Designing Liner Shipping Feeder Service Networks in the New Era of Mega Containerships

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List of Abbreviations

ACS	Ant Colony System
ALT	Alternating Heuristic
ANN	Artificial Neural Network
ANS	Adaptive Neighborhood Search
APM	Adaptive Perturbation Mechanism
CIH	Cluster Insertion Heuristic
cst	centiStoke, a unit of kinematic viscosity
dwt	Deadweight tonnage, ship carrying capacity measured in metric tones
EVNS	Enhanced Variable Neighborhood Search
FCRP	Feeder Containership Routing Problem
FND	Feeder service Network Design
H&S	Hub-and-Spoke
IBH	Insertion Based Heuristic
ILS	Iterated Local Search
ISO	International Organization for Standardization
LNS	Large Neighborhood Search
LSND	Liner Shipping service Networks Design

m	Meter is the fundamental unit of length in the International System of Units
m^3	Cubic meter is derived unit of volume in the International System of Units
MILP	Mixed-Integer Linear Programming
MLVRPSPD	Vehicle Routing Problem with Simultaneous Pickup and Delivery with Maximum Distance Length
MPC	Multi-Port-Calling
MVRPB	Mixed Vehicle Routing Problem with Backhauls
NP	Non-deterministic Polynomial-time
NSP	Nearest Sweep with Perturbation
PDP	Pickup and Delivery Problems
PSO	Particle Swarm Optimization
RTS	Reactive Tabu Search
SA	Savings Algorithm
SBAA	Saving Based Ant Algorithm
TEU	Twenty-foot Equivalent Unit
TS	Tabu Search
ULCV	Ultra Large Container Vessel
UNCTAD	The United Nations Conference on Trade and Development
USA	United States of America
US$	The United States dollar

VND	Variable Neighborhood Descend
VNS	Variable Neighborhood Search
VRP	Vehicle Routing Problem
VRPB	Vehicle Routing Problem with Backhauls
VRPMTTL	Vehicle Routing Problem with Multi Trip and Time Limit
VRPPD	Vehicle Routing Problem with Pickup and Delivery
VRPPDTW	Vehicle Routing Problem with Pick-up and Delivery with Time Windows
VRPSPD	Vehicle Routing Problem with Simultaneous Pickup and Delivery
VRPSPDTL	Vehicle Routing Problem with Simultaneous Pickup and Delivery with Time Limit
VRPSPDTW	Vehicle Routing Problem with Simultaneous Pickup and Delivery with Time Windows

Abstract

In the new era of mega containerships, global containership liners design their transportation service as Hub-and-Spoke networks to improve the access to local transportation markets and to reduce operational costs by using short-sea connections for low-volume transportation lanes. These connections from the hub ports to the regional ports constitute the feeder network which is serviced by small or medium-sized feeder containerships. This study analyzes general characteristics of feeder services in liner shipping and provides operation research based solutions to major challenges that feeder service providers face in planning their service networks. For this purpose, an adaptive neighborhood search approach, which is proved to be effective in vehicle routing problem variants, is developed in order to determine the feeder ship fleet size and mix, fleet deployments, service routes and voyage schedules to minimize operational costs for static and dynamic sailing seasons. A Monte Carlo simulation and an artificial neural networks based forecasting framework is also developed to estimate unstable throughput demands of regional ports. In our case study investigation, we assume the feeder network design problem of a Turkish short-sea shipping company in view of the opening of the new Candarli port near Izmir. The cost performance of alternate feeder network configurations serving the Black Sea region is compared under both stable and unstable demand environments. Numerical results show that the new Candarli port has great potential as hub port in the Black Sea region and feeder service network designs should consider unstable demand environment of the regional ports.

Zusammenfassung

Spätestens seit der Einführung von Mega-Containerschiffen planen Reedereien ihre Netzwerke für die Container-Linienschifffahrt nach dem 'Hub-and-Spoke'-Prinzip, um ihre Verbindungen zu regionalen Märkten zu stärken und die operativen Kosten für Kurzstrecken mit niedrigem Frachtvolumen zu reduzieren. Das sogenannte Feeder-Netzwerk besteht aus solchen Kurzstrecken zwischen Hubs und Regionalhäfen, welche üblicherweise von kleinen oder mittelgroßen Containerschiffen bedient werden. Diese Studie analysiert die allgemeinen Eigenschaften des Feederverkehrs in der Container-Linienschifffahrt und schlägt OR-basierte Lösungsansätze für Netzwerkplanungsprobleme von Feederverkehr-Dienstleistern vor. Es wurde eine, aus der Tourenplanung bewährte, adaptive Nachbarschaftssuche entwickelt, welche Größe, Zusammensetzung und Einsätze der Feederflotte sowie die Routen und Reisefahrpläne bestimmt, um die operativen Kosten zu minimieren. Außerdem wurden eine Monte-Carlo-Simulation und ein Neuronales Netz für die Prognose und Auswertung von Bedarfen in regionalen Häfen entwickelt. In einer Fallstudie wurde das Netzwerkplanungsproblem einer Türkischen Kurzstrecken-Schifffahrtsgesellschaft betrachtet im Hinblick auf die Eröffnung des Hafens in Candarli. Die Performance neuer Feederverkehr-Konfigurationen für die Schwarzmeer-Region wurde sowohl für statischen Bedarf als auch dynamische Bedarfsentwicklungen evaluiert. Numerische Ergebnisse belegen, dass der neue Hafen in Candarli ein großes Potential als möglicher Hub in der Schwarzmeer-Region besitzt. Zusätzlich wird die Notwendigkeit bestätigt, dynamische Bedarfsentwicklungen bei Planung des Feederverkehrs zu berücksichtigen.

Özet

Mega konteyner gemilerinin yeni döneminde, küresel konteyner gemi hatları yerel taşıma marketlerine ulaşımlarını arttırmak ve operasyon maliyetlerini azaltmak için taşıma hizmetlerini düşük hacimli hatlarda kısa mesafe deniz taşımacılığını kullanarak Göbek-ve-İspit ağları şeklinde tasarlamaktadırlar. Göbek limanlar ve bölgesel limanlar arasındaki bu bağlantılar, küçük veya orta ölçekli konteyner gemileri tarafından hizmet verilen besleyici ağları oluşturmaktadır. Bu çalışma, besleyici servislerin genel karakteristiklerini analiz etmekte ve besleyici servis sağlayıcılarının servis ağlarını planlamakta karşılaştıkları temel zorluklara yöneylem araştırması temelli çözümler sunmaktadır. Bu amaçla, besleyici gemi filosu boyutunun ve karışımının, filo yayılımının, servis rotalarının ve sefer çizelgelerinin sabit ve değişken planlama sezonlarında belirlenmesi için araç rotalama problem varyantlarında etkinliği ispatlanan bir uyarlanabilir komşuluk araması yaklaşımı geliştirilmiştir. Ayrıca bölgesel limanların düzensiz talep çıktılarının kestirmek için Monte Carlo benzetimi ve yapay sinir ağları temelli bir tahminleme yapısı geliştirilmiştir. Vaka çalışması araştırmamızda, İzmir yakınlarında yeni açılan Çandarlı limanı kullanılarak bir Türk kısa mesafeli deniz taşımacılığı firmasının besleyici ağ tasarım problemi üstlenilmiştir. Düzensiz ve düzenli talep ortamları altında Karadeniz bölgesine servis vermek için farklı besleyici ağ yapılarının maliyet performansları karşılaştırılmıştır. Sayısal sonuçlar göstermiştir ki yeni Çandarlı limanı bölgenin göbek limanı olmak için büyük bir potansiyele sahiptir ve besleyici servis ağ tasarımları bölgesel limanların dengesiz talep koşularını dikkate almalıdır.

1. Introduction

Since the nineteenth century, the importance of global transportation has enlarged with the strong increase in world trade. Thanks to the industrial revolution and raw material resources, the world experienced a big increase in the international trade of goods in the twentieth century, as freight transported from industrialized Europe to the rest of world. However, the pattern has started to change from West to East after the World Wars. Thanks to relatively high and cheap labor resources, Eastern emerging countries have started to produce labor-intensive industrialized goods and transport them from East to West. After the Cold War, Eastern emerging countries have also further developed their economies with increased technological production capacities.

The changes in the world trade pattern have formed new global transportation networks. Freight is transported via a combination of transportation modes which could include road, rail, air, and seaways, without any handling of the freight itself when changing modes. The need to efficiently transfer the freight between these modes has created door-to-door intermodal transport operations (commonly by using containers). A sea-based intermodal container transport operation typically begins by picking up a container from the sender and transferring it to a regional feeder port via truck or combination of truck and train. The containers, collected from hinterland, are transferred from feeder port to regional hub port via small-sized feeder ships on short seas. The containers collected from regional ports are transported to hub port of destination feeder port via large sized trunk ships on deep seas. The feeder ship transfers the containers from a hub port to the related feeder port and then transport trucks, or a combination of trucks and trains deliver the container to the receivers. A typical sea-based intermodal container transportation chain is shown in Figure 1.1.

Apart from geographical limits to using single mode transportation, there are also time and cost advantages to use multi-modal transportation over long distances. Trucks are flexible and relatively fast and could easily reach most of the locations; however, they have limited carrying capacity and are a bit costly. Trains could carry more goods than trucks and are relatively cheap in cost; however, they are limited between continents. On the other hand, ships can carry a large amount of goods at very low-cost within seas and between continents but as slower speeds (see Christiansen et al. (2004) for detailed comparison). Air modes are not considered in the content of this thesis.

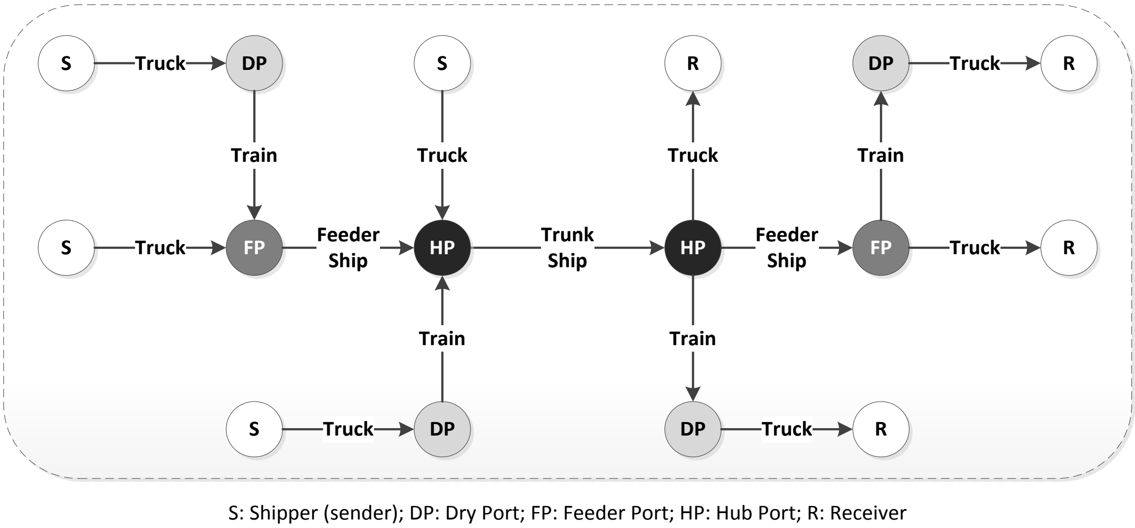


Figure 1.1 A typical sea based intermodal container transportation chain

Seaborne shipping is the most important transportation mode in international trade. More than 80% of the international trade in 2010 was transported overseas (UNCTAD 2012). In the shipping market, three forms of operations are distinguished: tramp shipping, industrial shipping and liner shipping (Lawrence 1972). Tramp ships do not have a fixed schedule and are used for immediate deliveries where the most profitable freight is available. Therefore, the activities in tramp shipping are very irregular. In industrial shipping, the cargo owner controls the ship and the objective becomes to minimize the cost of shipping. Liner shipping, consists of ships visiting a larger number of ports within a fixed route and time schedule; this is the most common transportation means where intermodal containers on sea are concerned (Christiansen et al. 2004).

In terms of volume, the majority of the seaborne transportation is carried via tramp and industrial shipping forms; however, more important than tonnage is total trade value. More than 70% of the total trade in terms of value is carried by the liner shipping form (UNCTAD 2012). International merchandise trade is one of the most important factors affecting the container shipping demand. Tandem to international merchandise trade, total world container shipping trade increased from 28.7 million TEU (Twenty-foot Equivalent Unit) in 1990 to 151 million TEU in 2011, and worldwide container port throughput has increased from 88 million TEU in 1990 to 572 million TEU in 2011 (UNCTAD 2012).

Despite the rise in the amount of containerized trade, the cost of shipping containers (freight rates) has fallen dramatically since its initiation. Low freight rates, increasing oil costs and the recent financial crises of the 2000's have tremendously affected the liner shipping industry. As a result, many of shipping lines operate their service with margin loses ranging from -3% to -25% in 2011 (Alphaliner 2011). The decreasing margins resulted in increased focus of the industry to redesigning service networks so they operate more efficiently.

Parallel to the increase in containerized trade, the complexity of liner shipping services has increased. A liner shipping carrier usually has a global service network, consisting of several main (i.e. trunk) line loops between multiple continents on fixed schedules. Liner shipping carriers have mainly two different design alternatives for their service networks: multi-port-calling (MPC) network and Hub-and-Spoke (H&S) network. In H&S networks, main ports are served usually by using mega containerships in deep seas and feeder ports are served by using feeder containerships in short seas.

The evolution of H&S networks, particularly in minor trade routes like the Black Sea, Africa and Latin America, is a recent popular challenge to deal with in liner shipping. The expansion of demand for containerized goods has developed a growing number of ports in both national and regional markets. The growths in the containerized trade, the global containership fleet, size of mega containerships, and number of container ports are all results of expanding global markets.

The development of H&S networks has also given rise to the need for efficient feeder services. The feeder service network is comprised of ships which visit a number of ports along predefined lines of feeder ports and feed trunk containerships as to avoid their calling at too many ports in the region. The liner shipping feeder service network design (FND) problem aims to find an optimal service network for a feeder liner shipping service provider. In a sailing season, an optimal service network includes joint solution of tactical planning decisions, such as fleet size and mix, fleet deployment, ship routing and scheduling. The container feeder network design depends on the characteristics of feeder ships, the feeder ship ports, the operating and chartering costs of the ships and bunker costs, as well as container demand throughputs of the ports.

Parallel to world trade, container throughputs have been directly affected by unexpected local and global crises (i.e. financial, political, etc.) as well as seasonal conditions. Therefore, forecasting container throughputs of ports is playing a critical role in all the levels of planning decisions of liner shipping lines. Since liner shipping involves considerable capital investment and huge daily operating costs, the appropriate throughput demand estimation of a whole sailing season will state the development of service network design. In order to cope with the dynamic nature of shipping markets, it is important to design more agile and flexible feeder service networks.

The objective of this thesis is to provide operation research based solutions to major challenges that feeder service providers face in planning their service networks. The remainder of this thesis is structured as follows:

The background of containerization and details of liner shipping are presented in Chapter 2. Chapter 3 provides information about the characteristics of liner shipping feeder service. The compressive literature review is given in Chapter 4.

The FND problem is mathematically modeled in four levels in Chapter 5. While the first level handles the problem in aspects of vehicle routing problem, the second level handles the problem as feeder containership routing problem. The third level deals with the basic FND problem of a stable sailing horizon by reducing the total transportation cost and the last level approaches the problem more realistically by considering varying forecasted throughput demands for a dynamic sailing season and vessel charter operations.

The first part of Chapter 6 proposes a novel solution approach (adaptive neighborhood search) combined with the classic savings heuristic as initial solution construction algorithm, variable neighborhood search in order to improve the initial solution, and a perturbation mechanism to escape from local optima. The second part of the chapter provides a Monte Carlo simulation and an artificial neural networks based forecasting frame in order to analyze the impact of seasonal demand fluctuation on the liner shipping feeder service.

The experimental design is presented in Chapter 7, concluding with a number of well-known benchmark problems and a real feeder service case study from the Black Sea region. The numerical results of benchmark studies show that the proposed method produces superior solutions compared to those reported in the literature and effective feeder service networks for both static and dynamic sailing seasons. Finally, conclusions are drawn and suggestions for further research are given in Chapter 8.

2. Container shipping

2.1 Containerization

2.1.1 History

For many thousands of years, shipping has been used to transport freight from one land to another. Before the development of intermodal containers, break-bulk shipping was used to transport freight from one land to another in crate, barrel and pallet forms. However, in break-bulk shipping, the loading/unloading of freight to/from ships was extremely slow and labor intensive. Since the ships were spending too much time at ports and carrying less freight volume, shipping of freight was extremely expensive (Levinson 2008).

The industry has developed various types and sizes of boxes for the efficient movement of goods between transportation modes. These developments were too labor intensive to be practical until the end of World War II. A war tanker, the Ideal X, was converted with a reinforced deck to carry fifty-eight metal containers as well as 15,000 tons of bulk petroleum by truck entrepreneur Malcolm McLean. The first voyage of it was from Port Elizabeth, New Jersey to the Port of Houston on April 26, 1956. Please see Levinson (2008) for evaluation of container shipping.

McLean’s intermodalism based idea aimed to move the freight with the same container between transportation modes with minimum interruption. Intermodal containers could be efficiently and safely transported between trucks, trains and ships. During the years, all areas of the transport chain had to been integrated and adapted to handle the containers in order to realize efficient intermodal container transport. This idea led to a revolution in freight transportation and international trade over the next 50 years.

2.1.2 Containers

Mclean’s initial design for the container was at 8 feet tall, 8 feet wide and 10 feet long units. Until the early 1960’s, there was no standardization for container constructions and size; each shipping line was using its own standards. In 1961, International Organization for Standardization (ISO) set standards to help effectively transport containers between shipping lines all over the world (Levinson 2008). Weights and dimensions of some common types of containers are shown in Table 2.1 (Wikipedia 2013b).

Table 2.1: ISO standards for common container types

	20′ container	40′ container	40′ high-cube	45′ high-cube
External length (m)	6.058	12.192	12.192	13.716
External width (m)	2.438	2.438	2.438	2.438
External height (m)	2.591	2.59	2.896	2.896
Interior length (m)	5.710	12.032	12.000	13.556
Interior width (m)	2.352	2.352	2.311	2.352
Interior height (m)	2.385	2.385	2.650	2.698
Door width (m)	2.343	2.343	2.280	2.343
Door height (m)	2.280	2.280	2.560	2.585
Box volume (m^3)	33.1	67.5	75.3	86.1
Max gross weight (kg)	30,400	30,400	30,848	30,400
Empty box weight (kg)	2,200	3,800	3,900	4,800
Net load weight (kg)	28,200	26,600	26,580	25,600

Source: Wikipedia (2013b)

Standard containers are also identified as general dry purpose containers. In addition to standard containers, there are also a range of special container types such as open top, open side, flat rack, refrigerated, tank, etc. Open top containers are generally used for easy loading of odd sized goods such as logs and machinery. Open side containers are generally used for air needed goods such as onions and potatoes. Flat racks are open side and top containers used for transportation of extraordinary sized goods such as boats and industrial equipment. Refrigerated containers (reefers) can control temperatures and allow transportation of perishable goods such as meat, fruit, vegetables, dairy products, chemicals and drugs. Tank containers are used for transportation of liquid bulks such as chemicals, wine and vegetable oil.

There are more than 20 million container units which equal more than 31.25 million TEU in the container fleet including all these types (UNCTAD 2012). Please see Levinson (2008) and Wikipedia (2013b) for details of container standardization.

2.1.3 Vessels

Marine vessels designed to carry intermodal containers on their hulls and decks are called containerships. From their beginnings in 1956, the designs of containerships have been continuously changed in order to improve efficiency. The maximum ship size has been enlarged 9.66 times from 1,500 TEU in 1976 to 16,000 TEU in 2012; fuel efficiency of 4,500 TEU sized ship has improved 35% between 1985 and 2008; carbon efficiency on a per-mile freight volume basis has improved 75% between a 1,500 TEU containership build in 1976 and a modern 12,000 TEU ship built in 2007 (WorldShipping 2013b). Please see Section 2.2.3 for evaluation of freight rates.

The share of containerships in the world seaborne trade is about 12.9%, but about 70% of the total trade in terms of value is carried with containerships (UNCTAD 2012). Figure 2.1 shows world fleet by principal vessel types during the years 1980 and 2011 in millions of dwt (UNCTAD 2012).

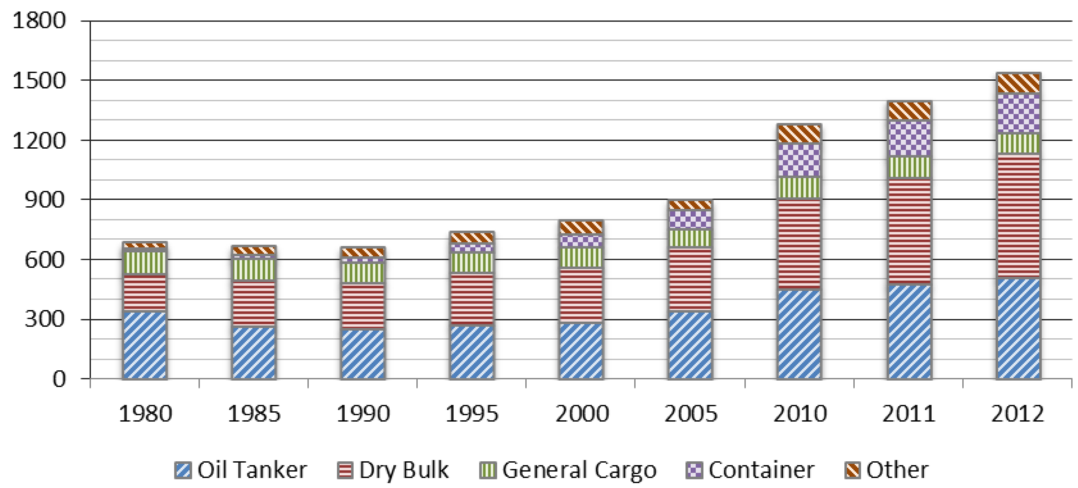


Figure 2.1: World vessel fleet by principal vessel types (millions of dwt)

According to Alphaliner (2010, 2013a), the number of containership fleets have been increased almost 3 times and the fleet capacity has been increased about 8.5 times since 1990. Thus, average ship size has increased 1.39 times from 1390 TEU in 1990 to 3307 TEU in 2012. Figure 2.2 shows the evolution of containership fleets during 1990-2012 (Alphaliner 2010, 2013a). Containerships have been growing increasingly larger over time. In 2012, there were about 5,000 containerships in operation with more than 16 million TEU total capacities in the industry. The sizes of newly delivered containerships continued to grow in 2012 and 73.12% of the new ordered containerships are sized more than 7,500 TEU. The numbers, capacities and percentages of existing and ordered containerships according to size ranges are shown in Table 2.2 (Alphaliner 2013a). The average age of the containership world fleet is 10.90 years and the average age per vessel was almost twice as high at 21.9 years. 23.8 % of world vessel fleet is between 0-4 years, 27.9% are 5-9 years, 18.3 % are 10-14 years, %17.4 are 15-19 years and the rest %12.6 are more than years old (UNCTAD 2012).

