C. C., & Ma, S. J. (1999). The fleet planning for multi-modal express services in Taiwan. *Journal of the Eastern Asia Smiety lbr Tlansportation Studies, 3*(3), 271-285.

List, G. F., Wood, B., Nozick, L. K., Turnquist, M. A., Jones, D. A., Kjeldgaard, E. A., et al. (2003). Robust optimization for fleet planning under uncertainty. *Transportation Research Part E: Logistics and Transportation Review*, *39*(3), 209-227.

Lowe, D. (2006). *Intermodal freight transport.* Great Britain: Elsevier.

Macharis, C., & Bontekoning, Y. M. (2004). Opportunities for OR in intermodal freight transport research: A review. *European Journal of Operational Research,153*(2), 400-416.

Mahoney, J. H. (1985). *Intermodal freight transportation*. Westport: Eno Foundation for Transportation.

McKenzie, D.R., North M.C., & Smith D.S. (1989). *Intermodal transportation:* The Whole Story. Omaha, NE: Simmons-Boardman Books, Inc.

Meisel, F., Kirschstein, T., & Bierwirth, C. (2013). Integrated production and intermodal transportation planning in large scale production–distribution-networks. *Transportation Research Part E: Logistics and Transportation Review*, *60*, 62-78.

Mole, R. H. (1975). Dynamic optimization of vehicle fleet size. *Operational Research Quarterly, 26*(1), 25-34.

Muller, G. (1989). *Intermodal freight transportation*. Virginia: Eno Transportation Foundation and IANA.

New, C. C. (1975). Transport fleet planning for multi-period operations. *Operational Research Quarterly, 26*(1), 151-166.

Nossack, J., & Pesch, E. (2013). A truck scheduling problem arising in intermodal container transportation. *European Journal of Operational Research,230*(3), 666-680.

Okşaş, O. (2014). *Intermodal taşımacılıkta maliyet analizi ile optimum değer taşıma uzaklıklarının belirlenmesi.* M.Sc Thesis, İstanbul University, İstanbul, Turkey.

Orhan, O. Z. (2003). *Dünyada ve Türkiye'de lojistik sektörünün gelişimi*. İstanbul: İstanbul Ticaret Odası.

Papier, F., & Thonemann, U. W. (2008). Queuing models for sizing and structuring rental fleets. *Transportation Science, 42*(3), 302-317.

Parikh, S. C. (1977). On a fleet sizing problem and allocation problem. *Management Science, 23*(9), 972-77.

Powell, W. B., & Sheffi, Y. (1989). OR Practice-design and implementation of an interactive optimization system for network design in the motor carrier industry. *Operations Research, 37*(1), 12-29.

Qiuping, Y., Xinlian, X., & Weiwei, H. (2009). Modeling fleet planning strategy based on multimode investment. In *Computational Intelligence and Design, Second International Symposium on IEEE*, 1, 493-496.

Redmer, A., Sawicki, P., & Zak, J. (2000). Multiobjective optimisation of the fleet size in the road freight transportation company. In *Proceedings of Rome Jubilee 2000 Conference: Meeting of the Euro Working Group Transportation-EWGT*.

Redmer, A., Żak, J., Sawicki, P., & Maciejewski, M. (2012). Heuristic approach to fleet composition problem. *Procedia-Social and Behavioral Sciences, 54,* 414-427.

Rodrigue, J. P., Slack B., & Comtois C. (2013). The geography of transport systems. *ULA ~ style citations of electronic resources.* Retrieved July 10, 2015, from https://people.hofstra.edu/geotrans/eng/ch3en/conc3en/ch3c1en.html

Roy, D., Sebastian, J., & Sharma, D. (2013). Fleet sizing for transporters with seasonal demands. *International Journal of Automation and Logistics, 1*(1), 105-115.

Saatçioğlu, C. (2011). *Ulaştırma ekonomisi teori ve politika*. Ankara: Gazi Kitabevi.

Sayarshad, H. R., & Ghoseiri, K. (2009). A simulated annealing approach for the multi-periodic rail-car fleet sizing problem. *Computers & Operations Research, 36*(6), 1789-1799.

Sayarshad, H. R., & Tavakkoli-Moghaddam, R. (2010). Solving a multi periodic stochastic model of the rail–car fleet sizing by two-stage optimization formulation. *Applied Mathematical Modelling, 34*(5), 1164-1174.

SteadieSeifi, M., Dellaert, N. P., Nuijten, W., Van Woensel, T., & Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. *European Journal of Operational Research, 233*(1), 1-15.

Stojanović, Đ., Nikoličić, S., & Miličić, M. (2011). Transport fleet sizing by using make and buy decision-making. *Economic annals, 56*(190), 77-102.

Tuna, O. (2001). Türkiye için lojistik ve denizcilik stratejileri uluslararası ve bölgesel belirleyiciler. *Dokuz Eylül University, Journal of Institute of Social Science, 3*(2), 194-208.

Turnquist, M. A., & Jordan, W. C. (1986). Fleet sizing under production cycles and uncertain travel times. *Transportation Science, 20*(4), 227-236.

UNECE, (2009). *Illustrated glossary for transport statistics* (4th Ed.). Luxembourg: Publications Office of the European Union.

US Department of Transportation, (2008). The effect of rising fuel costs on goods movement mode choice and infrastructure needs. *ULA ~ style citations of electronic resources.* Retrived September 16, 2015, from http://tampabayfreight.com/wp-content/uploads/The-Effectof-Rising-Fuel-Costs-on-Goods-Movement-Mode-Choice-and-Infrastructure-Needs.pdf

Vis, I. F., de Koster, R. M. B., & Savelsbergh, M. W. (2005). Minimum vehicle fleet size under time-window constraints at a container terminal. *Transportation science*, *39*(2), 249-260.

White Paper (2010). *European transport policy for 2010: Time to decide.* Commission of the European Communities.

Williams, W.W., & Fowler, O. S. (1980). Minimum cost fleet sizing for a university motor pool. *Interfaces 10*(3), 21-29.

Wu, P., Hartman, J. C., & Wilson, G. R. (2005). An integrated model and solution approach for fleet sizing with heterogeneous assets. *Transportation Science*, *39*(1), 87-103.

Wyatt, J. K. (1961). Optimal fleet size. *Journal of the Operational Research Society*, *12*(3), 186-187.

Zhao, Q. H., Wang, S. Y., Lai, K. K., & Xia, G. P. (2001). Dynamic multi-period transportation model for vehicle composition with transshipment points. *Advanced Modeling and Optimization*, *3*(1), 17-28.