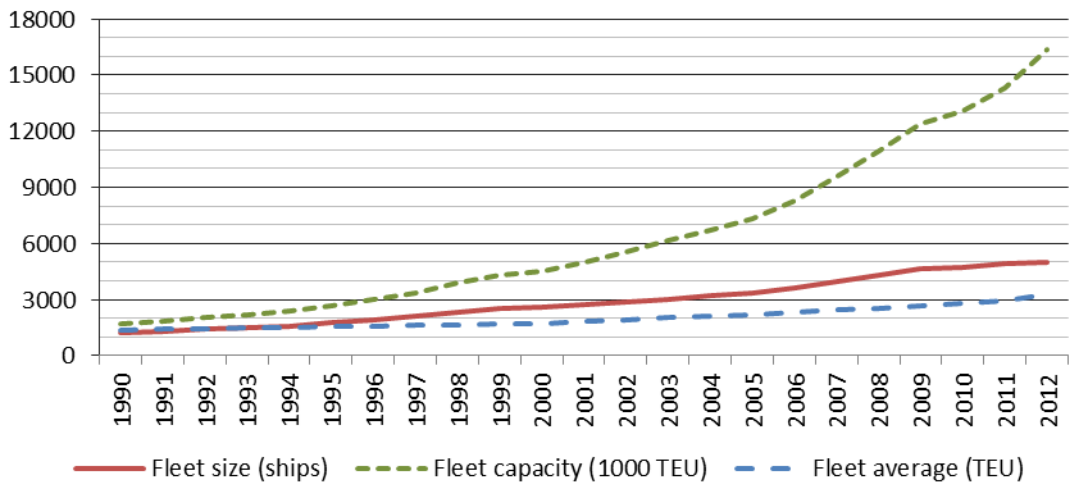


Figure 2.2: Evaluation of containership fleet (1990-2012)

Table 2.2: Global existing and ordered containership fleet

Size ranges	Existing fleet				Ordered fleet			
TEU	Ships	% Ships	1000 TEU	%TEU	Ships	% Ships	1000 TEU	%TEU
10000-18000	163	3.29%	2080	12.69%	120	24.74%	1656	47.82%
7500-9999	332	6.70%	2880	17.57%	98	20.21%	876	25.30%
5100-7499	476	9.60%	2922	17.83%	26	5.36%	172	4.97%
4000-5099	741	14.95%	3348	20.43%	78	16.08%	367	10.60%
3000-3999	291	5.87%	996	6.08%	54	11.13%	199	5.75%
2000-2999	674	13.60%	1716	10.47%	33	6.80%	84	2.43%
1500-1999	572	11.54%	972	5.93%	43	8.87%	76	2.19%
1000-1499	699	14.10%	819	5.00%	25	5.15%	27	0.78%
500-999	782	15.78%	581	3.55%	8	1.65%	6	0.17%
100-499	226	4.56%	73	0.45%	0	0.00%	0	0.00%
Total	4956	100.00%	16387	100.00%	485	100.00%	3463	100.00%

Source: Alphaliner (2013)

Containerships could be categorized according to their generations, type of vessels, given dominations or largest possible size that can pass major transit canals. Table 2.3 shows a common categorization of containerships according to their capacities. Please see Chan and Lee (2000) and Wikipedia (2013a) for more detailed categorization.

Table 2.3: Containership size categories

Name	Capacity(TEU)	Length (m)	Beam (m)	Draft (m)
Ultra Large Container Vessel (ULCV)	14,501>	366.00≥	48.80≥	15.2≥
New panamax	10,001-14,500	365.80	48.80	15.2
Post panamax	5,101-10,000	365.80	39.8-45.6	15.2
Panamax	2,801-5,100	294.13	32.31	12.04
Feeder	1,001-2,800	200-250	23.0-30.2	11.00
Small (Barge)	≤1000	≤190.00	≤23.00	≤9.50

Source: Chan and Lee (2000) and Wikipedia (2013a)

Feeder containerships transport containers between transshipment ports and other regional ports. These types of ships are often customized with gear, at least when put in service, in order to efficiently service small ports without quay cranes. The size of feeder containership term depends on the application. While barge containers are used in canal/river based systems, relatively big sized containerships are started to use in elongated embayment ports with the evaluation of mega containerships. Please see Chapter 3 for details of feeder service.

2.1.4 Ports

Ports represent the places where containerships could berth and exchange their container freights between sea and land sides. Inside of the ports, the operations such as loading/unloading containers to/from ship, storage, transportation, and gate movements are managed by container terminals. Berthing time of a containership in a port depends on the number of assigned cranes to load/unload containers to/from ship and efficiency of container terminal operations (Notteboom 2004). A port could be operated by several terminal operators. In intermodal container transportation chain, container terminals of ports are the gateways between land and sea-based transport networks. Please see Kim and Günther (2010) for more details on container terminal operations.

The evolution of container shipping has led to the categorization of container ports into three categories: hub ports, feeder ports and trunk (main) ports (Zeng and Yang 2002). The hub ports are where container transshipments may take place between trunk (main) and feeder containerships. Feeder ports are regional hinterland gateways linked to over-sea ports with feeder containerships via hub ports. Trunk (main) ports are regional ports called by trunk ships due to their relatively high demand volumes.

Table 2.4 shows the top twenty world container ports according to their total TEU throughputs in 2011 (ISL 2012). Total throughputs of these twenty ports increased 157.7% between 2001 and 2011 and 47.5% of containerized seaborne trade of the world is handled by these ports in 2011. Parallel to change in global trade pattern in last decades, ports of emerging East Asia countries are dominating global containerized seaborne trade. 77.20% of the total throughputs of the top twenty ports are handled by thirteen East Asia ports. As the largest containerized trade exporter of the world, Chinese ports represent nine of these ports. During the last ten years, Chinese ports are continued to increase their container throughputs on average 17.83%, despite the 6.8% increase average of other top twenty ports. The other ports are mainly on the list because of their regional hub positions.

Table 2.4: The top 20 world container ports in 2011

Ranking 2011	Ranking 2001	Port	Country	Millions TEUs 2001	Millions TEUs 2010	Millions TEUs 2011	TEU % growth 2010-11	TEU % growth 2001-11
1	(5)	Shanghai	China	6.3	29.0	31.7	9.4	17.5
2	(2)	Singapore	Singapore	15.6	26.0	29.9	15.1	6.8
3	(1)	Hong Kong	China	17.8	23.7	24.4	2.9	3.2
4	(8)	Shenzhen	China	5.1	22.3	22.6	1.0	16.1
5	(3)	Busan	S. Korea	8.0	14.2	16.2	14.0	7.3
6	(50)	Ningbo	China	1.2	13.1	14.7	12.6	28.4
7	(31)	Guangzhou	China	1.7	12.5	14.3	14.2	23.4
8	(17)	Qingdao	China	2.6	12.0	13.0	8.4	17.3
9	(13)	Dubai	U.A.E.	3.5	11.6	12.6	9.0	13.7
10	(6)	Rotterdam	Netherlands	6.1	11.1	11.9	6.6	6.9
11	(26)	Tianjin	China	2.0	10.1	11.6	15.0	19.1
12	(4)	Kaohsiung	Taiwan	7.5	9.2	9.6	5.0	2.5
13	(12)	Port Kelang	Malaysia	3.8	8.9	9.4	6.4	9.6
14	(9)	Hamburg	Germany	4.7	7.9	9.0	14.2	6.8
15	(11)	Antwerp	Belgium	4.2	8.5	8.7	2.3	7.5
16	(7)	Los Angeles	U.S.A.	5.6	7.8	7.9	1.4	3.5
17	(47)	Xiamen	China	1.3	5.2	6.5	24.1	17.4
18	(49)	Dalian	China	1.2	5.2	6.4	22.1	18.1
19	(10)	Long Beach	U.S.A.	4.5	6.3	6.1	-3.2	3.1
20	(15)	Bremen	Germany	3.0	4.9	5.9	21.0	7.1

Source: ISL (2012)

2.1.5 Trade

In today's globalized world, almost no country could depend entirely on what it domestically produces. At some different levels, most of the countries are depending on international trade which could be defined as the exchange of capital, goods and services between the countries. As explained in previous sections, seaborne shipping is the most efficient method of transporting bulk goods. Over 90% of international trade is carried on the water, and in terms of value, more than 70% of the trade was transported by containerships in 2011 (UNCTAD 2012). Global container trade has enlarged 2.02 times from around 20 million TEUs in 1996 to around 151 million TEUs in 2011. In the same period, global total container port throughput has increased 2.65 times from around 157 million TEUs to around 573 million TEUs in 2011. These indices provide evidence as to how container trade has become an important player in the development of globalized world economies. Figure 2.3 shows evolution of global total seaborne container trade and port throughput during 1996-2011 in millions TEU (UNCTAD 2012).

The export side of international trade is extremely dominated by East Asia countries. Table 2.5 shows the top twenty seaborne exporting countries in 2009-10 (IHS 2012). According to these throughputs, global exportation of containers is also highly concentrated. Around 31.50% of the global seaborne trade volume was exported by Greater China (including Taiwan and Hong Kong) to rest of the world in 2010. The top ten exporter countries account for 62.11% and the top twenty accounts for 75.68% of the total international export. On the hand, the import side of international trade is almost equally dispersed around the world, except 25.90 total shares of USA and China (see Table 2.6). Contrary to the export side, the top ten countries imported only 48.73% of the total international trade. Similarly to the export side, the top twenty countries imported almost 75% of the total international trade.

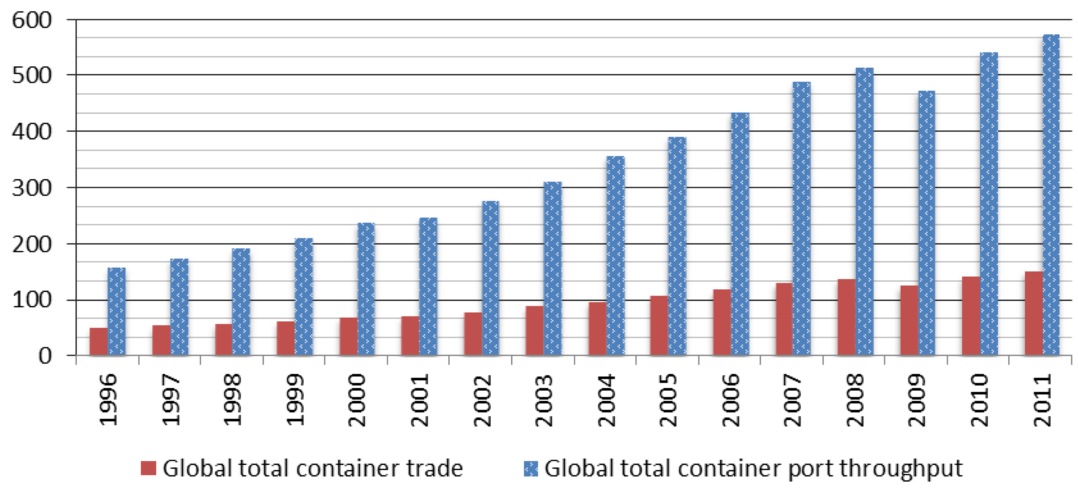


Figure 2.3: Global total container trade and port throughput (1996-2011)

The transfer direction of the trade between origin and destination countries is referred to as an international trade route. In this route, with the origin side making the export operations, the destination side makes the import operations.

Table 2.7 shows how these trade routes are changing around the world according to regions or country groups (IHS 2012). As a biggest exporter and second biggest importer country group, Great China is extremely directing the routes. Great China oriented or destined routes are encompassing 46.37% of the total international routes. The top ten trade routes account for 46.37% and top twenty trade routes account for 60.37% of the global container trade volume.

Table 2.5: The top 20 seaborne container exporter countries (2009-2010)

Rank	Exporter Country	Millions TEUs 2009	Millions TEUs 2010	TEU % growth 2009-10
1	China	26.1	31.3	19.92
2	United States	10.2	11.2	9.80
3	Japan	4.8	5.7	18.75
4	South Korea	4.5	5.2	15.56
5	Taiwan, China	2.9	3.4	17.24
6	Thailand	3.0	3.4	13.33
7	Germany	2.6	3.0	15.38
8	Indonesia	2.7	3.0	11.11
9	Malaysia	2.2	2.5	13.64
10	Brazil	2.3	2.3	0.00
11	India	1.6	1.9	18.75
12	Vietnam	1.3	1.6	23.08
13	Saudi Arabia	1.1	1.6	45.45
14	Italy	1.5	1.6	6.67
15	Turkey	1.4	1.6	14.29
16	Netherlands	1.4	1.6	14.29
17	Canada	1.4	1.5	7.14
18	United Kingdom	1.4	1.5	7.14
19	France	1.2	1.3	8.33
20	Hong Kong	1.2	1.3	8.33
Total	Top 20	74.8	86.5	15.64
Total	World	99.8	114.3	14.53

Source: IHS (2012)

Table 2.6: The top 20 seaborne container importer countries (2009-2010)

Rank	Importer Country	Millions TEUs 2009	Millions TEUs 2010	TEU % growth 2009-10
1	United States	15.0	17.6	17.33
2	China	11.2	12.0	7.14
3	Japan	5.4	6.1	12.96
4	South Korea	3.9	4.5	15.38
5	Germany	2.4	2.8	16.67
6	Other Arabian Gulf	2.3	2.7	17.39
7	United Kingdom	2.3	2.5	8.70
8	Indonesia	2.1	2.5	19.05
9	Taiwan	2.2	2.5	13.64
10	Hong Kong	2.3	2.5	8.70
11	Western Africa	2.5	2.4	-4.00
12	United Arab	2.0	2.1	5.00
13	Malaysia	1.7	2.1	23.53
14	Thailand	1.6	2.0	25.00
15	Vietnam	1.8	2.0	11.11
16	India	1.7	2.0	17.65
17	Brazil	1.3	1.9	46.15
18	Austrailia	1.5	1.8	20.00
19	Italy	1.6	1.8	12.50
20	Netherlands	1.3	1.7	30.77
Total	Top 20	66.1	75.5	14.22
Total	World	99.7	114.3	14.64

Source: IHS (2012)

Table 2.7: The top 20 seaborne container trade routes (2009-2010)

Rank	Trade Route Destination	Origin	Millions TEUs 2009	Millions TEUs 2010	TEU % growth 2009-10
1	United States	Greater China	7.1	8.5	19.72
2	European Union	Greater China	5.8	6.9	18.97
3	Other Asia	Greater China	4.3	5.3	23.26
4	Other Asia	Other Asia	4.5	5.0	11.11
5	Middle East and	European Union	3.1	3.4	9.68
6	Greater China	United States	3.2	3.4	6.25
7	Middle East and	Greater China	2.7	3.3	22.22
8	European Union	Other Asia	2.8	3.1	10.71
9	Greater China	European Union	2.9	3.1	6.90
10	Other Asia	European Union	2.6	2.9	11.54
11	Greater China	Greater China	2.6	2.9	11.54
12	Greater China	Other Asia	2.3	2.8	21.74
13	Middle East and	Other Asia	2.7	2.7	0.00
14	United States	Other Asia	2.3	2.6	13.04
15	United States	Latin America	2.2	2.4	9.09
16	Japan	Greater China	2.1	2.4	14.29
17	Other Europe	Greater China	1.8	2.3	27.78
18	United States	European Union	1.8	2.1	16.67
19	Latin America	Greater China	1.6	2.0	25.00
20	European Union	Middle East and	1.6	1.9	18.75
Total	Top 20		60.0	69.0	15.00%
Total	World		99.7	114.3	14.64%

Source: IHS (2012)

2.1.6 Land side

Since most of the containers come to ports from land side by using trucks and trains, efficient and timely transportation of containers from their origins will affect the performance of container terminals. Actually, the continued schedule of success of global intermodal transportation chain depends on whole effectiveness of each node. Therefore, a disruption anywhere on one of the transportation networks could result in shipment delays of the cargo (WorldShipping 2013c). Since the content of this study is to provide solutions to challenges of sea side container transportation, please see Iannone et al. (2007) for more detailed information on inland container transportation operations.

2.2 Liner shipping

2.2.1 Origination

Until the end of the 18th century, the ships were sailing between lands according to daily wind and weather conditions. With the successful integration of steam engines to ships in the mid-19th century, the ships started to provide regular passenger and cargo service. Before developments on intermodal container transportation in around mid-20th century, shipping lines had commonly provided a combined service with bulk cargo, passenger and mail (Wikipedia 2013c).

After the launch of containerships in around the mid-20th century, the world had experienced a strong increase in exchanging containerized goods and resources between regions. With the growing demand of containerized trade, the shipping lines commonly transformed their fleet to fully cellular containerships. Transfer simplicity and safety of the containers have started to meet with economic efficiency. The liner shipping industry has presented this service between lands more efficiently and changed the world trade pattern day by day (Levinson 2008).

Liner shipping is accepted as the most efficient mode for transportation of goods. A large containership with 8,000 TEU capacities could transport more than 200,000 TEUs in one year. In order to transport this amount, it would require using hundreds of freight aircraft, many miles of rail cars, and fleets of trucks. The containerized transport cost of a bicycle from Asia to Europe is about US$10, a media player is about US$1.50, a kg of coffee is just US$0.15, and a can of beer is around US$0.01 (WorldShipping 2013a).

2.2.2 Shipping lines

A liner container shipping line operates a fleet of containerships to provide shipping service between ports on fixed routes and schedules with regular frequencies (Windeck 2013). A shipping line has to service its customers with fixed sailing schedules in order to make containers available to ensure loading of the containers into the ships. In liner shipping, it could be expected that a ship will serve various ports on its route. The necessity of keeping the schedule on these ports will make the route fixed as well. A result of a deviation from this route could be non-availability of a contracted container in another port. As in public transport bus service, liner shipping service has to follow regular service frequencies in order to meet periodic demands of customers. Further analyses on determinants of container liner shipping are recently provided by Ducruet and Notteboom (2010).

Despite the increase on the scale of liner shipping economy and oil prices over years, the profit ranges of the shipping line industry have decreased (see Section 2.2.3). Therefore, in order to cope with growing demand and decreasing rates, the organizational structure of shipping lines have commonly reformed in order to increase effectiveness of their services. While some shipping lines independently continue to operate their services, much more of them have gone to operational collaborations (liner conferences, strategic sharing/alliances, and mergers and acquisitions). Therefore, the structure and the slot share of the top twenty shipping lines have significantly changed over the last thirty years. The top twenty shipping line operators controlled 26% in 1980, 41.6% in 1992, and 58% in 2003 of the world slot capacity (Notteboom 2004). Table 2.8 shows vessel numbers, capacities and shares of the top twenty shipping line operators in 2013 (Alphaliner 2013b). 85.79% of the world container slot share is controlled by the top twenty shipping line operators in 2013. The top three line operators have controlled 38.21% and the top ten have controlled 64.73% of the total container capacity. See Appendices (Table A.1) for more details about the top 100 liner shipping operators in 2013.

Table 2.8: The top 20 liner shipping operators in 2013

Rank	Shipping Line Operator	Slot TEU	World Share	Total Ships	Average Size TEU
1	APM-Maersk	2,562,353	15.56%	588	4,358
2	MSC	2,306,196	14.01%	475	4,855
3	CMA CGM	1,423,193	8.64%	420	3,389
4	COSCO	731,588	4.44%	159	4,601
5	Evergreen Line	721,571	4.38%	183	3,943
6	Hapag-Lloyd	648,247	3.94%	140	4,630
7	APL	606,865	3.69%	128	4,741
8	Hanjin Shipping	585,309	3.56%	112	5,226
9	CSCL	572,283	3.48%	139	4,117
10	MOL	499,893	3.04%	108	4,629
11	OOCL	448,051	2.72%	97	4,619
12	NYK Line	414,299	2.52%	95	4,361
13	Hamburg Süd	409,118	2.48%	101	4,051
14	K Line	352,106	2.14%	71	4,959
15	Yang Ming	350,646	2.13%	81	4,329
16	HMM	341,074	2.07%	57	5,984
17	Zim	320,018	1.94%	82	3,903
18	PIL	300,133	1.82%	146	2,056
19	UASC	277,665	1.69%	48	5,785
20	CSAV Group	254,392	1.55%	55	4,625
Total	Top 20	14,125,000	86%	3,285	4,300
Total	World	16,464,087	100.00%	4953	3,324

Source: Alphaliner (2013b)

2.2.3 Rates

During the years, the freight shipment rates of the liner shipping industry have eroded due to economic forces. With the increase in the scale of global economy, the industry has increased the fleet capacity to cope with international trade demand. However in these years, parallel to world trade, industry has been directly affected by unexpected local and global crises (i.e. financial, political etc.) as well as seasonal conditions. The major ups and downs in the economy have caused overcapacity on the slots of the fleets. Since the liner shipping is a highly capital-industry, when the large, expensive networks are set up, the operators make pressure to fully utilize these unused capacities of the ships. Since the shipping industry cannot influence the total throughputs of the market, the shipping industry has been decreasing its freight prices in order to attract more share from the market. As a result of the erosion in freight rates and explosion of bunker prices, shipping lines have started to operate with very low freight revenue. This marginal cost approach often causes direct operational losses on low demand periods due to high fixed costs (Notteboom 2004).

Figure 2.4 shows how the bunker, freight and slot index rates fluctuated between March 2011 and February 2013. In the figure, bunker index is the average global bunker price for all 380-centistoke (cst) port prices (US$) for per metric ton published on BunkerIndex (2013). During the period of time in the figure, the related bunker index fluctuated between $267 and $753 with $568 being average. Freight index represents, as an example, the shipment price of a container from China to Europe which fluctuated between $413 and $1872 with an average of $1210 in the same period (ShippingChina 2013). Slot index represents the daily slot rate (US$) of a chartered containership, i.e. the figure illustrates the slot cost of a 2500 TEU sized containership according to charter index of VHSS (2013).

Generally, Figure 2.4 implies that both uncontrolled global economy conditions and the explosion of bunker prices results in an unstable environment for freight shipment rates. This instability led shipping lines to intensely concentration on their network related costs in short-term perspective.

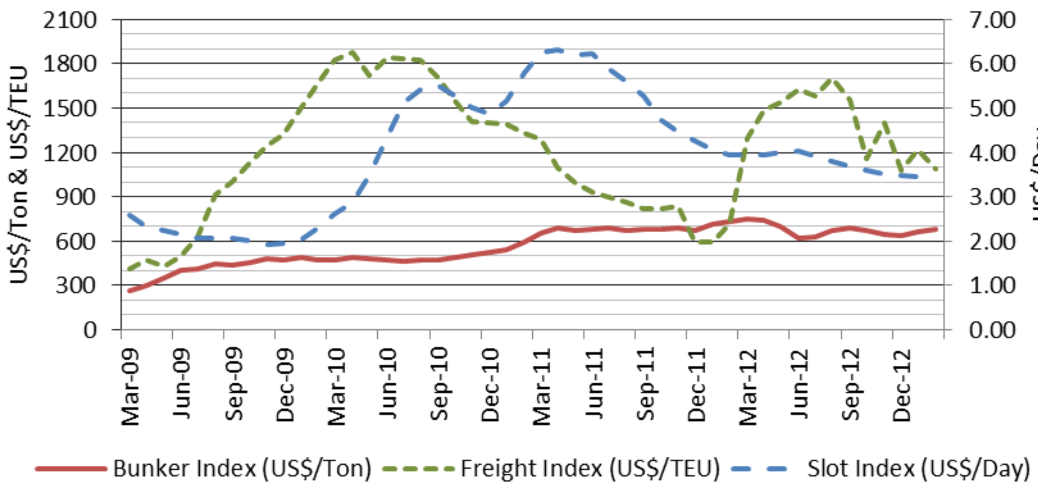


Figure 2.4: Evaluation of shipping industry indexes (March 2009 - February 2013)

2.3 Service networks

The liner shipping service networks are developed in order to meet the growing demand of shipping lines in terms of throughputs, port accessibility, shipping durations, and service frequencies. Shipping lines implicitly have to balance the requirements of the customers and operational cost considerations when designing their networks. Customers would demand direct services between the origin and the destination of their freights which would create an impossible pressure on the service schedules, frequencies and routes, and as well as the complexity of networks. On the other hand shipping lines would like to design their service networks in order to optimize utilizations of ships, to increase coverage of ports and to minimize transportation cost by using effectiveness of large containerships (Zohil and Prijon 1999; Lirn et al. 2004; Ducruet and Notteboom 2012).

Shipping lines could design their service in a great variant of network patterns in order to optimize their service efficiency. However, the more efficient a service network design from the perspective of carriers, the less appropriate the service network for customer expectations could become (Notteboom 2006). Therefore, shipping network design of each shipping line is dependent upon their offered service type and covered trade route. In contrast to conventional shipping, bundling is one of the key components of the liner service networks. In the liner service network design, the bundling of the containers could occur at two levels: bundling within service and bundling by linking two or more services (Ducruet and Notteboom 2012).

The objective of bundling within an individual liner service is to collect containers by serving a number of ports along the similar route patterns and time intervals (multi-port calling). Such a line bundling service usually starts from farthest contacted port of the region and sails to the farthest contracted port of another region by visiting a set number of ports in the regions. A line bundling service operation could be symmetric (see Figure 2.5a) or asymmetric (Figure 2.5b), depending on the return journey (Ducruet and Notteboom 2012). An example of such a line bundling service might be a route from Hamburg, London, Rotterdam, and Antwerp, ports of North Sea, to Sharjah, Mumbai, Colombo and Chennai, ports of Arabic Sea.

Pendulum and round-the-world services are extensions of the line bundling service. In pendulum (see Figure 2.6a), liner services usually cover more than two trade routes, i.e., from North Sea ports via Far East ports to North Pacific ports and vice versa. In the round-the-world service (see Figure 2.6b), the ship never turns around, it just keeps sailing until it completes a circumnavigation and returns to its starting point, i.e., a ship starting from Singapore port might follow Trans-Indian, Trans-Mediterranean, Trans-Atlantic and Trans-Pacific routes until returning back to Singapore.

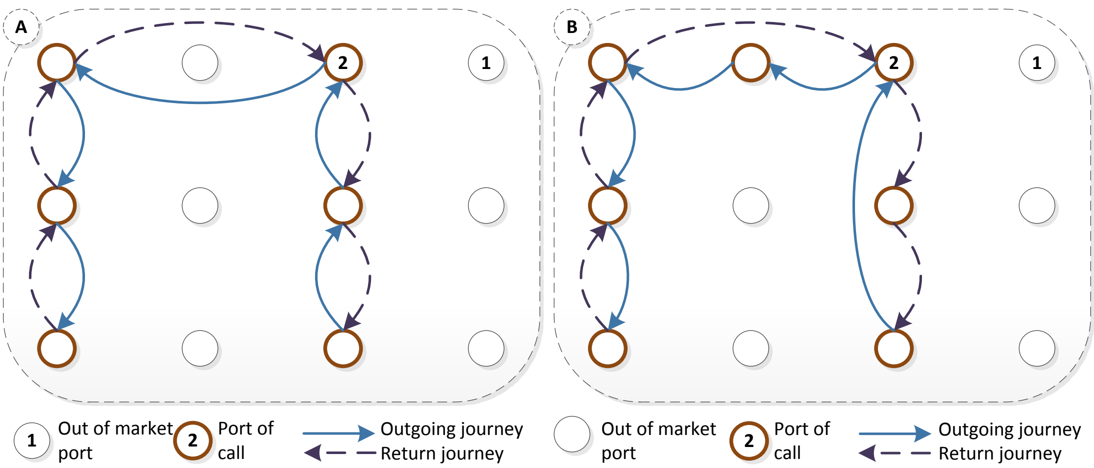


Figure 2.5: Symmetric and asymmetric line bundling networks

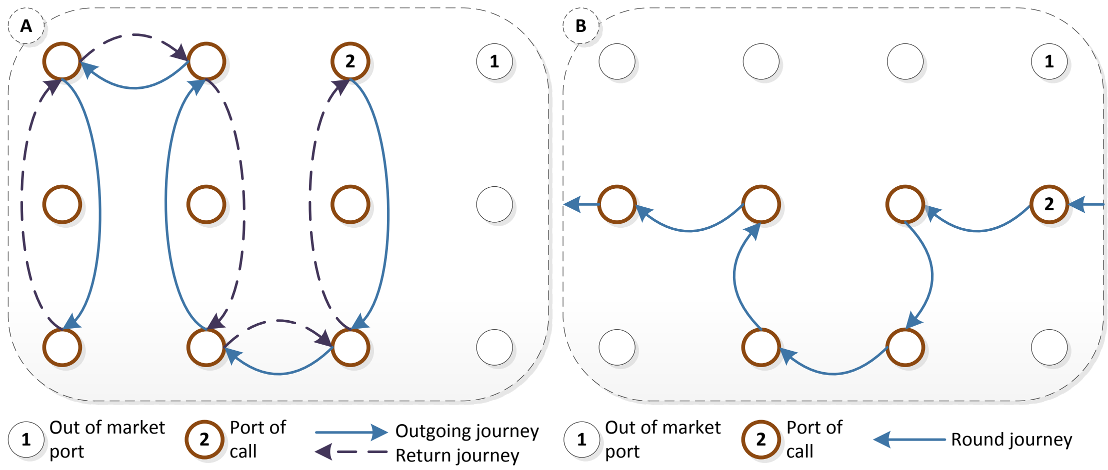


Figure 2.6: Pendulum and round the world service networks

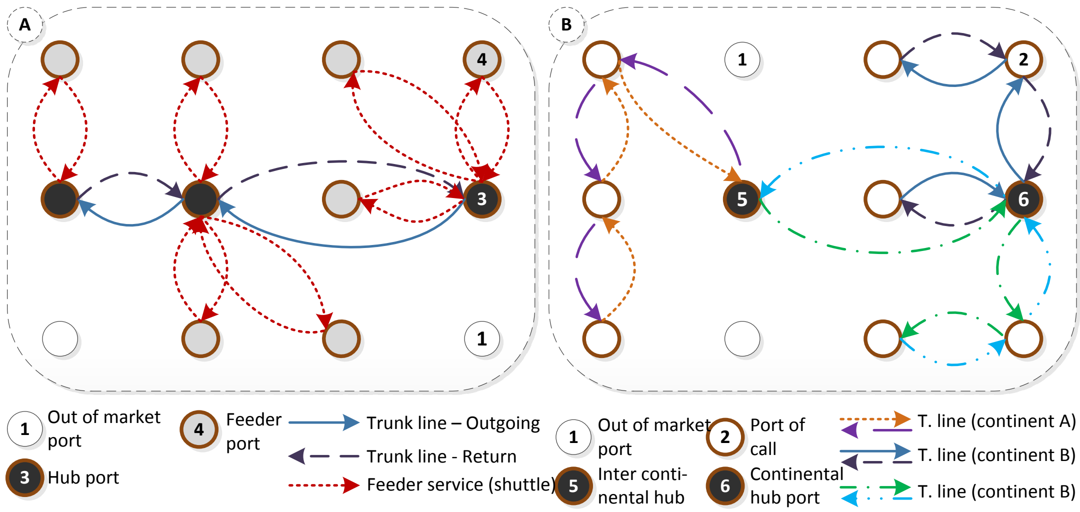


Figure 2.7: Hub-and-Spoke and Interlining/Relay network

Hub-and-Spoke (H&S) networks, interlining and relay are the main options to bundle containers by using more than one liner service. With the growing complexity of service networks in the mid-1990s, shipping lines established hub ports in order to make transshipment activities in order to reply the demands of market (Ducruet and Notteboom 2012). A hub port serves as a transshipment port and the character of this port changes depend on service patterns. In H&S service networks, the port serves as regional transshipment center between trunk line and feeder services (see Figure 2.7a). In this network, export containers are first delivered from feeder ports to hub ports via feeder services, then main liner services transports these containers to destination ports. Similarly, import containers are dispatched from hub port to feeder ports by using feeder services. In interlining service, a hub port serves as continental transshipment center between trunk lines, and in relay service, it serves as regional transshipment center between trunk lines (see Figure 2.7b).

Further analyses on dynamics and determinants of liner shipping networks are recently provided by Lam and Yap (Lam and Yap 2011), Wilmsmeier and Notteboom (2011), and Ducruet and Notteboom (2012).

3. Feeder Service

3.1 Background

From the beginning of containerization, it was commonly believed that shuttle operations could decrease the cost of container liners (McKinsey 1967). The required shuttle transportation could be executed by road, rail and sea feeder service modes depending on specific situations. Rail service could be an effective inland transportation mode as long as distance, volume and geographic conditions were appreciable. Road transportation mode could be selected in low volume short distance cases where rail service was not provided, and sea feeder service could be preferred on relatively long distances where geographically appreciable demand existed (Jansson and Shneerson 1982).

However, until development of modern liner shipping networks, sea based feeder services were not preferred unless road/rail transport was impossible (i.e. to island markets) due to their extra transshipment cost and longer transit time. In the early years of containerization, a deep sea containership was calling on a relatively large number of various sized ports (multi-port calling). Evaluation of mega sized containerships come with efficient transportation costs over long distances. But by visiting a number of various sized regional ports, the ships were wasting too much time on ports (Jansson and Shneerson 1982). Therefore, as an alternative to multi-port calling transportation by using individual liner service, H&S based transformation networks by using two or more liner services appeared in the industry. In this network, bigger sized containerships serve among the trans-shipment hub ports, and smaller sized containerships provide feeder service between hub port and the regional feeder ports. Large containerships were able to concentrate on sea crossing operations and do not waste time on small demand sized ports.

Both of the service alternatives have been criticized during the years, since direct service based multi-port calling systems and feeder (indirect) service based H&S have clear advantages *and* disadvantages (Imai et al. 2009). In next section, the advantages of the direct service and advantages of the feeder service are provided in detail. Note here that the advantages of direct service are the disadvantages of feeder service and the advantages of feeder service are the disadvantages of direct service.

3.2 Advantages of direct and feeder service

Direct service means a service where an individual ship carries the containers from origin port to the destination port or a group of ports without transshipment of containers from one ship to another ship via hub ports during its journey. Direct service is seen commonly in line-bundling (multi-port calling) networks. Feeder service means a service where containers are transported by a feeder vessel from regional port to hub port and delivered to the final port by using main and other feeder vessels via different hub ports. Feeder service is commonly seen in H&S networks.

3.2.1 The advantages of direct service

Main advantages of using direct service are less transit time, less additional cost, more attractive service, more reliable service, increased shelf life, and decreased transportation damage.

Less transit time: Direct service offers reduced transit time as compared to a feeder service via transshipment on hub port. The transit time will contain only loading and unloading operations on ports and routing time between origin and destination port. Therefore, there will be no waiting time on hub port for next trunk/feeder line service.

Less additional cost: Since there is no transshipment operation on hub port, there will also be no extra transshipment cost on hub ports and feeder service cost to transfer containers to regional ports (Cullinane 1999).

More attractive service: When direct service operators provide higher capacity ships between potential high demanded ports, the service operator could reduce freight cost with the help of less transit time and less additional cost. This may help individual, direct service operators to attract more shippers in the market as compared to transshipment based service operators (Ducruet and Notteboom 2012).

More reliable service: Since the ships in direct services are not correlated with the other ships, they are not affected by other ships impacted by delays. Any delay in feeder service could cause missing of trunk line service which means waiting for the next trunk ship to get loaded. Generally, the gap between the two sailings would be a week and this delay will have a major impact on the trade sustainability of shippers.

Increased shelf life: Faster transit time will come with the increased shelf life of products. This will give a chance for traders to deal with the transportation of perishable goods or sensitive health care products, etc. In addition, less transit time will decrease energy consumption of refrigerated containers (reefers).

Decreased transportation damage: Another advantage of using direct service is that there is less risk of damage, since the container is handled less often than feeder service based transportation during its journey.

3.2.2 The advantages of feeder service

Feeder service based networks are selected by global shipping operators due to the following advantages.

Increased port range: Trading of goods is not limited to any specific region or a specific port of the region. In today's world, every region has its own specific production potential and the excess of production beyond their consumption could be sent to a different region where the demand exists or insufficient products could be supplied from a different region where the excess of related product exists. Therefore the demand of the different regions and different ports of a region is dependent on the requirements. The demand of the small sized ports cannot be met with economical requirements of large sized ships (Jansson and Shneerson 1982). The feeder service allows these small sized ports to meet with the rest of the world; shipping line could be able to cover a range of ports around the service networks.

Eliminates port restrictions: Serving mega-sized containerships presents several problems for small sized ports which have restrictions on berth draft and lack of adequate handling equipment. Therefore, in order to benefit from the increasing efficiency of mega-sized ships, these types of small ports could be served with feeder ships.

Increased benefit from small sized ships: The demand of regions and ports of a region is different. The low potential demand of extra small ports does not mean that they will not be covered by global networks. The barge and feeder sized ships are still quite efficient under low demand conditions in both short and long distances compared to mega containerships. Using these types of ships in feeder services, extra small sized ships could become a part of global transportation networks.

Increased service number: When a large containership is deployed between continents, generally it takes at least thirty-five to forty days to complete a voyage. Since liner shipping requires fixed routes and schedules with regular frequencies, it is necessary to deploy a number of ships. Putting operation to such a large number of ships could be covered only with adequate demand from the ports. However, this could always not be satisfied by covering a limited number of ports directly. Economical effectiveness of large containerships comes from capacity utilization. In order to reach necessary utilization, operators of the direct shipping service increase the interval between service frequencies to load more containers. Increased service intervals will melt away the attractiveness of direct service, which comes from less transit time. On the other hand, feeder services will carry demand and supply of a range of regional ports to trunk line ships. In order to cover this demand, shipping lines will increase the number of service numbers. The time interval between services and waiting times in hub ports will decrease.

Increased benefit from mega containerships: By calling on a fewer number of ports with high demand volume, mega containers could concentrate on long distance sea crossing operations (Imai et al. 2009). Requested benefit of mega-containerships could be handled with only high capacity utilization which decreases the related capital cost of per transported container.

Decreased network cost: Despite the related transshipment and transfer cost of feeder service based systems, increased demand of hub ports, increased service numbers and increased benefit from mega containerships could decrease overall network costs of global shipping lines (Imai et al. 2009).

Decreased inland traffic and air-pollution: Among the other advantages of feeder services, the concentrated sea based network will decrease inland freight traffic congestion and air pollution problems caused by road transportation (Liao et al. 2010).

In addition to main advantages of feeder service, efficient distribution of containers to far away regions through feeder service, out of main line regions could be able to subsist in a worldwide market.

3.3 Modern H&S service networks

In the beginning of implementation of hub ports to service networks, the shipping industry was curious about the cost efficiency of the system. Economic scale of relatively small sized trunk ships was not sufficient to cover extra transshipment cost and feeder service cost (Lun et al. 2010). Day by day, increasing size and efficiency of large scale containerships are converted from hub ports to essential nodes of almost all service network patterns by maximizing port coverage and minimizing total transportation cost. Although different in scale, relatively huge sized regional ports act as hub ports to other small sized regional ports with feeder services in almost all of the service patterns. While this feeder service is more complex in H&S spoke networks, it is also somehow existing and critically important in other network patterns.

Traditional H&S networks (see Figure 2.7a), widely used in early ages of transshipment operations, was originated from airline transportation. The common aim was collection and distribution of containers from regional ports to hubs with direct shuttle services, and transshipment of containers among hub two ports via relatively bigger sized ships (Lu and Meng 2011).

Increasing requirements of both shipper and operators led to development of the modern H&S service networks. Thus, less transit time and more service number demands of shippers are met with sustainable and cost-effective design demands of operators in modern service networks (Løfstedt et al. 2010). A global service network frequently and reliably connects feeder ports with hub ports and the main ports of the regions by merging effective sides of both direct and feeder services in order to increase competitiveness of network for specific situations. Figure 3.1 shows a modern service network design which merges pendulum line bundling services with efficiency of H&S services. An example of such a multilayered service might be a route using a mega containership from Hamburg to Busan by using Rotterdam and Le Havre as trunk ports, by using Algeciras and Port Said as a hub port in Mediterranean, and by using Singapore and Hong Kong as a hub port in East Asia.

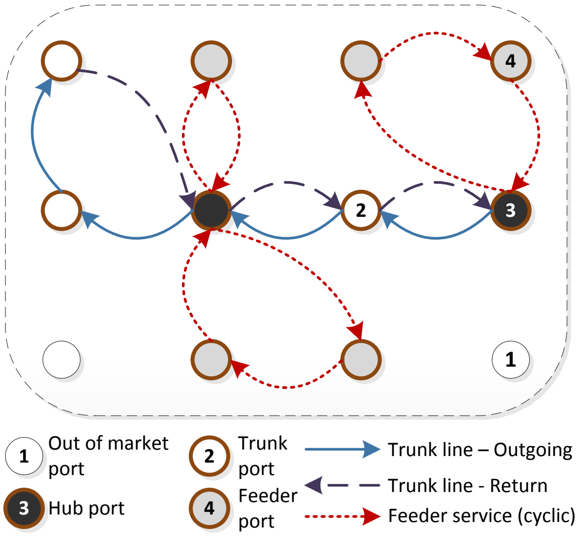


Figure 3.1: A modern multi layered H&S service network

The evolution of H&S networks has led to hierarchical categorization of container ports into three categories: hub ports, feeder ports and trunk ports (Zeng and Yang 2002). The hub ports are where container transshipments may take place between trunk and feeder line containerships. The hub ports have commonly high productivity ratios on loading and unloading of container to trunk and feeder ships. Feeder ports are regional hinterland gateways linked to over sea ports with feeder line containerships via hub ports. Due to both their geographical location, technological and low productivity limitations, feeder ports are commonly not visited by trunk line containerships. Trunk (main) ports are regional ports called by trunk lines due to their relatively high demand volumes. Trunk ports usually have medium to high productivity, favorable geographical location, and relatively good inland connections.

In the liner shipping industry, there is no fit to all approaches for hierarchical port of call position of a container port. The port hierarchy is determined by the strategic, tactical and operational planning level decisions of individual shipping lines. The hierarchical ports of call decisions of these lines are rarely identical for whole liner shipping industry. Therefore, a port may operate as a feeder port for a shipping line and a transshipment hub for another line. Alternatively, a shipping line might benefit from a hub port of another line as a trunk port.

3.4 Feeder service networks

Modern global H&S networks are led to two design challenges: trunk line design and feeder service design. Generally, trunk line design determines which ports will be used as a hub port and it provides line bundling based on route sequence for called hub and trunk ports. In addition, it could provide detailed information about service frequencies, routes, schedules, deployed numbers of fleet mix in these routes, and some additional management challenges (see Section 3.7).

In addition to network design of a trunk line, design of regional feeder service is a critical issue in designing whole global H&S networks of shipping lines. Because the regional ports do not have enough cargo demands to fill ships, they cannot attract the main lines to operate a regular service. The feeder services allow these ports to meet with the world. In conceptual terms, the feeder service is meant to simultaneously collect/distribute containers from/to specific regions with feeder ships and feed/discharge trunk containerships at hub ports as to avoid their calling at too many regional ports. The connections between hub port and regional ports could use a shuttle feeder service containing one feeder port or a cyclic line bundling service by containing more than one feeder ports (Wijnolst et al. 2000). The first service strategy has the lowest transit time but typically requires more feeder ships and smaller feeder containerships. In contrast, indirect feeder services benefit from economies of bigger ship size but incur longer distances and longer transit times. Figure 3.2 represents a feeder service network design as a part of H&S network. The majority of massive feeder service networks are located in the zone of landlocked seas or huge sea gulfs (Jadrijević and Tomašević 2011). Examples of such a network could be seen in the East Mediterranean area which covers Black Sea region ports, Sea of Marmara region ports, Aegean Sea region ports and East Mediterranean Sea region ports via Port Said. The various sized feeder containerships could serve these regional ports with both shuttle and cyclic service routes (Polat et al. 2012).

Feeder services play an irreplaceable role in global shipping networks (see Section 3.2.2 for advantages of feeder service). It was the feeder service network design that made the entire container service economically rational, efficient and more profitable, and consequently cheaper and timely for the end users (Rudić and Hlača 2005).

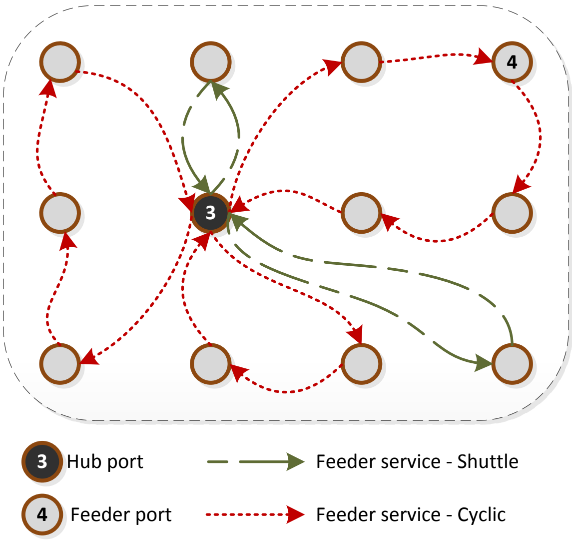


Figure 3.2: Feeder service network as a part of H&S network

The feeder service design could be regarded as a typical vehicle routing problem variation (Andersen 2010). It deals with simultaneous transportation problems of feeder lines in order to pick up containers from feeder ports to hub port and deliver containers from hub port to feeder ports. In this problem, feeder lines commonly aim to design optimal service routes by using a fleet of capacitated heterogeneous feeder container-ships under ship due date constraints for returning to the hub port at minimum cost. With these specifications feeder, service network design problems fundamentally fit to the vehicle routing problem with simultaneous pickup and delivery with time limit (Polat et al. 2012). See Section 5.3 for details of feeder service network design problem.

3.5 Feeder shipping lines

3.5.1 Characteristics of feeder lines

Although a single shipping line could operate both trunk and feeder service, it is increasingly common that regional shipping lines provide feeder service in short seas for global shipping lines (Andersen 2010). Depending on the size of regional economies, global shipping lines could use their own subsidiary feeder line services or third party feeder line services (Foschi 2003).

As long as enough demand cached from the region, global shipping lines are usually operating their own subsidiary feeder service lines which are only responsible transfer containers between destination ports and hub ports (Styhre 2010). The subsidiary feeder lines operate together with trunk lines to catch more freight from the shipper market.

Operators aim to decrease total network cost by serving related regional demands of all vessels of a trunk shipping line. The third party common feeder lines are usually used for low regional demands by global shipping lines. This type of operator aims to maximize total network revenue by serving a number of trunk shipping lines. They allocate slot space in ships to many global shipping line customers and charge their customer on the basis of total slot usage per voyage. Since the customers of the third party operators are usually global shipping lines, they do not get into competition with them in freight market.

For global shipping lines both feeder service operation decisions have the same advantages. The main advantages of using subsidiary service are low freight costs on high volume demands, more flexible feeder vessel schedules, full control on slots of feeder ships, and more flexible service networks. The advantages of using third party services are sharing of operating cost with the other customers, paying the cost of only used slots, no pressure to increase utilization of feeder ship, more frequency feeder services, less transit times, and no competition with regional shipping lines.

The top twenty shipping lines, which control 85.79% of the world container slot and 66.50% of the total fleet size, could be defined as global shipping lines (Alphaliner 2013b). Within global lines, the top three shipping lines, which control 38.21% of world slot and 29.98% of total fleet, are operating their feeder service almost with its own fleet. The other global shipping lines are benefiting from both owned feeder service and third party services depending on the conditions of the regions. Except these twenty shipping line, structure of the top 100 shipping lines are in a great variety which operates 97.26% of total world slot (see Table A.1 in Appendices). Some of them just concentrate on the trunk line operations between region with couple of mega containerships and benefitting from common feeder shipping lines for their regional services. A few of the top fifty shipping lines are large feeder shipping lines which totally concentrate on common feeder service with vast fleets in different regions. Within the top 100, the top fifty shipping lines operate almost 95% of the total world slot. The rest fifty shipping lines are usually small fleet sized direct shipping operators or small ship sized regional feeder service operators.

3.5.2 Differences between trunk and feeder lines

The main concepts, components and challenges are generally the same for trunk and feeder lines (Andersen 2010). The significant differences between feeder and trunk shipping lines could be compared as follows:

Operation area: The trunk lines operate in deep seas between regions and feeder lines operate in short sea within a region. While the trunk lines usually cover global service network, feeder trunk lines have limited regional service networks.

Demand volume: Since trunk lines serve strong hinterland connected main ports and regional transshipment hub ports, the demand volume for transportation is very high. On the other hand, since feeder lines serve relatively small regional ports, the demand for transportation is very low.

Vessel size: The high demand volumes of main and hub ports and long distances between regions allow trunk lines to benefit from the effectiveness of mega containerships. The demand volume and operating scale of short sea shipping make it necessary to operate with small sized ships in feeder service. Please see Sys et al. (2008) for more details about scale economies of containership sizes and operations.

Service frequency: In liner shipping, it is expected to serve each port at least one time in each week to meet customer demands and to provide customers with a regular schedule. However high demand volume trunk lines usually increase service frequencies of hub ports in particular. In order to optimize operation costs, subsidiary feeder lines generally operate less frequent service to feeder ports. And, third party common feeder lines act like trunk lines in service frequency, since they serve generally more than one trunk lines.

Voyage time: Parallel to size of ships, the loading and unloading times of trunk line ships on the ports are longer than port operation times of feeder line ships. In addition, parallel to distance between regions, the trunk lines need more time to cross seas despite higher operation speeds of mega ships. On contrary, the total voyage times of feeder lines are rather narrow, due to short distance and low port operation times.

Fleet size: Depending on the voyage time, service frequency, and the covered regions, trunk lines usually need medium/large fleet sizes in order to meet necessities of their complex service networks. On the other hand, related to short voyage times and less service frequencies, feeder lines need small/medium fleet size in regional service network.

Demand pattern: Main ports are usually localized in strong industrialized hinterlands and hub ports have wide connections with various regional ports. Therefore, trunk lines have usually less affected from seasonal demand fluctuations. On the other hand, the demand patterns of regional ports are rather unstable and seasonal. Hence, feeder lines limited scales; they have rather affected from seasonal demand fluctuations. See Section 3.6 for more information about the effect of demand fluctuation on operations of feeder lines.

Planning horizon: Trunk lines are more restricted to their service network; usually they plan their operations for medium to long term periods, since their huge capital investments. On the other hand, feeder lines are more flexible to adapt their self to changes on market environment.

Fleet ownership: Shipping lines could be owner of operated ships, or they could charter them as for a voyage time, or monthly, seasonally, yearly etc. Since trunk lines have operated on more restricted network pattern, they predominantly operate with their own ships which decrease costs over long term periods. Feeder lines usually operate a small, fixed number of owned ships and balance its requirements with chartered ships. They could decrease their capital costs and make their network more flexible to changes in trade.

Slot capacity: While trunk lines work with fixed slot capacity during the planning horizon, with the help of low chartering costs of small ships, feeder lines could operate with flexible carrying slot capacity.

Service schedule: Trunk lines operate under fixed service schedules for defined planning horizons. On the other hand, feeder lines could change their schedules a number of times in a planning horizon. With the help of flexible schedules, feeder lines could adopt themselves to seasonal demand fluctuations.

Service strategy: Trunk lines depend on the demand on their market coverage could provide direct of transshipment based service. Feeder lines generally provide direct service to customers. However, for some far away regions some large sized feeder lines could use another small sized regional feeder service, as well.

Customer type: While the customers of trunk lines are shippers; customers of feeder lines are global shipping lines.

Port selection: There are some common and unique factors in port choice behaviors of trunk liners and feeder service providers. Local cargo volume, terminal handling charge, land connection, service reliability and port location are most common important factors for trunk and feeder service. On the trunk liners side, water draft, feeder connection, and port due are also determining factors. On the other hand, berth availability, transshipment volume and cargo profitability are the other determining factor for feeder service providers (Chang et al. 2008).

Collaboration and competition: There is high collaboration required between trunk and feeder lines in order to create efficient service networks. Since the trunk lines are the cheapest mode to transfer containers across oceans, they usually have only competition with other trunk lines. On the other hand, the feeder lines generally compete with direct lines and other shipping lines, as well as regional truck and rail operators.

In conclusion, feeder lines are the intermediaries of the complex service networks between regional shippers and trunk lines. While trunk lines connect main global ports to each other; feeder lines help secondary ports, which have irregular and low quantities, to survive.

3.5.3 Effecting factors on performance of feeder lines

Performances of feeder shipping lines are affected from by various factors. These factors could be mainly categorized as external and internal factors. Market, customer, port and surrounding factors are external factors and management and vessel factors are internal factors (Styhre 2010).

Market factors: The numbers of refrigerated, dangerous and standard containers, the imbalance of import and export containers, the mix of full and empty containers, daily and seasonal demand fluctuations, and the competition and cooperation with other regional feeder lines are affecting factors on the design networks and as well as performance of shipping lines.

The numbers of refrigerated and standard containers will define transportation capacities of vessels due to essential power requirements of refrigerated containers and limited power supply slot of ships as well as limited dangerous container stacking area.

The imbalance of import and export trade of region ports will configure the sequence of the ports; the vessels commonly at first will serve import intense ports and then will serve export ports in order to maximize transportation volume. Other effecting factor of trade imbalance is the cargo mix of empty and full containers.

The daily and seasonal demand fluctuations of regional ports have critical importance on the configuration of all planning decisions of feeder service networks; because the mix and number of ship fleets, deployment of owned and chartered ships, the sequence of ports etc. will be planned according to demand forecasts of the regions (see Section 3.6).

Since feeder shipping lines operate under low freight rates, competition and cooperation of shipping lines and inland transportation modes are also critical on the performance of feeder services.

Customer factors: The main customers of feeder service lines are usually global trunk shipping lines. Usually schedules of feeder ships are planned according to arrival and departures of trunk ships. The feeder vessels have to follow schedules of trunk ships in order to decrease waiting times of containers in hub ports. The waiting time will both increase stacking cost of a container in the yard area of container terminal and transit time of a container from origin to destination.

The delays of trunk ships are also important factors on stability of feeder service. In addition, efficient information exchange between shipping lines will affect stowage planning decisions of feeder lines.

Port factors: Compared to hub ports, the equipment infrastructures of container terminals and quay depths of feeder ports are quite scarce and in wide variation. Therefore, loading and unloading turnover durations are higher in feeder ports. In addition to these specifications, working hours, additional pilotage requirements on berthing, bunker and cleaning facilities of feeder ports are significant on design of networks. On the other hand, despite usually huge infrastructures, hub port gives priorities to trunk ships which could also effect of overall performance of feeder services.

Surrounding factors: Long queue times at both feeder and hub ports, weather conditions on the sea and ports, regional safety, security and environmental legislations and regulations are affecting factors on performance of feeder services. Long queue times and weather conditions usually create delays on route schedules and increases bunker consumptions. Since the feeder containerships usually operating in short sea areas, they are more restricted to use high quality bunkers in order to decrease emotions (Wang et al. 2013b; Windeck 2013). Since the feeder containerships usually operating in short sea areas, they are more restricted to use high quality bunkers in order to decrease emissions.

Management factors: Organizational structures, efficient decision support tools, and size and mix of owned fleets are internal factors affecting performance of feeder lines. The third party or subsidiary company role of feeder line for a trunk liner will affect property of encountered planning and organizing problems (see Section 3.5.1). Owned computer-based decision support tools will also help to deploy efficient solutions to faced planning problems such as route design, vessel stowage planning, scheduling etc. The size and mix of owned fleets will allow great flexibility in handling fluctuations on both regional and trunk ship operations.

Vessel factors: Another affecting factor is the specifications of owned or chartered ships such as numbers, capacities, lengths, beams, draft, speeds, ages, geared equipment, electrical power supplies, charter and purchasing costs, and bunker consumptions. The vessel related factors have intensive influence on all planning level decisions of feeder lines.

3.6 Demand fluctuation

The demand for liner shipping is generally closely linked to the development of world economy and world trade (Zachcial and Lemper 2006). There are also nearly cooperative relations between regional economic developments and feeder services. On the one hand, regional economic development affects the supply of export goods as well as the demand of import goods and raw materials which are the need of global liner shipping. On the other hand, efficiency of feeder service in H&S system allows world-wide economic exchange of goods.

Liner shipping as well as feeder service requires high capital investment, because of the huge capital of fixed and variable costs of containerships. The return of these investments depends on transported container volume. Therefore, a change in world or regional trade will lead to a change in transportation volume (Lun et al. 2010). In addition to volume, the balance between import and export volume of ports will affect the revenue of shipping service. Theoretically, a feeder ship could carry up to twice of its slot capacity in a cyclic route. It will depart from the hub port with the import containers, will deliver the import container to regional feeder ports, will simultaneously pick up export containers from them, and arrive back to hub port with export containers. When the trade is imbalanced in the ports, some slots could become idle in the departure or arrival of the ship from/to hub port. The idle slots will be more if there is an imbalance in the trade of the whole region and will be less if there is a balance in the related region. The idle slots will effect utilization of ships; a decrease in utilization will cause an increase in the total transportation cost per container.

The demand for liner shipping fluctuates over a year with seasonal changes, peaks at certain times of years, and unexpected sharp drops and cancelations (Schulze and Prinz 2009; Polat and Uslu 2010). The production and consumption of some goods could vary over the year, some following harvest seasons for fruit or fish and others following public, national, and religious holidays. While some of these are affecting a single port or region, several of them could create peaks in global trade, like Christmas and Chinese New Year. Another affect which causes demand fluctuation is unexpected local and global crises periods (i.e. financial, political etc.). In these periods, global or regional liner shipping industry could usually experience a sharp decline in demand. In addition in liner shipping, shippers usually pay for container transportation when the container is loaded into a vessel or delivered to its destination. This situation allows shippers to cancel their bookings before loading, even their long term contractual agreements. Hence the demand of the ports is occasionally steady during a year (Løfstedt et al. 2010).

The demand of ports reflects the necessary slot capacity for a liner shipping line. Since the demand is uncertain, shipping lines must carefully consider their capacity decisions on whether or not to expand it. However, postponing the increase of slot capacity could lead shipping lines to the risk of carrying less than capacity when the demand volume is enlarged (Lun et al. 2010). In addition to capacity decision, the demand is the driving force in the design of service network; even small variations of the demand pattern could prompt to entirely different service network designs (Andersen 2010).

Since accurately predicting the condition's effect on liner shipping is almost impossible, making reliable forecasts with certainty is also nearly impossible. But that does not mean forecasting is pointless. The aim of forecasting is not to estimate accurately, it attempts to help decision-makers to understand the future by reducing uncertainty by exploring the current information. Therefore, forecasting container throughputs of ports is playing a critical role in the planning decisions of liner shipping lines. Since liner shipping involves considerable capital investments and huge daily operating costs, the appropriate liner shipping feeder service network design will affect the development of the feeder shipping lines.

Under conditions of high uncertainty, planning methods are usually based on deterministic forecasts, which may be prone to failure in the long run. More realistic stochastic forecasting methods, known from the academic literature, are not preferred in liner shipping because of their complexity and high statistical data requirement (see Chapter 4). On the other hand, simulation could be used to assist with constructing a forecasting frame by using deterministic forecasting methods that only need limited data. Indeed, a simulation-based forecasting frame might be better suited in a stochastic environment where unexpected drops or peaks could occur.

The dynamic, complex, and flexible nature of feeder service makes accurate forecasting a long-term challenge for feeder lines. Therefore, it is important to develop an efficient methodology for forecasting container demands in order to better assist feeder line companies in developing strategies and investment plans (see Section 6.2).

3.7 Planning levels in feeder service

As in liner shipping, decisions in feeder service are commonly characterized under strategic, tactical, and operational planning levels. The main challenges are generally same for liner shipping and feeder services. Please see Christiansen et al. (2004), Christiansen et al. (2007), Andersen (2010), and Windeck (2013) for more detailed information about problems faced in strategic, tactical and operational planning levels in liner shipping.

The planning decisions in feeder service depend on the organizational structure of feeder lines. If the related feeder line is a subsidiary firm of a global shipping line, the planning activities of feeder services will be more dependent to future plans of global line. On the other hand, the activities of the third party common feeder lines will be more relevant to expectations from shipping market.

Although the problems are presented below in a certain planning level, some of them might span to more than one planning level and/or might contain collaborative decisions with trunk lines. Since this study covers the challenges in the feeder service network design, other decision problems in land and port side operations are not examined in this study.

3.7.1 Strategic planning

Strategic planning levels include long term decisions which are taken by top management of feeder services. In liner shipping, while long term strategic decisions refer to one to five years for trunk lines, it usually refers to one to three years for feeder lines (Andersen 2010). In some long term projects such as new building terminals or fleets, this period could spread over five to ten years. Main strategic planning decisions for a feeder line are generally selection of service region, selection of feeder ports, hub port options, ship types, firm scale, and ownership of fleet.

Selection of service region: A subsidiary feeder line will serve sub-regions of a trunk line’s transshipment hub port. Hence, service region selection of subsidiary firms are related to hub port selection of trunk lines. A subsidiary firm of a global line could operate in only one region or could operate more than one region served by a trunk line. When trunk lines do not use a subsidiary feeder line in the region of a transshipment port, they have to link feeder ports by using third party feeder lines. These common feeder lines select their service markets according to current and future development and competition expectations of regions.

Strategic options for hub ports: Considering the economic progress in the region and the prospects of international trade relationships as well as trends in the choice of the transportation mode, scenarios reflecting the future development of demand for container traffic between the regional ports have to be defined. These scenarios are used to evaluate different feeder network configurations, in particular, the strategic options for hub ports.

Selection of feeder ports: Subsidiary feeder lines do not have the chance to select feeder ports; they have to serve all regional feeder ports which have demands and/or supplies to trunk shipping line by minimizing network transportation costs. On the other hand, common carriers might not provide services to some low demand and/or supply volume ports, since they try to maximize the revenue from the region.

Ship types: Selection of service region and feeder ports comes with alternate feeder ship types. The length, breadth, and drought of a ship could not be feasible for sailing in the region, passing from straights or canals and approaching to ports. Moreover, terminal specifications of feeder ports are also important in the selection of alternative feeder ship types. Hence, feeder lines have to design service network according to specific requirement of regions (see Chapter 5).

Firm scale: The slot capacity of a feeder line with operation scale affects the performance of the firm. The total carrying capacity of feeder lines reflects the characteristic of operation in the regional market. Large slot sized firms are more likely to create high freight rate pressure and market share against their competitors.

Ownership of fleet: Another strategic decision on feeder lines is the ratio between owned and chartered ships in the fleet. Feeder lines usually operate a small fixed number of owned ships and balance its requirements with chartered ships. This could decrease their capital costs and make their network more flexible to changes in trade. However, if there is a stable or increasing demand trend in the market, operating with a high number of charter ships could be couple of times more costly than operating with owned ships. Therefore, it is crucial for feeder lines to define the minimum number of owned feeder ships for long term efficiency (see Chapter 5).

3.7.2 Tactical planning

Tactical planning levels usually include medium term decisions which are taken by transportation planning departments of feeder lines. In liner shipping, tactical planning levels focus on planning decisions which take from 2-3 months up to 1 year. The tactical level problems usually consist of decisions over designing of feeder service networks. Main tactical planning decisions for a feeder line are generally contract management, service frequency, ship routes, ship scheduling, fleet size and mix, and fleet deployment.

Contract management: A key decision problem at the tactical level is contract management which involves the analysis and the development of the existing contract relationships with ports in the region and with cooperating companies.

Service frequency: In feeder service, it is expected to serve each feeder port at least one time in each week to maintain customer demands and to provide customers with a regular schedule. However, feeder lines could change service frequencies to ports according to their demand volumes. Feeder lines could increase service frequency for highly demanded feeder ports in order to increase satisfaction of shippers and decrease low demanded feeder ports in order to decrease total transportation cost. Therefore, it is important for feeder lines to decide service frequencies of feeder ports (see Chapter 5).

Ship routing: This problem aims to construct optimal service routes for a fleet of vessels by defining service sequences of a set of ports which have both pick-up and delivery containers. Each feeder port has to be served once for both operations with a given fleet of identical capacitated feeder ships. Each ship leaves the hub port carrying the total amount of containers it has to deliver and returns to the hub port carrying the total amount of containers it must pick-up. While subsidiary lines aim to minimize total transportation costs by satisfying all demands of related feeder ports, common lines aim to maximize the profit from the region by sometimes declining some low profit ports.

Fleet size, mix and deployment: The aim of the fleet size and mix decision is to determine the optimal composition of the fleet. The characteristic of the containerships are important to calculate operational costs of ships. For a feeder line, operational costs for ships include fixed costs (owning, chartering, operating, management, insurance, etc.) and variable costs (on-sea bunker cost, on-port bunker cost, port set-up charges). Fleet deployment is the allocation of the most suitable ship types to specific routes. In feeder service, a deployed ship will be available after unloading whole pick up containers in a hub port. Since the feeder ports have to be served with defined service frequencies, the interval duration between two service times could not be enough for returning back to hub port. Therefore, it is usually necessary to deploy more than one ship to routes. The total fleet size and mix is the summary of all deployed ships to all routes of service network. Some of the deployed fleet could be owned ships; some of necessary ships could be chartered in from the market. Since the high capital fixed and variable costs of ships, if there are unnecessary or over capacity ships they could be chartered out.

Ship scheduling: Even scheduling is not a common problem in transportation; liner shipping has essential features that make scheduling decisions an integral part of its network design. Ship scheduling is one of the most essential and nonetheless most problematic planning problems for feeder lines. In feeder service design, in a given set of port sequences (routes) and available time-windows of ports, scheduling mainly concerns with the appointments and arrival and departure times to deployed ships and determination of expected berthing time. In feeder service, the deployed vessels usually lack of schedules due to congestion at ports, delays in berthing, delays in trunk lines, inefficient terminal equipment, worse weather conditions, waiting for tug and pilots, accidental delays and channel/straight queues (Varbanova 2011a).

The routing, scheduling and fleet size, mix and deployment problems are main parts of the feeder service network design. The decisions made in any of these problems affect the decisions in the other problems as well. As an example, even if the routes are optimally designed, a poorly designed ship schedule could increase the necessary number of ships and decrease total profit of the network. Therefore, an efficient feeder service network design requires simultaneous solutions to these problems. In feeder service network design problems, all decisions related to three individual problems have to be given at same time (see Chapter 5).

3.7.3 Operational planning

Operational planning level includes short terms decisions which could span from a few hours to a few months. The operational planning level decisions are usually linked to decisions made at tactical or strategic level. Main operational planning decisions for a feeder line generally determine sailing speeds of deployed vessels, vessel stowage planning, environmental routing, and empty container repositioning.

Sailing speed: Sailing speed concerns the optimal average speed between two ports in route sequence or average speed of the voyage. Since a 30% decrease in sailing speed of vessels reduces the fuel consumption by 50% and greenhouse gas emissions by 30% per time unit, shipping lines started to operate in slow steaming mode in the last years. In slow steaming mode, feeder lines could also decrease waiting idle times of their feeder ships in hub ports for the next voyage. Feeder vessels could operate on different speeds in different steps of the voyage. A ship usually operates faster speeds in high demand volume direction and slower speeds in low demand directions (Christiansen et al. 2007; Windeck 2013).

Stowage planning: Stowage planning decisions are related to the positioning of containers on vessel's board. Efficient stowage planning is essential for a good weight balance and sailing stability of the vessels. Moreover, since the access to the containers is only possible from the top of the stack, efficient stowage planning reduces the number of unnecessary shifts in unloading of the delivery containers and berthing time of vessels at feeder ports.

Environmental routing: Environmental routing considers the optimal sailing path between two ports in route sequence by considering water depths, tides, regulations, and direction and speed of waves and winds (Windeck 2013).

Empty container repositioning: The trade imbalance in the region results in the empty container repositioning problem. In order to supply additional empty container requirement of import intense ports, the feeder lines have to transport surplus empty containers of export intense ports to import ports. Also the route design should consider the maximum deadweight of the vessels by mixing empty and full containers to increase utilization of vessels.

4. Literature Review

The related literature review summarized in five parts in this chapter. While Section 4.1 summarizes the recent related liner shipping network design papers, Section 4.2 overviews the feeder service management and feeder network design related papers. Section 4.3 gives a basic categorization for vehicle routing problems and summarizes the VRPSPDTL papers in the literature. Section 4.4 give a compression over the liner shipping related forecasting approaches and Section 4.5 summarizes the studies which handle liner shipping problems under unstable demand environments.

4.1 Liner shipping network design

Maritime liner shipping has become a popular topic of academic research worldwide. Hence, a huge amount of papers has been published focusing on different planning aspects in this area. A large number of papers addresses ship routing and scheduling, cf. Ronen (1983, 1993), Christiansen et al. (2004; 2013), Kjeldsen (2011) and Meng et al. (2013) for comprehensive reviews. Additional review papers appeared on container shipping (Notteboom 2004), fleet size and mix (Pantuso et al. 2013), fleet composition and routing (Hoff et al. 2010) and liner shipping network design (Ducruet and Notteboom 2012; Yang et al. 2012). Because of the availability of some detailed literature reviews, we highlight some recent papers which are considered more related to liner shipping feeder service network design in this chapter. In Table 4.1 an overview of these papers is given.

In the liner shipping service network design literature, ever since the studies of Rana and Vickson (1988, 1991), much attention has been paid to routing and scheduling of the ships in MPC shipping networks. Ting and Tzen (2003) proposed a mathematical model for service network design of MPC liner shipping line by considering service time windows. In order to minimize total network cost, the authors developed a dynamic programming model and solved a case study for transatlantic service with 10 ports.

Table 4.1: Liner shipping service network design related studies

Authors and Years	Problem	Network	Formulation	Object function	Solution Methodology	Feeder	Case Area
Ting and Tzen (2003)	Fleet deployment, Ship scheduling, Ship routing	MPC	Dynamic programming	Min. total cost	-	-	Transatlantic
Shintani et al. (2007)	Ship routing, Empty container repositioning,	MPC	Cost model formulation	Max total profit	Genetic Algorithm	-	Southeast Asia
Lei et al. (2008)	Ship scheduling, Collaboration	MPC	Mixed integer linear programming	Min. total cost	CPLEX	-	Randomly generated
Yan et al. (2009)	Ship scheduling	MPC	Integer multiple commodity network flow	Min. total cost	CPLEX	-	Taiwan
Lam (2010)	Fleet deployment, Ship scheduling, Ship routing	MPC	Cost model formulation	Max total profit	Intelligent system	-	-
Wang and Meng (2011)	Ship scheduling	MPC	Mixed integer linear programming	Max total profit	Two staged column generation	-	Asia-Europe
Windeck (2013)	Ship routing, ship scheduling, environmental routing	MPC	Mixed integer programming	Max total profit	Variable Neighborhood Search	-	Gulf of Mexico, N. Atlantic, North Sea
Gelareh and Meng (2010), Wang et al. (2011)	Service frequency, Fleet deployment, Ship scheduling, Chartering	MPC	Mixed integer linear programming	Min. total cost	CPLEX	-	Transpacific, Transatlantic, Asia– Oceania Europe
Ronen (2011)	Fleet deployment, Bunker cost, Slow streaming	MPC	Cost model formulation	Min. total cost	-	-	Various
Meng and Wang (2011b)	Fleet deployment	MPC	Mixed integer linear programming, Dynamic programming	Max total profit	CPLEX	-	Transpacific, Southeast Asia - Oceania, intra-Indian Ocean
Agarwal and Ergun (2008)	Ship scheduling, Ship routing	Interlining	Mixed integer linear programming	Max total profit	Column generation, Benders decomposition	-	Randomly generated
Alvarez (2009)	Ship routing, Fleet deployment	Interlining	Mixed integer programming	Min. total cost	Column generation, CPLEX, Tabu Search	-	Global
Lachner and Boskamp (2011)	Ship routing, Ship scheduling	Interlining	Cost model formulation	Max total profit	Multi-start local search heuristics	-	Asia-Europe
Reinhardt and Pisinger (2012)	Ship routing, Ship size	Interlining	Mixed integer linear programming	Min. total cost	CPLEX	-	Randomly generated
Wang and Meng (2012a)	Fleet deployment, Chartering	Interlining	Mixed integer linear programming	Min. total cost	CPLEX	-	Asia–Europe–Oceania
Wang et al. (2013c)	Container path routing	Interlining	Integer linear programming	Min routing cost	CPLEX	-	Global

Authors and Years	Problem	Network	Formulation	Object function	Solution Methodology	Feeder	Case Area
Hsu and Hsieh (2005)	Ship routing, Ship size, Sailing frequency	MPC, H&S	Multi-Objective Model	Min. shipping costs, inventory costs	Pareto optimal solutions	Shuttle	Transpacific
Løfstedt et al. (2010)	Complex network design	MPC, H&S	Rich integer programming model	Max total profit	-	-	Benchmark sets
Chen and Zhang (2008)	Ship routing, Ship size	MPC, H&S	Mixed integer linear programming	Min. total cost	TSP heuristic, Minimum location	Shuttle	Asia-Europe, Asia-North America
Imai et al. (2009)	Ship routing, Ship size, Empty container repositioning	MPC, H&S	Mixed integer linear programming	Min. total cost	LINGO	Shuttle	Asia-Europe, Asia-North America
Meng and Wang (2011a)	Empty container repositioning, Combined MPC& H&S	MPC, H&S	Mixed integer linear programming	Min. total cost	CPLEX	Cyclic	Asia–Europe–Oceania
Kjeldsen (2011)	Ship routing, Container routing	H&S	Mathematical flow model	Max total profit	Dantzig-Wolfe decomposition, column generation	Cyclic	Africa, Europe, North America
Takano and Arai (2009)	Hub location and spoke allocation	H&S	Uncapacitated single-allocation p-hub median	Min. total cost	Genetic Algorithm	Shuttle	East Asia
Gelareh et al. (2010)	Hub location and spoke allocation	H&S	Mixed integer programming	Max market share	Lagrangian relaxation and CPLEX	Shuttle	Randomly generated
Gelareh and Nickel (2011)	Hub location and spoke allocation	H&S	Mixed integer programming	Min. total cost	Benders decomposition, Greedy neighborhood search, CPLEX	Shuttle	AP dataset
Gelareh and Pisinger (2011)	Hub location and spoke allocation, fleet deployment	H&S	Mixed integer linear programming	Max total profit	Benders decomposition, CPLEX	Shuttle	Randomly generated for North-American and European
Zacharioudakis et al. (2011)	F. deployment, Slow streaming, Frequency, Chartering	H&S	Generic cost model	Min. total cost	Genetic Algorithm	Cyclic	Transpacific & Intra-Asia
Mulder (2011)	Fleet deployment, Container path routing, Ship scheduling	H&S	Linear programming model	Max total profit	Genetic Algorithm	Cyclic	Asia-Europe
Hsu and Hsieh (2007)	Ship routing, Ship size, Sailing frequency	H&S	Multi-Objective Model	Min. shipping costs and inventory costs	Pareto optimal solutions	Shuttle	Transpacific
Yang and Chen (2010)	Ship routing, Ship size, Sailing frequency	H&S	Bi-level programming	Min. transportation cost	Genetic Algorithm	Cyclic	China –West America
Lu and Meng (2011)	Ship routing, Ship size	H&S	Cost model formulation	Min. operation cost.	Tabu Search	Cyclic	East Asia - South Asia - North Europe

Their results show that optimization based models could help planners to make better estimation for voyage fixed costs and freight variable costs in MPC liner shipping network design.

Shintani et al. (2007) developed MPC container shipping network design model by considering the empty container repositioning. In order to maximize total profit from the network, the authors proposed a genetic algorithm based solution approach and solved case studies from Southeast Asia region with 20 ports and 3 ships. Lei et al. (2008) developed service network design for a MPC liner shipping line by considering service time windows and different collaboration policies between carries. In order to minimize total transportation cost, the authors developed mixed integer linear programming models for the non-collaborative policy, the slot-sharing policy, and the total-collaboration policies and solved a number of randomly generated test instances by using CPLEX. Their results show that the total- collaboration policy between carriers has great potential to decrease total network cost. Yan et al. (2009) proposed a mathematical model for short-term fleet scheduling problems in already designed MPC service routes. In order to minimize total network cost, authors formulated the problem as integer multiple commodity network flow and solved Lagrangian relaxation with sub-gradient method by using CPLEX. The proposed model has been implemented to liner shipping network of a Taiwanese liner shipping provider who serves 11 ports in East Asia.

Lam (2010) presented an integrated approach for designing MPC service routes by considering time windows and suggested an decision support system for the problem. The proposed approach selects the calling ports from the regions’ candidate ports according to preferences of carriers and offers optimal routes, fleet deployment and scheduling for the selected ports by minimizing total network cost. Wang and Meng (2011) developed service network design for MPC liner shipping line by considering service time windows. In order to maximize total profit from the network, the authors proposed a two staged column generation based solution approach with numerical examples from the Asia-Europe liner service. Windeck (2013) proposed a mixed integer programming model for joint routing and scheduling of MPC shipping lines under environmental influences to maximize total network profit. The authors developed a Variable Neighborhood Search for case studies with up to 33 ports and 6 ships.

A field concerning the deployment of the ships to already designed MPC liner shipping networks is one of the recent study areas. Gelareh and Meng (2010) developed a joint service frequency and fleet deployment model to already designed liner shipping MPC service network by considering service time windows and vessel charter operations. In order to minimize total network cost, the authors proposed a mixed integer linear programming model and solved transpacific service with 7 ports, transatlantic service with 6 ports, and Asia–Europe service with 9 ports by using CPLEX. Later, Wang et al. (2011) reformulate the fleet deployment model of Gelareh and Meng (2010) in order to increase efficiency of the model. Ronen (2011) developed fleet development model to already designed liner shipping MPC service networks by considering different levels of bunker costs and vessel speeds. In order to find optimal speed for minimizing network cost, the authors developed a mathematical formulation and solved some numeric case studies exists in the literature. Their results show that operating under lower speed has potential to reduce total operating costs but increases transit times. Meng and Wang (2011b) proposed an integer linear programming model to determine fleet size, mix and deployment on already designed service network during yearly periods. The shipment demands between ports are also given and increases yearly 10% during the periods.

Another common research area is designing interlining service networks of trunk shipping lines by considering transshipment operations. Agarwal and Ergun (2008) developed interlining service network design for liner shipping lines with transshipment operations by considering simultaneous ship routing and scheduling problem without considering transshipment cost. In order to maximize total network profit, the authors proposed a mixed integer programming model and solved the joint problem by using a greedy heuristic, a column generation based algorithm and a two phase Benders decomposition based algorithm. The authors solved a number of randomly generated instances consisting up to 20 ports and 100 ships. Alvarez (2009) developed a global sized interlining service network design by considering simultaneous ship routing and fleet deployment problem. In order to minimize total network cost, the authors proposed a mixed integer programming model and solved the joint problem by using Tabu Search heuristics and CPLEX. The authors solved an assumption based case study of global container trade number with 2.6 million TEUs demand of 120 ports.

Lachner and Boskamp (2011) proposed a joint ship routing and scheduling model for interlining service network design problem to maximize total network profit. The authors proposed a multi-start local search heuristic with several variations and solved case studies from Asia-Europe shipping network with 58 ports. Reinhardt and Pisinger (2012) developed interlining service network design for trunk lines of liner shipping with transshipment operations by considering fleet assignment problems. In order to minimize total network cost, the authors proposed a mixed integer linear programming model and solved problem up to 15 ports by using branch-and-cut. Wang and Meng (2012a) also developed fleet deployment model to already designed liner shipping interlining service network with transshipment operations by considering vessel charter operations. In order to minimize total network cost, authors proposed a mixed integer linear programming model and solved Asia–Europe–Oceania shipping network with 46 ports by using CPLEX. Wang et al. (2013c) proposed an integer linear programming model for generating optimal container routing paths in already designed network in order to minimize transportation cost per container while considering the transit time and maritime cabotage constraints. The authors applied model to a liner shipping network provided by a global liner shipping company with 166 ports from all over the world, 75 ship routes, and 538 voyage legs.

Just a few papers deal with the economic evaluation of the MPC and H&S network designs. Hsu and Hsieh (2005) developed a two-objective model for container shipping lines in order to compare the optimal routing, ship size, and sailing frequency decisions for MPC and H&S service networks. In order solve the model, the authors used Pareto optimality concept instead of a complete optimal solution and solved the model for transpacific shipping service case study with 5 ports. Their results show that optimal decision tends to be direct shipping as container flow between origin and destination ports increases for such a small networks. Chen and Zhang (2008) compared economic viability of mega-size containership in both MPC and classical H&S network design by considering transshipment and feeder service costs. In order to minimize total network cost, authors proposed a mixed integer linear programming model and solved Asia-Europe network with 17 ports and Asia- North America network with 12 ports by using travelling salesman heuristics for MPC and minimum location for H&S. Their results show that Mega containers were competitive in Asia-Europe trade in all scenarios and competitive for Asia- North America as long as feeder costs are low.

Imai et al. (2009) also compared MPC and classical H&S network service designs by including the empty container repositioning for both MPC and H&S service networks of liner shipping. The authors proposed a number of numerical experiments for

Asia–Europe and Asia–North America trade lanes and solved the problem with the help of LINGO solver. Their results show that MPC has total cost advantages in Asia-North America shipping network and H&S has total cost advantages in Asia-Europe shipping network. Meng and Wang (2011a) compared the cost-effectiveness of already designed pure H&S, pure MPC, and combined H&S and MPC service networks by including the empty container repositioning. The authors formulated a mixed-integer programming model in order to minimize total operation cost. The authors proposed a case study for Asia–Europe–Oceania shipping service network consisting of 46 ports and related 24 test instances are solved by using CPLEX. Their results show that combined network design is more cost-effective than pure H&S and pure MPC service network. Kjeldsen and Lysgaard (2011) presented a mathematical flow model for joint routing of ships and cargo in H&S and MPC liner shipping service networks by including various deployment issues to maximize total network cost. The authors proposed a heuristic is developed based on Dantzig-Wolfe decomposition and column generation and solved case studies with various network instances in Africa, Europe, and North America with up to 25 ports and 45 ships by using CP.

A growing number of studies aim to determine optimal configuration of hub locations and allocation of feeder ports to hub in H&S networks. Baird (2006) presented a methodology for evaluating and comparing hub ports in Northern Europe. Shuttle feeder shipping costs for current hub locations and a newly proposed hub port in the Orkney Islands are compared. Takano and Arai (2009) considered a hub location problem in H&S service network design with shuttle feeder service by considering allocation of feeder ports to hub ports. In order to minimize total network cost, the authors formulated the problem as an uncapacitated single-allocation p-hub median and solved problem by using Genetic Algorithm approach with a case study from East Asia containing 14 ports. Gelareh et al. (2010) also considered a hub location problem in H&S service network design under competition between a newcomer liner service provider and an existing dominating operator. In order to maximize market share of new comer line, the authors proposed a mixed integer programming model and solved the case studies up to 72 ports with the help of Lagrangian relaxation and CPLEX.

Gelareh and Nickel (2011) proposed a formulation for the uncapacitated multiple allocation hub location problem for H&S liner shipping network design. In order to minimize total network cost, the authors developed a mixed integer programming model and solved the problem by using a Benders decomposition with CPLEX for small sized test instances and Benders decomposition with greedy neighborhood heuristic for large sized test instances. Gelareh and Pisinger (2011) developed a joint hub location and fleet deployment model for H&S networks with direct feeder services for container transportation. In order to maximize total network profit, the authors proposed a mixed integer linear programming model formulation solved a number of randomly generated test instances for North-America Asia trade by using benders decomposition model and CPLEX.

Fleet deployment of designed shipping networks is also one of the recent study areas in H&S liner shipping networks. Zacharioudakis et al. (2011) proposed a fleet deployment model for already designed H&S service network by considering various service options. The authors developed a generic cost model methodology to minimize total network costs by using Genetic Algorithms and solved transpacific shipping trunk service network including cyclic intra-Asia feeder routes with 20 ports. The proposed model decreased the total operation cost of the network almost 36%. Mulder (2011) developed a combined fleet deployment, ship scheduling and container routing path problem model in an already designed H&S service network by considering both trunk and feeder line operations. The author proposed a linear programming model to maximize total network cost and provided a genetic algorithm based approach to solve case studies from Asia-Europe shipping network consisting 58 ports. Proposed model improved the total network profit about 40% compared to the reference network.

In the literature, only a few papers have been published which consider H&S systems with origin-to-destination transportation processes as a whole. Hsu and Hsieh (2007) presented a two-objective model for H&S service network model in order to determine the optimal routing, ship size, and sailing frequency by minimizing shipping costs. In order solve the model, the authors used Pareto optimality concept instead of a complete optimal solution and solved the model for transpacific shipping service case study with 7 ports. Løfstedt et al. (2010) developed a benchmark suite for liner shipping by including various types network design problems along with a rich integer programming model. The authors also presented a set of benchmark data instances with offset in real world data.

Yang and Chen (2010) considered a joint routing, ship size, sailing frequency problem for a modern H&S service network design with cyclic feeder service by considering allocation of feeder ports to hub ports. In order to minimize total operating cost per voyage, the authors proposed a bi-level programming model formulation and solved a case study China-West America with 14 ports by using Genetic Algorithm. The authors used trunk lines for high demanded main ports and hub ports, and feeder services for low demanded small ports in order to avoid too much port calling of trunk lines. Lu and Meng (2011) proposed a solution for simultaneously routing problem and ship size of trunk and feeder lines in a modern H&S service network by considering allocation of feeder ports to hub ports. In order to minimize total operation cost per voyage, the authors mathematically formulated the problem and proposed a Tabu Search based solution approach to solve East Asia - South Asia - North Europe liner service network consisting 11 hub ports and main ports and 51 feeder ports. The authors did not include capital costs of the ships and the necessary number of ships per voyage.

4.2 Feeder service

Nowadays feeder services play an irreplaceable role in global shipping networks. The related literature primarily addresses regional conditions and prospects in the development of feeder services. For instance, Waters (1973) searched adaptability of full coastal container shipping services by comparing different types of ships to feed main line ports in New Zealand. The author suggested using of only small type containerships due to lack of equipment of faraway small ports. Robinson (1998) discussed the development of Asian ports between 1970 and 2000. The authors reported that during the years, operation and organization of direct, feeder and trunk service networks always changed parallel to development of the region. The author argued the importance of feeder network will continue to grow over a long period of time. Frankel (2002) analyzed the feeder service structure Caribbean ports and compared economics of shuttle, cyclic, pendulum feeder service operations with direct trunk service for three regional ports. The authors suggested use direct trunk services or shuttle services to region ports under low level of bunker prices. Evers and Feijter (2004) discussed feeder ship service operations in the Rotterdam port.

Ridolfi (1999) examined problems and prospects of global and regional shipping lines in the Mediterranean region. The author argued that with the increasing volume of transshipment traffic services, feeder service networks will continue to stimulate the regional transportation role at many more terminals around the region. In addition, Francesetti and Foschi (2002), Goulielmos and Pardali (2002), Foschi (2003), Ham and Autekie (2005) and Jadrijević and Tomašević (2011) discussed prospects and problems of Mediterranean Sea feeder services and ports.

Kolar et al. (2000) analyzed necessities of feeder service from a small regional port Rijeka (Croatia) to a hub port Gioia Tauro (Malta) in Mid- Mediterranean region. 5 years later after starting of the feeder service between Rijeka and Gioia Tauro, Hlača and Babić (2006) evaluated the effect of the feeder service to region and the current conditions and the future prospects of the feeder service. Buksa and Kos (2005) and Rudic and Hlaca (2005) analyzed the structure of feeder containership services in the Adriatic ports. In addition to these studies, few studies concentrated on CCS line networks. Luo and Grigalunas (2003) simulated demand of CCS line networks for US coastal ports. Ran et al (2008) analyzed characteristics of Chinese CCS market.

Further analyses on determinants of container liner shipping are recently investigated by couple of researchers. Chang et al. (2008) compared port selection behaviors of trunk liner and feeder line providers. The authors argue that local cargo volume, terminal handling charge, land connection, service reliability, berth availability, transshipment volume and cargo profitability are the main determining factor for feeder service providers. Ng and Kee (2008) evaluated optimal containership size of shuttle feeder services by using economic and simulation models in Southeast Asia from the perspective of carriers. Styhre (2010) analyzed the factors affecting utilization of feeder service vessels. The author argue that market, customer, port and surrounding factors are external factors and management and vessel factors are internal factors in the utilization performance of feeder lines. Recently, Buksa and Zec (2011) and Buksa and Buksa (2011) analyzed risk and quality issues of coastal container liner shipping lines.

Recently, Varbanova (2011a, b) analyzed transportation conditions and efficiency factors of feeder lines in the Black Sea region. The author also summarized the operational planning problems of container feeder lines which are related to schedule integrity between trunk lines, shipping capacity utilization, service speed optimization under high bunker prices, recent regulations for control of air pollution from ships, shipping policy impulsions of the European Union, structure and capacity of the container terminals, and increased dwell time of containers at the terminals.

Nowadays feeder services play an irreplaceable role in global shipping networks. Just a few papers deal with real feeder service network settings and consider existing or projected hub locations. Bendall and Stent (2001) developed a mixed integer linear programming model for deployment and scheduling of ships in an already designed feeder service network. The proposed model, firstly, determines the number of voyages to be commenced on each route in order to maximize total network profit by sometimes declining some low profit and secondly, schedules ships in the determined voyages. The authors solved a case study from South East Asia with six ports and eight voyages and a couple of homogenous fast feeder containerships. Mourao et al. (2001) proposed an integer linear programming model for assignment of a number of ships to an already designed network containing one feeder route and two trunk routes by considering delivery containers and inventory costs. Catalani (2009) proposed a cost-minimization based expert system model for sequencing and scheduling feeder ports for just one feeder service route within the Mediterranean area with one hub ports and four feeder ports by considering time windows and both pick-up and delivery containers.

Other papers put a stronger focus on mathematical modeling and related solution methodologies with unique feeder service configurations. Chou et al. (2003) presented sea freight inventory-routing problem by considering both direct and feeder service to distribute demands of regional ports from a supply port by using a fleet of homogenous ships. Direct shipping modeled as traveling repairman problem and feeder service modeled by using mixed integer problem formulation to minimize the average in-transit inventory cost. The proposed models are solved by using CPLEX and Multi-start Tabu Search algorithm and compared in a case study from South East Asia with 10 ports. One example is the paper by Baird (2006) who presents a methodology for evaluating and comparing hub ports in Northern Europe. Based on mainline ship deviations and direct feeder shipping costs increased transshipment capacities of ports are given.

Sigurt et al. (2005) and Andersen (2010) presented a regional feeder service network by allowing direct and indirect delivery between feeder ports, recurring visits and considering time windows. The authors proposed different mathematical modeling formulations and solution approaches based on decomposition of the problem into two subproblems dealing with master problem and freight routing. Firstly, the authors initialize a number alternative route by using one hub port and determine optimal service network design by deploying ships to these routes. Then, allocates a number of origins to destination freights to these routes in order minimize total freight routing cost in the network.

In the academic literature, only a few studies treated the feeder service problem as a variant of vehicle routing problem. Fagerholt (1999; 2004) considered feeder shipping problem in a special network where all pick-up cargo are collected from a set of feeder ports to a single hub port by using various size ships with same speed. The problem is solved by first initializing all feasible single ship routes according to biggest sized ship by implementing time limits, and then allocating optimal ship types to these routes. Contrary to classic vehicle routing problem approach, ships could operate more than one route (multi-trip) in allowed time limit (VRPMTTL). The author solved instances with up to 40 ports by using up to 19 ships in 23 routes within a couple of seconds.

Jin et al. (2005) evaluated feeder containership routing problem as a VRP with pickup and delivery with time windows formulation. The authors proposed a mixed integer programming model for minimizing total weighted cost, which is a weighed sum of the total travel times, the number of ships used, total waiting time, and total tardiness time in order to serve feeder ports from one hub port with a fleet of homogenous ships under port time windows constraints. The proposed model is solved for VRP test instances up to 100 ports by using Variable Neighborhood Search and Tabu Search aproaches. Later, Sun and Li (2006) also handled same problem by using immune Genetic Algorithm approach and improved the solutions of Jin et al. (2005)'s the test instances.

Sambracos et al. (2004) present a case study of dispatching small containers via coastal freight liners from a hub port to 12 Greek island ports. In this study total operating costs including fuel consumption and port charges are minimized assuming a homogeneous fleet and given container shipment demand. The authors formulate a linear programming model which is solved by use of a list-based threshold acceptance heuristic. Later Karlaftis et al. (2009) generalized this container dispatching problem by minimizing total travel distances with simultaneous container pick-up and delivery operations and time deadlines. To solve the problem they propose a mixed-integer programming formulation and a Genetic Algorithm assuming soft time limits, i.e. tolerating violations of

Table 4.2: Overview of feeder service network design related studies

Authors and Years	Problem	Freight	Fleet	Formulation	Object function	Solution Methodology	Feeder service	Case Area
Bendall and Stent (2001)	Fleet deployment, ship scheduling, Recurring visit	Container	Homogenous	Mixed integer programming	Max. total network profit	Branch and Bound	Shuttle, Cyclic	South East Asia
Mourao et al. (2001)	Fleet size, inventory	Container	Homogenous	Integer linear programming	Minimize total annual trade cost	Excel solver	Cyclic	Portugal
Catalani (2009)	Port sequencing, Ship scheduling	Container	Homogenous	Mathematical cost modeling	Min. operating cost	Expert System	Cyclic	Aegean Sea
Chou et al. (2003)	Ship inventory-routing	Ores	Homogenous	Mixed integer programming	Min. average in-transit inventory cost	CPLEX, Multi-start tabu search	Cyclic	South East Asia
Sigurt et al. (2005)	Master problem, Ship scheduling, Freight routing	Cargo	Heterogeneous	Mixed integer linear programming	Min total freight routing cost	Linear programming relaxation, Heuristic branch-and-price algorithm	Cyclic, recurring visit	Randomly generated
Andersen (2010)	Master problem, Ship scheduling, Freight routing	Container	Heterogeneous	Mixed integer linear programming	Min total freight routing cost	Linear programming relaxation, CPLEX	Cyclic, recurring visit	Randomly generated
Fagerholt (1999; 2004)	Ship routing, fleet size and mix (VRPMTTL)	Container	Heterogeneous	Integer programming	Min total transportation cost	Set partitioning, CPLEX	Shuttle, Cyclic	Randomly generated
Jin et al. (2005)	Ship routing (VRPPDTW)	Container	Homogenous	Mixed integer programming	Min. total weighted cost	Variable neighborhood search, Tabu search	Cyclic	VRP instances
Sun and Li (2006)	Ship routing (VRPPDTW)	Container	Homogenous	Mixed integer programming	Min. total weighted cost	Immune genetic algorithm	Cyclic	VRP instances
Sambracos et al. (2004)	Ship routing (CVRP)	Container	Homogenous	Plain linear programming problem	Min operation cost	List-based threshold Acceptance heuristic	Cyclic	Aegean Sea
Karlaftis et al. (2009)	Ship routing (VRPSPDTL)	Container	Homogenous	Mixed integer linear programming	Min total travel time	Genetic algorithm	Cyclic	Aegean Sea

certain constraints. As a case study they deal with a feeder network from the Aegean Sea with 26 ports including one hub port. Nevertheless, both studies did not consider heterogeneous ship types and the specific costs for operating the fleet. See Section 5.2 for mathematical model details of containership routing problem of Karlaftis et al. (2009) and Section 7.2 for implementation of the problem with developed hybrid solution heuristic called Adaptive Neighborhood Search (Section 6.1).

However, so far none of the feeder service network design studies has considered detailed variable and fixed cost structures for a heterogeneous vessel fleet over a complete sailing horizon. In this study, we propose a mixed-integer linear programming model to simultaneously determine the fleet size and mix, fleet deployment, ship routing and ship scheduling in feeder service network design by minimizing total network costs in a sailing season (see Section 5.3). A hybrid solution heuristic called Adaptive Neighborhood Search (see Section 6.1) is proposed to solve the joint problem using a case study from Black Sea region (See Section 7.3).

4.3 Vehicle routing problem

Since basic specifications of feeder service network design problem fundamentally fits to the vehicle routing problem with simultaneous pickup and delivery with time limit (VRPSPDTL) (Polat et al. 2012), this section provides a brief literature over VRP variations and VRPSPDTL applications.

The Vehicle Routing Problem (VRP) refers to serving a set of clients from a central depot with a homogeneous fleet of capacitated vehicles. This problem aims to determine a set of vehicle routes starting and finishing at the central depot which serves all clients just once, thereby minimizing the total distance travelled. A variation of the VRP is the Vehicle Routing Problem with Pickup and Delivery (VRPPD) where the vehicles serve both delivery and pick up operations at client locations. The VRPPD can be basically categorized into three classes (Nagy and Salhi 2005):

– VRP with Backhauls (VRPB): the vehicles first serve delivery operations, next pick up operations at clients.

– Mixed VRPB (MVRPB): the vehicles serve delivery or pick up operations to clients in any sequence.

– VRP with Simultaneous Pickup and Delivery (VRPSPD): the vehicles simultaneously serve delivery and pick up operations to clients.

Please see Berbeglia et al. (2007) and Parragh et al. (2008) for extended variants of Pickup and Delivery Problems (PDP). In the literature, the VRPSPD was first proposed by Min (1989). In this problem, the existing load of the vehicle has to be checked at each client to ensure that the vehicle capacity is not violated. The VRPSPD can also be categorized into three classes:

– VRPSPD with Maximum Distance Length (MLVRPSPD): the vehicles have a maximum voyage distance constraint for returning to the central depot.

– VRPSPD with Time Windows (VRPSPDTW): the vehicles have to start their service with the clients between a given earliest and latest time.

– VRPSPD with Time Limit (VRPSPDTL): the vehicles have to return to the central depot before a time deadline.

In this study, we consider the VRPSPDTL which was first proposed by Salhi and Nagy (1999). The authors impose service times for the clients and a maximum total duration (travel + service time) restriction for the vehicles in the VRPSPD.

Dethloff (2001) defined the VRPSPD as an NP-hard combinatorial optimization problem, meaning that practical large-scale problem instances are hard to solve through exact solution methodologies within acceptable computational times. In the VRPSPDTL the objective and constraints are the same as in the VRPSPD, except for the service time limit of vehicles. This makes the problem more complicated due to the difficulty in controlling of the voyage duration of the vehicle in addition to the service time of the clients along the route. As a result, this problem can be described as NP-hard, as well. In the literature, the interest was therefore focused on heuristic or metaheuristic solution approaches.

Since 1989, many heuristic and meta-heuristic solution approaches for VRPSPD benchmark problems have been proposed. See Zachariadis et al. (2009), Subramanian et al. (2010), Zachariadis and Kiranoudis (2011) and Goksal et al. (2012) for recent studies on the VRPSPD. See Tang and Galvao (2006), Zhang et al. (2008) and Fard and Akbari

(2013) for recent studies on the MLVRPSPD and Mingyong and Erbao (2010) for the VRPSPDTW.

However, just a few studies considered benchmark problems under time limit restrictions. Some authors proposed heuristic and metaheuristic implementations for the VRPSPD as well as VRPSPDTL.

Salhi and Nagy (1999) presented single and multi-depot VRPB benchmark problems including VRPB, VRPPD, VRPSPD and VRPSPDTL. The authors manipulated 7 original single depot VRP benchmark problem instances of Christofides et al. (1979) by imposing a maximum time restriction for the vehicles, giving a predefined service time, and splitting the original demand between pickup and delivery loads in order to create VRPSPDTL test instances. The remaining 7 instances were obtained by switching these pickup and delivery loads. The authors proposed a Cluster Insertion Heuristic (CIH) to solve problem in order to minimize the total travelled distance covered by a fleet of vehicles.

Later from Salhi and Nagy (1999), a number of studies improved best known solutions day by day with various heuristic and metaheuristic approaches. Detholff (2001) proposed an Insertion Based Heuristic (IBH) for solution of VRPSPDTL instances. The authors tested total distance, residual capacity, radial surcharge, and combination of residual capacity and radial surcharge insertion criterions within proposed IBH. They got their best results with combination insertion criterion for VRPSPDTL test instances. Nagy and Salhi (2005) developed a number of heuristics by integrating various neighborhood structures. The authors catch their best results in VRPSPDTL by using alternating integration of these heuristics called as Alternating Heuristic (ALT).

Ropke and Pisinger (2006) used a Large Neighborhood Search (LNS) approach by using a number of removal and insertion heuristics with and without learning layers to solve test instances. They got their best results by using six removal heuristics with learning layers. Montane and Galvao (2006) developed a Tabu Search (TS) algorithm to solve VRP and TSP instances including VRPSPDTL. The developed algorithm uses grouping and routing heuristics to construct an initial solution for TS and three types of inter-route neighborhoods (the relocation, interchange and crossover) and an intra-route neighborhood (2-opt) with intensification and diversification search strategies to improve solutions. Wassan et al. (2008) proposed a Reactive Tabu Search (RTS) algorithm which constructs an initial solution with forward and backward-sweep methods and improves initial solution with three intra-route and one inter-route neighborhoods by using a dynamic tabu list size.

Gajpal and Abad (2009) presented an Ant Colony System (ACS) approach to solve problem instances. The presented approach constructs an initial solution using the nearest neighborhood heuristic, generates routes with savings, and improves the solutions with the customer insertion/interchange multi-route scheme and the sub-path exchange multi-route scheme local search heuristics. Ai and Kachitvichyanukul (2009) developed an Particle Swarm Optimization (PSO) algorithm with multiple social learning structures by including the cheapest insertion heuristic and 2-opt methods to construct routes.

Catay (2010) Saving Based Ant Algorithm (SBAA) equipped with a new saving-based visibility function to construct routes and pheromone update procedure to improve solutions within ant algorithm. And recently, Jun and Kim (2012) offered an perturbation based solution which construct an initial solution with sweep method, improves the solution with a series of inter- and intra-route neighborhood structures and perturbs best solution destroy and repair based heuristic when the improvement stuck at a local optima. The developed approach called as Nearest Sweep with Perturbation (NSP). All these studies handled VRPSPDTL within VRPSPD problem instances.

Subramanian and Cabral (2008) presented the first investigation that deals with the pure VRPSPDTL considering the CMT 6-7-8-9-10-13-14 X&Y benchmark problems of Salhi and Nagy (1999). The authors proposed an Iterated Local Search (ILS) procedure in order to solve this problem. Their approach constructs an initial solution with greedy method, improves the solution with variable neighborhood descent method by using six neighborhood structures and perturbs the best solution with double-bridge perturbation function when it is necessary.

In all VRPSPDTL benchmark problems of Salhi and Nagy (1999), service time for all clients are considered the same within the instances. In the corresponding literature, Salhi and Nagy (1999), Detholff (2001), Nagy and Salhi (2005), Ropke and Pisinger (2006), Gajpal and Abad (2009), Ai and Kachitvichyanukul (2009), Catay (2010) and Jun and Kim (2012) solved these instances by including service time, Montane and Galvao (2006) determined solutions by excluding service time and Wassan et al. (2008)

and Subramanian and Cabral (2008) considered both situations. Please see Table 4.3 for brief overview of VRPSPDTL related studies.

In this study, we propose a mixed-integer linear programming model to solve VRPSPDTL (see Section 5.1) and a hybrid solution heuristic called Adaptive Neighborhood Search (see Section 6.1) is used to solve the benchmark instances, with and without service time, from Salhi and Nagy (1999) (See Section 7.1)

Table 4.3: Overview of VRPSPDTL related studies

Author (Year)	Solution methods	Abbreviations	With service time	Without service time
Salhi and Nagy (1999)	Cluster Insertion Heuristics	CIH	✓	-
Detholff (2001)	Insertion Based Heuristics	IBH	✓	-
Nagy and Salhi (2005)	Alternating Heuristic Algorithms	ALT	✓	-
Ropke and Pisinger (2006)	Large Neighborhood Search	LNS	✓	-
Montane and Galvao (2006)	Tabu Search	TS	-	✓
Wassan et al. (2008)	Reactive Tabu Search	RTS	✓	✓
Subramanian and Cabral (2008)	Iterated Local Search	ILS	✓	✓
Gajpal and Abad (2009)	Ant Colony System	ACS	✓	-
Ai and Kachitvichyanukul (2009)	Particle Swarm Optimization	PSO	✓	-
Catay (2010)	Saving Based Ant Algorithm	SBAA	✓	-
Jun and Kim (2012)	Nearest Sweep with Perturbation	NSP	✓	-

4.4 Container throughput estimation

In the literature, numerous studies have been undertaken on the network design of shipping lines. In these studies authors presented alternative solution models for container shipping lines in order to determine the optimal routing, ship size, and sailing frequency by minimizing shipping costs under fixed demand pattern without considering seasonal demand fluctuations which does not reflect the reality of container shipping network design.

Since the mid-1950s, forecasting accurate container throughput demands of ports is one of the major dream of all port economists (Goulielmos and Kaselimi 2011). Because of the fact that accurately predicting the conditions effect on liner shipping is almost impossible, making reliably forecasts ended with certainty is nearly impossible. But that does not mean forecasting is pointless. The aim of forecasting is not to estimate

Table 4.4: Container throughput forecasting related studies

Authors (Years)	Proposed Methodology	Comparison Methodologies	Case Area
Walter and Younger (1988)	Iterative Nonlinear Programming		New design
de Gooijer and Klein (1989)	One Vector Autoregressive moving average	One-variable Auto Regression Integrated Moving Average	Antwerp
Zohil and Prijon (1999)	Ordinary least squares regression		Mediterranean ports
Fung (2001)	Vector Error Correction Model with Structural Identification		Hong Kong
Seabrooke et al. (2003)	Ordinary least squares regression		Hong Kong
Mostafa (2004)	Multilayer Perception Neural Network	Auto Regression Integrated Moving Average	Suez Canal
Lam et al. (2004)	Multilayer Perception Neural Network	Linear Multiple Regression	Hong Kong
Hui et al. (2004)	Error Correction Model Approach		Hong Kong
Guo et al. (2005)	The grey Verhulst model	Grey Model (1,1)	
Liu et al. (2007)	Grey Prediction Model and Cubic Polynomial Curve Prediction Model mixed by the Radial Basis Function Neural Network	Radial Basis Function Neural Network With Grey Prediction Model, Radial Basis Function Neural Network With Cubic Polynomial Curve Prediction Model	Shanghai
Mak and Yang (2007)	Approximate Least Squares Support Vector Machine	Support Vector Machine, Least Squares Support Vector Machine, Radial Basis Function Neural Network	Hong Kong
Hwang et al. (2007)	Neuro-Fuzzy Group Method Data Handling Type Neural Networks	Conventional Multilayered Group Method Data Handling Type Neural Networks	Busan
Schulze and Prinz (2009)	Seasonal Auto-Regressive Integrated Moving Average	Holt–Winters Exponential Smoothing	Germany
Peng and Chu (2009)	The classical decomposition model,	The trigonometric regression model, The regression model with seasonal dummy variables, The grey model, The hybrid grey model, The SARIMA model	Taiwan
Gosasang et al. (2011)	Multilayer Perception Neural Network	Linear Regression	Bangkok
Sun (2010)	Conditional Expectation with Probability Distribution		Shandong
Chen and Chen (2010)	Genetic Programming	X-11 Decomposition Approach, Seasonal Auto Regression Integrated Moving Average	Taiwan
Wu and Pan (2010)	Support Vector Machine with Game Theory		Jiujiang
Li and Xu (2011)	Prediction Based on Optimal Combined Forecasting Model	Cubic exponential smoothing, GM (1,1), Multiple regression analysis	Shanghai
Goulielmos and Kaselimi (2011)	The Non-Linear Radial Basis Functions		Piraeus
Zhang and Cui (2011)	Elman neural network		Shanghai
Polat et al. (2011)	Monte Carlo Simulation with Holt–Winters Exponential Smoothing		Turkey
Xiao et al. (2012)	Feed forward neural network is developed based on the improved particle swarm optimization with adaptive genetic operator		Tianjin

accurately, it try to help decision-makers to understand the future by reducing uncertainty by exploring the current information. Therefore, forecasting container throughputs of ports is playing a critical role in the planning decisions of liner shipping lines.

Since liner shipping involves considerable capital investments and huge daily operating costs, the appropriate liner shipping feeder service network design will affect the development of the feeder shipping lines. In practice, forecasting container throughput demands of ports is anywise important for all planning level decisions of feeder service which are defined in Section 3.7. Table 4.4 summarizes some related studies on container throughput forecasting and highlights the methodologies and case studies used in the related papers.

All these works produced good results under low uncertainty conditions. However, the 2008 crisis showed that deterministic forecasts may be prone to failure in the long term (Pallis and de Langen 2010). More realistic stochastic forecasting methods, which could face uncertainty are not preferred in many practical applications, because of their complexity and high statistical data requirement (Khashei et al. 2009). Recently, Wang et al. (2013a) proposed a linear programming model to estimate capacity utilization of an already sequenced liner ship route with a bounded polyhedral container shipment demand pattern, but without considering seasonality.

On the other hand, simulation could be used to assist with constructing a forecasting frame by using deterministic forecasting methods that only need a limited amount of data. Therefore, in this study, a simulation and artificial neural networks based forecasting framework is developed in order to analyze the impact of seasonal demand fluctuation on the liner shipping feeder service network design (Section 6.2).

4.5 Liner shipping under unstable demand environments

The above literature review clearly shows that container demand uncertainty and seasonality are not well addressed by the liner shipping network design studies. Therefore, it is important to integrate them into the liner shipping network design problem in view of their importance in reflecting the reality. Liner shipping providers have to deal with some uncertain and seasonal factors like the real transportation time between two ports, demand and supply patterns, necessary number and sizes of ships, and the available capacity of vessels for repositioning empty containers, etc. (see Section 3.6). For instance, Chuang et al. (2010) developed a Fuzzy Genetic Algorithm approach to define sequence of ports for a containership in a region. The authors solved a case study with 5 ports to maximize the total profit from the ports without considering ship capacity by allowing declining low profit ports. The proposed fuzzy sets provide demand fluctuation, but not seasonality.

Since the beginning of containerization, empty container repositioning has been an on-going issue in the maritime transportation industry. There are several studies that take into account the uncertain nature of empty container demand parameters in already designed liner shipping networks. In an early work, Cheung and Chen (1998) proposed a two-stage stochastic model by considering the uncertainties in container demands and vessel capacity and their impact on empty container repositioning. Leung and Wu (2004) developed a multi-scenario time-extended optimization model with stochastic demands to dispatch empty containers from the Middle East to various export ports in the Far East region and reposition surplus empty containers from any port to shortage ports. Feng and Chang (2008) addressed the empty container reposition planning model by plainly considering safety stock management. The authors considered the model as a two-stage problem. The first stage was used to estimate the empty container stock at each port and the second stage reflected the empty container reposition problem in an already designed liner shipping network of a Taiwanese liner shipping provider.

Song and Dong (2008) considered the empty container repositioning problem in a dynamic and stochastic situation by minimizing the expected total costs consisting of inventory holding costs, demand lost-sale costs, lifting-on and lifting-off charges, and container transportation costs in an already designed network. Performance of a non-repositioning policy and three other heuristic policies were compared by using a simulation model. Later, Dong and Song (2009) evaluated container fleet sizing problems in already designed MPC route designs with empty container repositioning under uncertain and imbalanced customer demands which are reflected with uniform and normal distributions. In order to minimize total network costs, authors formulated a mathematical model for the problem, proposed a genetic algorithm approach to solve the problem. They solved problems with a transpacific shipping service which contains 3 ports and 4 vessels with a 22 month period and a Europe-Asia shipping service which contains 10 ports and 8 vessels for a 20 month period. Wang and Tang (2010) proposed a chance-constrained programming model to maximize the profit of a shipping company under uncertain heavy and empty container demands. The authors converted the chance-constrained programming model to an integer programming model and solved case studies by using Lingo solver.

Long et al. (2012) formulated a two-stage stochastic programming model with random demand, supply, ship weight capacity, and ship space capacity in order to include uncertainties in the operations model by minimizing the expected operational costs for empty container repositioning. The authors applied sample average approximation method to approximate the expected cost function with heuristic algorithms based on the progressive hedging strategy. Francesco et al. (2009) handled an empty container repositioning problem by considering demand fluctuations. The authors proposed a time-extended multi-scenario stochastic optimization model where historical data were useless for decision-making processes. Later, Francesco et al. (2013) generalized the empty container repositioning problem of Francesco et al. (2009) by considering possible port disruptions in an already designed service network.

Some recent studies deal with scheduling containerships in already designed liner shipping networks by considering the uncertain nature of ports. Qi and Song (2012) consider the problem of designing an optimal vessel schedule in an already designed liner shipping route to minimize the total expected fuel consumption and emissions by considering uncertain port times and frequency requirements. The authors mathematically formulated and solved a trans-Pacific container shipping service case study with eight ports and nine port-of-calls with simulation-based stochastic approximation methods. Wang and Meng (2012b) considered problems with liner ship schedule designs which aim to determine the arrival time of all ships at ports by considering the sailing speed function on each route and uncertainties at sea and port. The authors proposed a mixed-integer non-linear stochastic programming model to minimize the ship costs and expected bunker costs. A case study of an already designed Asia-Europe-Oceania shipping network with 46 ports, 11 ship routes and three types of ships was solved with the model. Wang and Meng (2012c) considered robust scheduling for liner services by including uncertain wait time due to port congestion and uncertain container handling time. This problem is formulated as a mixed-integer nonlinear stochastic programming model which recovers disruptions in the schedule recovery with fast steaming by keeping predetermined port sequence. The authors proposed a hybrid solution algorithm which integrates a sample average approximation method, linearization techniques, and decomposition scheme and solved a case study from an Asia-Europe-Oceania shipping service.

The operating efficiency of shipping networks also depends on appropriate slot allocation of containerships. Determination of slot allocations to ports under uncertain demand environment is another recent research area in liner shipping design. Lu et al. (2010) proposed an integer programming model for slot allocation planning problems of shipping lines with homogenous ships for satisfying seasonal demands. The authors solved a real case study from Eastern Asia for a liner shipping service network with 12 ports, 16 sailing legs and deployed 4 containerships with 1445 TEUs capacity. The proposed model works under already forecasted seasonal demands for an already designed network but does not account for demand fluctuations. Zeng et al. (2010) proposed a deterministic model to optimize the resource allocation for container lines considering ship size, container deployment, and slot allocation for shipping lines based on the equilibrium principle. The authors then converted the deterministic model to a robust optimization model which simultaneously considers demand uncertainty, model robustness, and risk preference of the decision maker. Zurheide and Fischer (2011, 2012) developed a simulation model for accepting or rejecting decisions of container bookings by including a quantitative slot allocation model with customer segmentations, the service network structure, and transshipment possibilities to maximize net profit of the provider under different demand scenarios, networks, and input settings.

Containership fleet deployment is a key issue in the liner shipping industry. A number of recent studies considered fleet deployment in already designed service networks by considering uncertain demand patterns. Ng and Kee (2008) evaluated optimal containership size of shuttle feeder services by using economic and simulation models in Southeast Asia from the perspective of carriers. The authors pointed out that none of the forecasted container demands of different ports which did not include seasonality and demand fluctuation were unable to fulfill the simulated optimal ship sizes according to the opinions of interviewees. Meng and Wang (2010) and Meng et al. (2011) proposed a chance constrained programming model for short-term liner ship fleet planning to minimize total network cost. The proposed model aims to determine fleet size, mix, deployment and frequency on predetermined routes by considering cruising speed. The authors converted the chance constrained programming model to a mixed integer liner programming model and solved case studies from an Asia-Europe-Oceania shipping service by using CPLEX. The shipment demands between ports are fluctuated by using normal distribution. Later, Meng et al. (2012) considered the same problem by taking into account container transshipment operations. The authors proposed a two-stage stochastic integer programming model and a solution algorithm by integrating the sample average approximation with a dual decomposition and Lagrangian relaxation approach. Recently, Wang et al. (2012) developed a robust optimization model for the related problem to maximize total profit under different container demand scenarios. Dong and Song (2012) evaluated containership fleet sizing problem by simultaneously considering uncertain customer demands and stochastic inland transport times in an already designed service network. The authors proposed a mathematical formulation for the problem and solved the case studies from trans-Pacific and Europe–Asia services with the help of simulation-optimization approaches.

In the dynamic liner shipping literature, considerable attention has been given to sequencing of ports, repositioning empty containers, determination of slot allocations, scheduling of ships, and deploying fleets in already designed service networks by using demand fluctuations. In addition to these studies, several papers considered these problems under seasonal demand patterns.

Chen and Zeng (2010) proposed a mixed integer non-linear programming model to maximize the average unit ship-slot profit with a homogenous ship fleet under seasonally changing demand and freight rates. The proposed model selects cyclic port sequence from a number of candidate ports by declining low profit ports and allocates slots to selected ports. The authors solved a case study from Far East Asia with 10 candidate ports under average annual and bi-monthly seasonal demand and freight rates by using a developed bi-level genetic algorithm approach and compared results. Their results show that designing slot allocations under changing demand and freight rates could increase maximal total profit 1.41 times and could decrease necessary average slot capacity 0.31 times. Please note that the authors used fixed ship size for the whole year in both seasonal and annual demand patterns, but allocated slot capacities to ports change depending on seasons.

Meng and Wang (2012) considered fleet deployment and container routing problem in an already designed liner shipping network with transshipment operations by including week dependent origin to destination container demands and maximum allowed transit time durations. The authors firstly created all possible origin to destination paths by using the space–time network approach subject to the transit time constraints in priori dependent routes. Then by using a mixed integer liner programming model, the optimal ships were assigned to ship routes and containers were assigned to paths by considering week dependent demands in order to minimize total cost while fulfilling the containership demand. Relaxation models were provided in order to solve the case studies from an Asia-Europe-Oceania shipping network consisting of 46 ports and 12 routes with 3 candidate ship types for a 26 week planning horizon. Please note that the authors deployed ships using fixed ship size for the whole year under weekly demand pattern, but allocated containers of different origin to destination paths according to seasons.

As is mentioned by Meng and Wang (2012), existing studies in the liner shipping literature designed liner shipping service networks under fixed demand patterns without considering seasonal demand fluctuations which does not reflect the reality of liner shipping network design. On the other hand, the studies considering demand fluctuations and seasonality evaluate specific problems such as slot allocation, empty container repositioning, ship scheduling, and fleet deployment under already designed service networks. In this study, we propose a mixed-integer linear programming model to simultaneously determine the fleet size and mix, fleet deployment, ship routing and ship scheduling in H&S service network design by minimizing total network costs under seasonal demand fluctuations in a sailing season (Section 5.4). A simulation-optimization based solution framework which contains a hybrid solution heuristic called Adaptive Neighborhood Search (Section 6.1) and a simulation and artificial neural networks based forecasting model (Section 6.2) is proposed to solve the joint problem by using a liner shipping feeder service case study from the Black Sea region (Section 7.4).

Notable influences of this study to liner shipping literature are fourfold. First, it contributes to the literature by developing a realistic liner shipping network design problem under seasonal demand fluctuations. Second, a mixed integer programming model is developed for the proposed liner shipping network design problem. Third, a forecasting model is constructed for estimation of ports under limited historical information. Fourth, a simulation optimization framework is developed to help decision makers in evaluating their strategic and tactical level service network decisions.

5. The Feeder Service Network Design Problems

The Feeder Service Network Design (FND) problem is mathematically modeled in four parts in this chapter. While Section 5.1 handles the problem in aspects of vehicle routing problem, Section 5.2 handles the problem as feeder containership routing problem. Section 5.3 handles the basic FND problem for a stable sailing horizon for reducing the total transportation cost and Section 5.4 approaches the problem more realistically by considering varying forecasted throughput demands for a dynamic sailing season and vessel charter operations.

5.1 The vehicle routing problem with simultaneous pickup and delivery with time limit

The problem considered in this study is designing the network of service vehicles, i.e. simultaneously dispatching/collecting cargo parcels from a central post station to/from regional post stations via trucks, simultaneously dispatching/collecting containers from a hub port to/from feeder ports via containerships, simultaneously dispatching/collecting passengers from a continental center airport to/from national airports via airplanes, etc.

In this context, the vehicle routing problem with simultaneous pickup and delivery with time limit (VRPSPDTL) a variant of Vehicle Routing Problem (VRP) can be stated as follows: A set of clients is located on a distribution network where clients require both delivery and pickup operations. Each client has to be served once for both operations with a given fleet of identical capacitated vehicles. Each vehicle leaves the central depot carrying the total amount of goods that it has to deliver and returns to the central depot carrying the total amount of goods that it must pick-up. Each client also has a specified service time which is the loading and unloading operation time of the vehicle at the client. Therefore, the voyage time of a vehicle is the sum of total travel time of the route and total service time of the clients. In order to determine the vehicle schedules and the staffing balance, each vehicle has to finish its voyage before the maximal allowed duration is reached.

This problem can be classified by using the notation offered by Berbeglia et al. (2007). They used a tuple notation of $[Structure\,|Visits|Vehicles]$ for PDP. In this notation, *structure* represents the number of origins and destinations of goods, *visits* represents information on the way pickup and delivery operations are performed at clients, *vehicles* represents the number of vehicles used in the problem. In this content, the VRPSPD is stated as $[1-M-1\,|\,PD\,|\,m]$; where $1-M-1$ shows one-to-many-to-one problems, goods are initially available at the depot and are transported to clients, and goods available at the clients are transported to the depot; PD represents each client being exactly once for a combined pickup and a delivery operation; m represents that the solutions could contain more than one vehicle (multi vehicle).

A mixed-integer linear programming (MILP) formulation for the VRPSPDTL has been presented with the following notation by extending VRPSPD formulation of (Montane and Galvao 2006):

Indices:

$i, j \in N$	the set of clients (0 represents the depot)
$k \in K$	the set of vehicles ($\lvert K\rvert < \lvert N\rvert$)

Parameters:

R	Maximum allowed voyage duration of vehicles
Q	maximum loading capacity of a vehicle
v	average travel speed of a vehicle
c_{ij}	distance between client i and j
s_i	service time at client i
d_i	delivery goods demand of client i
p_i	pick-up goods demand of client i

Decision variables:

x_{ij}^{k}	1, if the arc (i, j) belongs to the route served by vehicle k; 0, otherwise.
y_{ij}	pick-up goods transported on arc (i, j)
z_{ij}	delivery goods transported on arc (i, j)

The model formulation is given as follows:

$$min\sum_{k\in K}\sum_{i\in N}\sum_{j\in N}c_{ij}x_{ij}^{k} \tag{5.1}$$

s.t.

$$\sum_{i\in N}\sum_{k\in K}x_{ij}^{k}=1, \quad \forall \mathrm{j}\in \mathrm{N}/\{0\} \tag{5.2}$$

$$\sum_{i\in N}x_{ij}^{k}-\sum_{i\in N}x_{ji}^{k}=0, \quad \forall \mathrm{j}\in \mathrm{N}, \mathrm{k}\in K \tag{5.3}$$

$$\sum_{j\in N/\{0\}}x_{0j}^{k}\le 1, \quad \forall k\in K \tag{5.4}$$

$$\sum_{i\in N/\{0\}}x_{i0}^{k}\le 1, \quad \forall k\in K \tag{5.5}$$

$$\sum_{i\in N}y_{ji}-\sum_{i\in N}y_{ij}=p_{j}, \quad \forall j\in N/\{0\} \tag{5.6}$$

$$\sum_{i\in N}z_{ij}-\sum_{i\in N}z_{ji}=d_{j}, \quad \forall j\in N/\{0\} \tag{5.7}$$

$$y_{ij}+z_{ij}\le Qx_{ij}^{k}, \quad \forall i, \mathrm{j}\in \mathrm{N}, \mathrm{k}\in K \tag{5.8}$$

$$\sum_{i\in N}\sum_{j\in N}\frac{c_{ij}}{v}x_{ij}^{k}+\sum_{i\in N/\{0\}}\sum_{j\in N}s_{i}x_{ij}^{k}\le R, \quad \forall k\in K \tag{5.9}$$

$$\sum_{i\in B}\sum_{j\in B}x_{ij}^{k}\le |B|-1 \quad \forall k\in K, B\in N/0, B\ge 2 \tag{5.10}$$

$$x_{ij}^{k}\in\{0,1\}, y_{ij}\ge 0, z_{ij}\ge 0, \quad \forall i, j\in N, k\in K \tag{5.11}$$

The objective function (5.1) aims to minimize the total travelled distance. Equation (5.2) ensures that each client is served by only one vehicle; equation (5.3) guarantees that the same vehicle arrives at and departs from each client. Restrictions (5.4) and (5.5) ensure usage of maximum K vehicles. Equations (5.6) and (5.7) satisfy pick-up and delivery demands of the clients, respectively. Restrictions (5.8) are the vehicle capacity constraint; restrictions (5.9) represent the maximum voyage duration constraint. (5.10) are the vehicle sub-tour elimination constraints according to Karlaftis et al. (2009). Finally, constraints (5.11) define the variable domains. In general, the constraints ensure that each vehicle departs from the central depot with a load equivalent to the total delivery goods and each vehicle arrives at the central depot with a load equivalent to the total pick-up goods from clients in the route served by that vehicle (See Section 7.1 for the implementation of the model).

5.2 The feeder containership routing problem

A similar problem is handled by Karlafits et al. (2009) as a feeder containership routing problem (FCRP) between Aegean Island feeder ports and Greek mainland hub port. In this context, a set of feeder ports is located on a distribution network where feeder ports require both delivery and pickup container operations. Each feeder port has to be served once for both operations with a given fleet of identical capacitated containerships. Each ship leaves the regional hub port carrying the total amount of container it has to deliver and returns to the hub port carrying the total amount of containers it must pick-up. However, while VRPSPDTL has to finish its voyage before the maximal allowed duration, FCRP aims to deliver its delivery containers before predefined time deadlines (Karlaftis et al. 2009). Since maritime transportation and feeder port operations are highly influenced by weather conditions, FCRP uses this time deadline as soft time limit constraint. Contrary to VRPSPDTL, the routes could violate this time deadlines, however such routes are penalized some percent of the delays. Moreover, unlike the classical vehicle routing problems, FCRP aims to minimize overall container voyage time.

According to the definitions above, a mixed integer linear programming (MILP) formulation for the FCRP could be represented with the following notation:

Indices:

$i, j \in N$	the set of ports (0 represents the hub port)
$k \in K$	the set of containerships ($\lvert K \rvert < \lvert N \rvert$)

Parameters:

L	Service deadline time for feeder ports
Q	maximum loading capacity of a containership
v	average travel speed of a containership
c_{ij}	distance between port i and j
s_i	service time at feeder port i

d_i delivery container demand of feeder port i

p_i pick-up goods demand of feeder port i

α percentage indicating total time penalty for delays

Decision variables:

x_{ij}^k 1, if the arc (i,j) belongs to the route served by containership k; 0, otherwise.

y_{ij} pick-up containers transported on arc (i,j)

z_{ij} delivery containers transported on arc (i,j)

d_j^k Delay in reaching feeder port j for containership k

The model formulation is given as follows:

$$min \sum_{k\in K}\sum_{i\in N}\sum_{j\in N}\frac{c_{ij}}{v}x_{ij}^k + \sum_{i\in N\{0\}} s_i + \alpha\sum_{k\in K}\sum_{j\in N\{0\}} d_j^k \tag{5.12}$$

s.t.

$$\sum_{i\in N}\sum_{k\in K} x_{ij}^k = 1, \qquad \forall \mathrm{j}\in \mathrm{N}/\{0\} \tag{5.13}$$

$$\sum_{i\in N} x_{ij}^k - \sum_{i\in N} x_{ji}^k = 0, \qquad \forall \mathrm{j}\in \mathrm{N}, \mathrm{k}\in K \tag{5.14}$$

$$\sum_{j\in N/\{0\}} x_{0j}^k \le 1, \qquad \forall k\in K \tag{5.15}$$

$$\sum_{i\in N/\{0\}} x_{i0}^k \le 1, \qquad \forall k\in K \tag{5.16}$$

$$\sum_{i\in N} y_{ji} - \sum_{i\in N} y_{ij} = p_j, \qquad \forall j\in N/\{0\} \tag{5.17}$$

$$\sum_{i\in N} z_{ij} - \sum_{i\in N} z_{ji} = d_j, \qquad \forall j\in N/\{0\} \tag{5.18}$$

$$y_{ij} + z_{ij} \le Q x_{ij}^k, \qquad \forall i, \mathrm{j}\in \mathrm{N}, \mathrm{k}\in K \tag{5.19}$$

$$\sum_{i\in N}\sum_{j\in N/\{0\}}\frac{c_{ij}}{v}x_{ij}^k + \sum_{i\in N/\{0\}}\sum_{j\in N} s_i x_{ij}^k \le R, \qquad \forall k\in K \tag{5.20}$$

$$L - \sum_{i \in N} \sum_{j \in N/\{0\}} \frac{c_{ij}}{v} x_{ij}^k = d_j^k, \qquad \forall \mathrm{j} \in \mathrm{N}, \mathrm{k} \in K \tag{5.21}$$

$$\sum_{i \in B} \sum_{j \in B} x_{ij}^k \leq |B| - 1 \qquad \forall k \in K, B \in N / 0, B \geq 2 \tag{5.22}$$

$$x_{ij}^k \in \{0,1\}, y_{ij} \geq 0, z_{ij} \geq 0, d_j^k \geq 0, \qquad \forall i, j \in N, k \in K \tag{5.23}$$

The objective function (5.12) aims to minimize the sum value of total voyage duration (route duration + service time) and penalty of total delay. Equation (5.13) ensures that each feeder port is served by only one ship; equation (5.14) guarantees that the same ship arrives at and departs from each feeder port. Restrictions (5.15) and (5.16) ensure usage of maximum K ships. Equations (5.17) and (5.18) satisfy pick-up and delivery container demands of the feeder ports, respectively. Restrictions (5.19) are the vehicle capacity constraint; restrictions (5.20) represent service time deadline constraint. Equation (5.21) gives time delays of the ships to feeder ports. (5.22) are the vehicle subtour elimination constraints. Finally, constraints (5.23) define the variable domains. In general, the constraints ensure that each ship departs from the hub port with a load equivalent to the total delivery containers and each ship arrives at the hub port with a load equivalent to the total pick-up containers from feeder ports in the route served by that ship (See Section 7.2 for implementation of the model).

5.3 Feeder service network design problem

However, so far none of the feeder service network design studies has considered detailed variable and fixed cost structures for a heterogeneous vessel fleet over a complete sailing horizon. In this study, we propose a mixed-integer linear programming model to simultaneously determine the fleet size and mix, fleet deployment, ship routing and ship scheduling in feeder service network design by minimizing total network costs in a sailing season.

In a feeder network, ships visit a number of ports along the predefined routes connecting ports in the region. In the design of the feeder network, service factors such as the capacity of feeder ships, characteristics of the ports, container demand volume at the various ports as well as bunker costs and operating and chartering costs of the ships have to be considered. Specifically, the feeder network design problem (FND) can be described as follows. A set of feeder ports is located on a distribution network where feeder ports require both delivery and pickup operations. Each feeder port has to be served once for both operations with a given fleet of capacitated heterogeneous feeder ships. Each ship leaves the hub port carrying the total amount of containers it has to deliver and returns to the hub port carrying the total amount of containers picked up on the voyage. Each feeder or hub port also has a specific operation efficiency for loading and unloading containers. The service time of the ports depends on the port operation efficiency, ship size, the number of loaded and unloaded containers and the pilotage time for entering and exiting the port. Therefore, the total voyage duration of a ship consists of the total travel time of the route and the total service time at the hub and the feeder ports. The voyage starts in the hub port with commencing the loading operations to ships and completing the unloading operations from ships at the hub port. Each vessel has to finish its voyage before the allowed time deadline is reached. Before starting a new voyage, the ship needs a lay-up interval for repair, cleaning, waste disposal etc.

According to these considerations the FND problem has similarities with the *"vehicle routing problem with simultaneous pick-up and delivery with time limit"* (VRPSPDTL). For a review and classifications of vehicle routing problems, see e.g. Berbeglia *et al* (2007) and Parragh *et al* (2008). While the VRPSPDTL aims to minimize total voyage distance and FCRP aims to minimize total voyage duration, the FND problem aims to serve all contracted feeder ports by minimizing total operational costs for a sailing season. For a feeder network provider, operational costs of the planning period include containership related fixed costs for the necessary number of ships (chartering, operating etc.) and total service related variable costs (on-sea bunker cost, on-port bunker cost, port set-up charges). Table 5.1 shows the related basic cost calculations.

Table 5.1: Basic calculations of total costs for a sailing season

Parameter	Basic calculation
Total costs	*Fixed costs + Variable costs*
Fixed costs	*Number of necessary ships ∗ (Chartering + Operating costs)*
Variable costs	*Number of services * (Bunker (sea) + Bunker (port) + Port set up charges)*
Number of required ships	⌈*(Voyage duration + Lay up duration)* / *Service frequency*⌉
Number of services	⌈*Planning period / Service frequency*⌉
Voyage duration	*On-sea duration + On-port duration (feeder) + On-port duration (hub)*
Idle duration	*Number of necessary ships ∗ Service frequency - (Voyage + Lay-up duration)*
Ship total duration	*Voyage duration + Lay up duration + Idle duration*

Since our investigation is concerned with the design of a real world container feeder network, some assumptions have to be made in order to exclude elements of minor relevance and to focus on those aspects that are of paramount interest.

- All parameter values are deterministic, i.e. we exclude weather and seasonal effects, for instance.
- No direct delivery takes place between feeder ports.
- The queue time at ports is not considered.
- Time windows for berthing at a port are disregarded since they are not known in advance for a complete sailing season.
- Demand and supply quantities of feeder ports cannot be split.
- The ships of a certain type are identical regarding their carrying capacity.
- Bunker costs are the same in all ports.
- We only consider chartered ships.
- Set-up durations (pilotage, berthing, cleaning etc.) of a port only depend on the type of ship.
- Effects of speed dependent fuel costs as well as straight/canal durations and costs are not considered.

A mixed-integer linear programming (MILP) formulation of the FND problem is presented using the following notation:

<u>Indices & sets</u>

$i, j \in N$	The set of ports (0 represents the hub port)
$s \in S$	The set of containership types
$(i, j) \in L$	The set of allowed voyage legs between ports
$r \in R$	The set of routes ($\lvert R \rvert < \lvert N \rvert$)

<u>Parameters</u>

f	Service frequency	days
γ	Number of services in a sailing season	
D	Sailing season duration	days

K	Maximum allowed voyage duration	hours
v_i^s	Vessel set-up duration of ship type s in port i (pilotage, berthing, cleaning etc.)	hours
u^s	Lay-up duration of ship type s	Hours
m^s	Available number of containerships of ship type s	ships
q^s	Loading capacity of ship type s	TEU
h^s	Average travel speed of ship type s	n.mile/hour
o_i^s	Operation efficiency of port i for ship type s	TEU/hour
w_{ij}	Distance between ports i and j	n.mile
t_i^s	Berthing duration of ship s at port i	Hours
d_i	Daily container demand (delivery) of port i	TEU
p_i	Daily container supply (pick-up) of port i	TEU
α	Main fuel oil price	\$/ton
β	Auxiliary fuel oil price (distillate)	\$/ton
cc^s	Chartering cost of ship type s	\$/ship
fc^s	Operating cost of ship s (administration, maintenance, lubricant, insurance etc.)	\$/ship
a^s	Main fuel consumption of ship type s on sea	ton/n.mile
b^s	Auxiliary fuel consumption of ship type s at berth	ton/hours
bc_i^s	Vessel set-up cost of ship type s at port i	\$/ship

Decision variables

x_{ij}^{rs}	1, if the arc between ports i and j belongs to route r served by ship type s (0, otherwise)	Binary
y_{ij}	containers picked up from ports up to port i and transported from port i to j	Integer
z_{ij}	containers to be delivered to ports routed after port i and transported between port i and j	Integer
e^{rs}	Required number of ships of type s on route r	Ships
c^{rs}	Voyage cycle time of route r with ship type s	Hours
FC	Total fixed costs of a sailing season	\$

VC	Total variable costs of a sailing season	$

The MILP model formulation is given as follows:

$$\min FC + VC \tag{5.24}$$

s.t.

$$FC = \sum_{r \in R} \sum_{s \in S} \left(cc^s + fc^s \right) \cdot e^{rs} \tag{5.25}$$

$$VC = \left(\sum_{i \in N} \sum_{j \in N} \sum_{r \in R} \sum_{s \in S} w_{ij} \cdot a^s \cdot \alpha \cdot x_{ij}^{rs} + \sum_{i \in N} \sum_{s \in S} t_i^s \cdot b^s \cdot \beta + \sum_{i \in N} \sum_{j \in N/\{0\}} \sum_{r \in R} \sum_{s \in S} bc_i^s \cdot x_{ij}^{rs} \right) \cdot \gamma$$

$$with \quad \gamma = \left\lceil \frac{\mathrm{D}}{f} \right\rceil \quad and \quad t_i^s = \frac{\left(p_i + d_i \right) \cdot f}{o_i^s} \tag{5.26}$$

$$\frac{c^{rs} + u^s}{f} \le e^{rs} \qquad \forall r \in R, \mathrm{s} \in S \tag{5.27}$$

$$c^{rs} = \sum_{i \in N} \sum_{j \in N} \left(t_i^s + v_i^s + \frac{w_{ij}}{h^s} \right) \cdot x_{ij}^{rs} \qquad \forall r \in R, \mathrm{s} \in S \tag{5.28}$$

$$\sum_{i \in N} \sum_{r \in R} \sum_{s \in S} x_{ij}^{rs} = 1 \qquad \forall j \in \mathrm{N} / \{0\} \tag{5.29}$$

$$\sum_{i \in N} x_{ij}^{rs} - \sum_{i \in N} x_{ji}^{rs} = 0 \qquad \forall j \in \mathrm{N}, r \in R, \mathrm{s} \in S \tag{5.30}$$

$$\sum_{j \in N/\{0\}} x_{0j}^{rs} \le 1 \qquad \forall r \in R, s \in S \tag{5.31}$$

$$\sum_{i \in N/\{0\}} x_{i0}^{rs} \le 1 \qquad \forall r \in R, s \in S \tag{5.32}$$

$$\sum_{i \in B} \sum_{j \in B} x_{ij}^{rs} \le |B| - 1 \qquad \forall r \in r, s \in S, B \in N / 0, B \ge 2 \tag{5.33}$$

$$\sum_{i \in N} \sum_{j \in N} \sum_{r \in R} x_{ij}^{rs} \le m^s \qquad \forall s \in S \tag{5.34}$$

$$\sum_{i \in N} y_{ji} - \sum_{i \in N} y_{ij} = p_j \cdot f \qquad \forall j \in N \tag{5.35}$$

$$\sum_{i \in N} z_{ij} - \sum_{i \in N} z_{ji} = d_j \cdot f \qquad \forall \mathrm{j} \in N \tag{5.36}$$

$$y_{ij} + z_{ij} \le q^s \cdot x_{ij}^{rs} \qquad \forall i, j \in N, r \in R, s \in S \tag{5.37}$$

$$c^{rs} \leq K \qquad \forall r \in R, s \in S \tag{5.38}$$

$$x_{ij}^{rs} \in \{0,1\}, \quad y_{ij}, z_{ij}, e^{rs} \in \square^{+}, \quad c^{rs} \geq 0 \qquad \forall i, j \in N, (i, j) \in L, r \in R, s \in S \tag{5.39}$$

The objective function (5.24) minimizes total costs of the network for a sailing season. Equations (5.25) and (5.26) define fixed and variable costs, respectively. The necessary number of ships needed for a full service cycle on each route is calculated in (5.27). Equation (5.28) determines the cycle time of ships on each route (berthing duration + service duration + voyage duration). Equation (5.29) ensures that each feeder port is served by only one type of ship and one route. Equation (5.30) guarantees that a ship arrives at and departs from each feeder port on each route. (5.31) and (5.32) impose a similar condition for the hub port at which the route starts and ends. (5.33) are the vehicle sub-tour elimination constraints according to Karlaftis *et al* (2009). Constraints (5.34) represent an upper bound for the number of ships employed from each type. Equations (5.35) and (5.36) satisfy pick-up and delivery demand of containers at the feeder ports, respectively. (5.37) are the ship capacity constraints. (5.38) represent the maximum voyage duration constraints. Finally, constraints (5.39) define the variable domains. In general, the constraints ensure that each ship departs from the hub with a load equivalent to the total delivery of containers and each ship returns to the hub with a load equivalent to the total pick-up containers from feeder ports in the route served by that ship (See Section 7.3 for implementation of the model).

5.4 Liner shipping network design under unstable demand environments

In most existing studies, liner shipping service networks are presented under the assumption that the container supply and demand of ports is given only as a set of the stable values of sailing season. The studies considering demand seasonality and fluctuations are interested with the problems in already designed networks (see Section 4.5). However, so far none of the liner shipping service studies have considered the effect of seasonal demand fluctuations on the design of service networks over a complete dynamic sailing horizon. In this study, we propose a mixed-integer linear programming model to simultaneously determine the fleet size and mix, fleet deployment, ship routing and ship scheduling in H&S feeder service network design by minimizing total network costs under seasonal demand fluctuations over periods of a sailing season. The proposed model periodically allows changing service network designs, routes, fleet deployments and schedules according to forecasted demand of sailing season periods determined by the decision makers of the liner shipping industries.

The MILP formulation proposed in Section 5.3 is extended by considering unstable demand environments of ports over periods for a sailing season, including the ships on hand, and allowing unnecessary ships to charter out. An extended MILP formulation of the LSND problem is presented using the following notation:

Indices & sets

$i, j \in N$	The set of ports (0 represents the hub port)
$s \in S$	The set of containership types
$(i, j) \in L$	The set of allowed voyage legs between ports
$r \in R$	The set of routes ($\lvert R \rvert < \lvert N \rvert$)
$g \in G$	The set of allowed network change periods

Parameters

f	Service frequency	days
a_g	Duration of period g	days
γ_g	Number of services in period g	
K	Maximum allowed voyage duration	hours
v_i^s	Vessel set-up duration of ship type s in port i (pilotage, berthing, cleaning etc.)	hours
u^s	Lay-up duration of ship type s	Hours
m^s	Available number of containerships of ship type s for charter in	ships
sn^s	On hand number of ship type s	ships
q^s	Loading capacity of ship type s	TEU
h^s	Average travel speed of ship type s	n.mile/hour
o_i^s	Operation efficiency of port i for ship type s	TEU/hour
w_{ij}	Distance between ports i and j	n.mile
t_{gi}^s	Berthing duration of ship s at port i in period g	Hours

d_{gi}	Container demand (delivery) of port i in period g	TEU/days
p_{gi}	Container supply (pick-up) of port i in period g	TEU/days
α	Main fuel oil price	\$/ton
β	Auxiliary fuel oil price (distillate)	\$/ton
cc^s	Charter in cost of ship type s	\$/day
cp^s	Charter out price of ship type s	\$/day
oc^s	Owning cost of ship type s	\$/day
fc^s	Operating cost of ship s (administration, maintenance, lubricant, insurance etc.)	\$/day
mf^s	Main fuel consumption of ship type s on sea	ton/n.mile
af^s	Auxiliary fuel consumption of ship type s at berth	ton/hours
bc_i^s	Vessel set-up cost of ship type s at port i	\$/ship

Decision variables

x_{gij}^{rs}	1, if the arc between ports i and j belongs to route r served by ship type s in period g (0, otherwise)	Binary
y_{gij}	containers picked up from ports up to port i and transported from port i to j in period g	TEU
z_{gij}	containers to be delivered to ports routed after port i and transported between port i and j in period g	TEU
e_g^{rs}	Number of necessary ships from type s on route r in period g	Ships
c_g^{rs}	Voyage cycle time of route r with ship type s in period g	Hours
su_g^{rs}	Number of used owned ships on route r from type s in period g	Ships
co_g^s	Number of charter out ships from type s in period g	Ships
ci_g^{rs}	Number of used charter in ships on route r from type s in period g	Ships
FC	Total fixed costs of a sailing season	\$
VC	Total variable costs of a sailing season	\$

The MILP model formulation is given as follows:

$$\min FC + VC \tag{5.40}$$

s.t.

$$FC = \sum_{r\in R}\sum_{s\in S}\sum_{g\in B}\left(oc^s + fc^s\right)su_g^{rs} + \sum_{r\in R}\sum_{s\in S}\sum_{g\in G}\left(cc^s + fc^s\right)ci_g^{rs} - \sum_{s\in S}\sum_{g\in G} co_g^s cp^s \tag{5.41}$$

$$VC = \sum_{i\in N}\sum_{j\in N}\sum_{r\in R}\sum_{s\in S}\sum_{g\in G}\gamma_g w_{ij} x_{gij}^{rs} mf^s\alpha + \sum_{i\in N}\sum_{s\in S}\sum_{g\in G}\gamma_g t_{gi}^s af^s\beta + \sum_{i\in N}\sum_{j\in N/\{0\}}\sum_{r\in R}\sum_{s\in S}\sum_{g\in G}\gamma_g x_{gij}^{rs} bc_i^s$$

$$with \quad \gamma_g = \left\lceil \frac{\mathrm{a}_g}{f} \right\rceil \quad and \quad t_{gi}^s = \frac{\left(p_{gi} + d_{gi}\right)f}{o_i^s} \tag{5.42}$$

$$\frac{c_g^{rs} + u^s}{f} \le e_g^{rs} \qquad \forall r\in R, s\in S, g\in G \tag{5.43}$$

$$\sum_{i\in N}\sum_{j\in N}\left(t_{gi}^s + v_i^s + \frac{w_{ij}}{h^s}\right)x_{gij}^{rs} = c_g^{rs} \qquad \forall r\in R, s\in S, g\in G \tag{5.44}$$

$$\sum_{i\in N}\sum_{r\in R}\sum_{s\in S} x_{gij}^{rs} = 1 \qquad \forall j\in N/\{0\}, g\in G \tag{5.45}$$

$$\sum_{i\in N} x_{gij}^{rs} - \sum_{i\in N} x_{gji}^{rs} = 0 \qquad \forall j\in N, r\in R, s\in S, g\in G \tag{5.46}$$

$$\sum_{j\in N/\{0\}} x_{g0j}^{rs} \le 1 \qquad \forall r\in R, s\in S, g\in G \tag{5.47}$$

$$\sum_{i\in N/\{0\}} x_{gi0}^{rs} \le 1 \qquad \forall r\in R, s\in S, g\in G \tag{5.48}$$

$$su_g^{rs} + ci_g^{rs} = e_g^{rs} \qquad \forall r\in R, s\in S, g\in G \tag{5.49}$$

$$\sum_{r\in R} su_g^{rs} + co_g^s = sn^s \qquad \forall s\in S, g\in G \tag{5.50}$$

$$\sum_{r\in R} ci_g^{rs} \le m^s \qquad \forall s\in S, g\in G \tag{5.51}$$

$$\sum_{i\in N} y_{gji} - \sum_{i\in N} y_{gij} = p_{gj} f \qquad \forall j\in N, g\in G \tag{5.52}$$

$$\sum_{i\in N} z_{gij} - \sum_{i\in N} z_{gji} = d_{gj} f \qquad \forall j\in N, g\in G \tag{5.53}$$

$$y_{gij} + z_{gij} \le q^s x_{gij}^{rs} \qquad \forall i, j\in N, r\in R, s\in S, g\in G \tag{5.54}$$

$$c_g^{rs} \le K \qquad \forall r\in R, s\in S, g\in G \tag{5.55}$$

$$\sum_{i\in B}\sum_{j\in B} x_{gij}^{rs} \leq |B|-1 \qquad \forall r \in r, s \in S, g \in G, B \in N/0, B \geq 2 \tag{5.56}$$

$$\begin{aligned} & x_{gij}^{rs} \in \{0,1\} \\ & y_{gij}, z_{gij}, e_{g}^{rs}, su_{g}^{rs}, co_{g}^{s}, ci_{g}^{rs} \in \mathbb{R}^{+} \quad \forall i,j \in N, (i,j) \in L, r \in R, s \in S, g \in G \\ & c_{g}^{rs} \geq 0 \end{aligned} \tag{5.57}$$

The objective function (5.40) minimizes total costs of the network for a sailing season. Equations (5.41) and (5.42) calculate fixed and variable costs, respectively. The necessary number of ships needed for a full service cycle on each route is calculated in (5.43). Equation (5.44) calculates the cycle time of ships on each route (berthing duration + service duration + voyage duration). Equation (5.45) ensures that each feeder port is served by only one ship and equation (5.46) guarantees that the same ship arrives at and departs from each feeder port on each route. (5.47) and (5.48) impose a similar condition for the hub port at which the route starts and ends. Equations (5.49) and (5.50) calculate the number of charter in and charter out ships, respectively. Constraints (5.51) represent the maximum number of available charter in ships employed from each type. Equations (5.52) and (5.53) satisfy pick-up and delivery demand of containers at the feeder ports, respectively. Equations (5.54) are the ship capacity constraints. Restrictions (5.55) represent the maximum voyage duration constraint. (5.56) are the vehicle sub-tour elimination constraints. Finally, constraints (5.57) define the variable domains. In general, the constraints ensure that each ship departs from the hub with a load equivalent to the total delivery of containers and each ship returns to the hub with a load equivalent to the total picked-up containers from feeder ports in the route served by that ship.

In this study, the service network is revised at the beginning of every period in response to changes in demand patterns for a season. Changes to the service network may include introducing new routes, and schedules as well as fleet deployments which could contain chartering in new ships or chartering out unnecessary ships. In contrast to trunk liners, feeder service providers have the ability to perform frequent and efficient updates to the schedule and routes with the help of fleet deployments. This study also employs various service scenarios in order to better help decision makers of liner shipping providers. These scenarios contain different periodical season approaches, different demand allocations, different numbers of owned ships at the start of sailing season, different ship owning, chartering, and oil prices to provide a very high degree of flexibility to planning decisions (See Section 7.4 for implementation of the model).

6. The Proposed Solution Methodology

This chapter provides two frameworks for the feeder service network design problems. The first framework (Section 6.1) proposes a novel approach to optimally solve related feeder service network problems and second framework (Section 6.2) provides a simulation based forecasting approach in order to estimate seasonal demand fluctuations in feeder service.

6.1 The adaptive neighborhood search approach

The network design problems presented in the previous section is a highly complex combinatorial optimization problem and thus hard to solve by use of standard optimization software. Exact methods for solving the network design problems are generally not practical for large instances because of the problem complexity. Therefore the model is not intended for solving the mathematical models. In this study, we propose a novel adaptive neighborhood search (ANS) algorithm based on heuristic approaches. The steps of the approach are described in Figure 6.1.

The algorithm applies the Savings Algorithm (SA) in order to gain a fast and effective initial solution. The ANS is embedded with Variable Neighborhood Search (VNS) to improve the initial solution by searching neighborhoods. In order to escape from local optima, an Adaptive Perturbation Mechanism (APM) is developed.

6.1.1 Saving heuristics

The proposed ANS approach applies the Savings Algorithm of Clarke and Wright (1964) in order to gain a fast and effective initial solution. This classic heuristic aims at merging sub-tours based on cost savings which can be achieved by combining two sub-tours to be served by one vehicle (see Figure 6.2). In the literature, some enhancements of the Clarke and Wright savings algorithm have been suggested by adding new terms and parameterizing the savings formula. Since the VRPSPDTL problem is a generalization of the vehicle routing problem (VRP), we construct our initial solution by extending the savings formula proposed for the VRP by Altinel and Öncan (2005).

```
procedure: ANS approach
input: parameters and structures, k_max, m_max, n_max, s_max, p_max
output: π
start
  construct π^0; {construct an initial solution with savings heuristic}
  π^1 ← π^0, p ← 1, s ← 1;
  repeat
    repeat
      k ← 1
      repeat
        π^2 ← π^1_k; {shaking- π^1_k is a random solution in the k^th neighborhood of π^1 , k ∈ N_k }
        if f(π^2) < f(π^1)
          π^1 ← π^2, k ← 1;
        else
          π^3 ← π^2, m ← 1, n ← 1;
          repeat
            repeat
              π^4 ← π^2_m; {local search- π^2_m is a random sol. in the m^th n.hood of π^2 , k ∈ N_m }
              if f(π^4) < f(π^3)
                π^3 ← π^4;
              end
              m ← m + 1;
            until m= m_max
            n ← n + 1, m ← 1;
          until n= n_max
          if f(π^3) < f(π^1)
            π^1 ← π^3, k ← 1;
          else
            k ← k + 1;
          end
        end
      until k= k_max
      if f(π^1) < f(π^0)
        π^0 ← π^1; {move or not -π^0 is current best solution }
        p ← 1, s ← 1;
      else
        s ← s + 1;
      end
    until s= s_max
    π^1 ← π^0_r,;{ APM- π^0_r is a random solution in the random r^th n.hood of π^0 , r ∈ N_r }
    p ← p + 1, s ← 1;
  until p= p_max
π   ← π^0
end
```

* *k-max*: number of shaking structures of VNS; *m-max*: number of local search structures of VNS; *n-max*: number of local search repetition; *s-max*: termination number of ANS; *p-max*: perturbation call number of APM;: *N_k:* the set of shaking neighborhood structures; *N_m:* the set of local search neighborhood structures; *N_r:* the set of perturbation neighborhood structures.

Figure 6.1: Structure of the ANS approach

The savings formula is given in Equation (6.1) where c_{i0} is the distance of customer *i* to the depot, c_{0j} is the distance of the depot to customer *j*, and c_{ij} is the distance between customers *i* and *j*, d_i and d_j are the demand of customer *i* and *j*, $\overline{d}$ is the average demand.

$$S_{ij} = c_{i0} + c_{0j} - \lambda c_{ij} + \mu \left| c_{0i} - c_{j0} \right| + \nu \frac{d_i + d_j}{\bar{d}} \tag{6.1}$$

Here the First positive parameter λ aims to redesign the routes in order to find better solutions. Second positive parameter μ may exploit the asymmetry information between customers i and j regarding their distances to the depot. Third positive parameter ν gives an assignment priority to customers with larger demands (Doyuran and Çatay 2011).

Since this savings function is designed for the VRP, we assume d'_i as maximum value of demand (d_i) and pick-up (p_i) of customer i $\left(d'_i = \max(d_i, p_i)\right)$ in the VRPSPDTL. This assumption converts the VRPSPDTL into the vehicle routing problem with time limit (VRPTL). After an initial solution is constructed with the savings heuristics for the VRPTL, this solution is evaluated with an improvement algorithm according to the VRPSPDTL.

Step 1:	Calculate the savings *s(i, j)* for every pair *(i, j)* of customers.
Step 2:	Rank the savings *s(i, j)* in descending order. This creates the "savings list." Process the savings list beginning with the topmost entry in the list (the largest *s(i, j)*).
Step 3:	For the savings *s(i, j)* under consideration, include link *(i, j)* in the route, if no route constraints (vehicle capacity, route and time limit) will be violated through the inclusion of *(i, j)*, ***and*** if: a) neither *i* nor *j* have already been assigned to a route, in which case a new route is initiated including both *i* and *j*, b) ***or***, exactly ***one*** of the two customers (*i* or *j*) has already been included in an existing route and that customer is not interior to that route in which case the link *(i, j)* is added to that same route, c) ***or, both*** *i* and *j* have already been included in two different existing routes and neither customer is interior to its route, in which case the two routes are merged.
Step 4:	If the savings list *s(i, j)* has not been exhausted, return to Step 3, processing the next entry in the list; otherwise, ***stop***: the solution to the VRPTL consists of the routes created.
Step 5:	Any customer that has not been assigned to a route during Step 3 must be served by a vehicle that begins at the depot visiting the unassigned customer and returning to depot.

Figure 6.2: Structure of construction heuristic (Kulak et al. 2011)

6.1.2 Variable neighborhood search

In the next stage, the initial solution is improved with Enhanced Variable Neighborhood Search (EVNS). The EVNS is an adapted version of the Variable Neighborhood Search (VNS) approach of Mladenović and Hansen (1997). VNS is based on the idea of systematically changing the neighborhoods in order to improve the current solution and aims to explore the solution space which cannot be searched by local search (Hansen et al. 2010). Kytöjokia et al. (2007), Hemmelmayr et al. (2009) and Stenger et al. (2012)

showed the effectiveness of VNS in VRP applications. *Shaking*, *local search* and *move or not* operators are used in the implementation of the VNS. The shaking operator defines the search direction of the VNS by using the set of neighborhoods. The possibility of reaching a global solution increases when combining the shaking operator with local search rather than using a single shaking operator. Therefore, each solution obtained through the shaking operator is used in the local search operator in order to explore new promising neighborhoods of the current solution. In this study we implemented the Variable Neighborhood Descend (VND) algorithm as the local search operator. The VND aims to combine the set of neighborhoods (*m-max*) in a deterministic way, since using more than one neighborhood structure could obtain a better solution. After each shaking operation, the VND algorithm allows *n-max* trials for maximum possible improvement. At the end of the VND algorithm, if there is an improvement, then the shaking operations start from the first operation, if not, the shaking continues with the next operation. After reaching the maximum number of shaking operations (*k-max*), the search continues with the first operation in the new iteration (Hansen and Mladenović 2001).

In this study, a set of neighborhood structures [*3-opt*, *swap*, *insertion*, *2-opt*, *Exchange (m,n)*, *Cross*, *Shift (0,1)*, *Replace (1,1)*] is employed in a deterministic order as shaking and local search operators (Figure 6.3). To avoid redundant moves, only moves under violation acceptance limits are admitted in the shaking operator. The total route duration violation acceptance limit (α_1) is used to allow clients to join another route for possible future improvements. Also the vehicle capacity violation acceptance limit (α_2) is used as the maximum of all pick-up and delivery loads. However, just one of the routes is allowed to use this violation acceptance limit and the travel duration of this route is punished with a huge penalty cost in order to increase the improvement possibility of routes in the local search phase. In the local search phase, only feasible movements are admitted, i.e. those which do not violate the ship capacity and time limit. Also, reverse routes are checked in terms of a capacity violation.

The *3-opt*, *swap*, *insertion* and the *2-opt* are intra-route neighborhood structures defined according to an initial configuration (see Figure 6.3.a below).

The 3-opt, which was introduced by Lin (1965), tries all shifts of some subsequence to different positions in the same route. Specifically, three edges are deleted and replaced by three other edges. The links [1,2] (between customer 1 and 2), [3,4], [5,6] were deleted from route 1 (Figure 6.3.a) and the links [1,4], [5,2] and [3,6] were inserted (Figure 6.3.b).

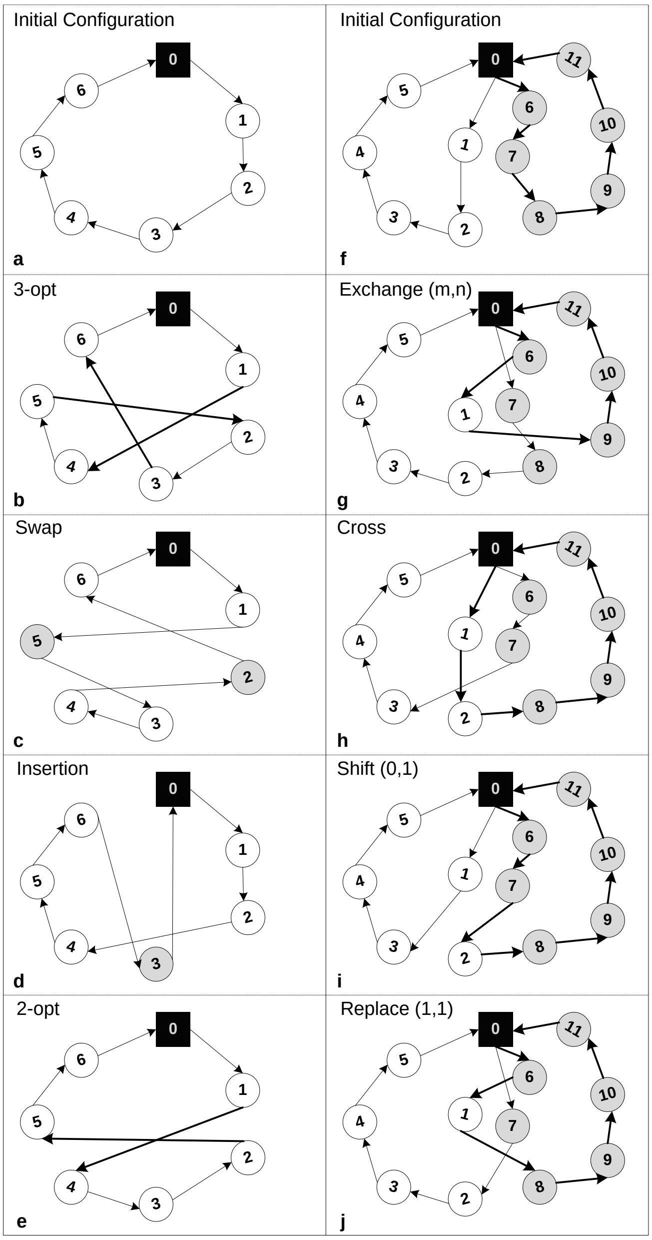


Figure 6.3: Neighborhood structures

The *swap* is a random permutation movement between two customers in the same route. The route order of customer 2 and customer 5 were swapped (Figure 6.3.c.)

Insertion operation selects a customer randomly and inserts it in a random position in the same route. Customer 3 was selected and inserted at the 6th position of the route (Figure 6.3.d)

The *2-opt* heuristic looks for improvements by swapping pairs of links (Croes 1958). Links [1,2] and [4,5] were deleted and links [1,4] and [2,5] were inserted (Figure 6.3.e).

Exchange (m,n), Cross, Shift (0,1) and *Replace (1,1)* are inter-route structures defined according to an initial configuration (see Figure 6.3.f).

Exchange (m,n) structure shown in Figure 6.3.g. is developed according to the idea of Osman (1993). In this figure, *m* sequential customers from one route (route 1) are transferred to another route (route 2) and n sequential customers from route 2 are transferred to route 1. In this study, m is randomly selected between 1 and 5, and n is randomly selected equal to m or one lower.

Cross exchange is a basic crossover structure between routes. In this structure, the link [2,3] from route 1 and the link [7,8] from route 2 are removed. Later, links [2,8] and [7,3] were inserted (Figure 6.3.h).

Shift (0,1) is a random transposition movement of a customer from one route to another. Customer 2 from route 1 was transferred to route 2 (Figure 6.3.i).

Replace (1,1) is a random permutation movement between two customers from different routes. Customer 1 from route 1 is permutated with customer 7 from route 2 (Figure 6.3.j).

In all inter-route neighborhood structures, the route pairs are selected according to the roulette wheel in order to eliminate the number of infeasible exchange operations. In this selection, the center of gravity coordinates of each route is calculated. After one route is randomly selected, the distances between center of this route and the center of other routes are calculated. All distances between the selected route and remaining routes are scaled by a $1/distance^{0.5}$ factor in order to give exchange opportunity to distant routes. Another route is selected from these routes according to principles of roulette wheel method.

6.1.3 Adaptive perturbation mechanism

The temporary solution which is obtained via the shaking and local search operators is compared with the current solution in order to decide whether to *move or not.* In the proposed VNS and VND, the acceptance criterion of the temporary solution accepts only improvements. However, this procedure may cause the search to stuck in a local optimum. Therefore, it is necessary to employ a strategy of accepting non-improving solutions. Perturbation is an effective strategy used to jump out of a local optimum and to search a new promising region. A commonly used perturbation strategy is to destruct the previous local optimum partially in a random way (Subramanian et al. 2010). Another strategy is the destroy-and-repair based perturbation mechanism (Jun and Kim 2012).

The previously obtained local optimum solution combines global statistical information and local information of good individual solutions. In this study, the current solution is there-fore used to develop a novel perturbation method called Adaptive Perturbation Mechanism (APM). This perturbation mechanism runs after a number of non-improving iterations counted from the last improving iteration (*p-max*). In addition to the perturbation move, a local optimization method with the previously defined four intra-route neighborhood structures is applied in order to improve the perturbed solution quality (see Figure 6.4 for the steps of the algorithm).

---

procedure: ANS approach
input: parameters and structures, h_{max} , z_{max} , π^0, AL
output: π^1
start
  $\pi^1 \leftarrow \pi^0 + AL;$
  repeat
    $z \leftarrow 1;$
    $\pi^5 \leftarrow \pi_r^0$; *{perturb- π_r^0 is perturbed with a random perturbation structure r $(r \in N_r)$ }*
    repeat
      $h \leftarrow 1;$
      repeat
        $\pi^6 \leftarrow \pi_h^5$;*{ optimization- π_h^5 is a random sol. in the h th n.hood of $\pi^5, h \in N_h$};*
        if $f(\pi^6) < f(\pi^5)$
          $\pi^5 \leftarrow \pi^6, z \leftarrow 1, h \leftarrow 1, y \leftarrow 1;$
        else
          $h \leftarrow h + 1;$
        end
      until $h = h_{max}$
      $z \leftarrow z + 1;$
    until $z = z_{max}$
    if $f(\pi^5) < AL$
      $\pi^1 \leftarrow \pi^5;$
    end
  until $\pi^1 < AL$
end

---

* *h-max*: number of optimization structures; *z-max*: max number of perturbation method attempts; N_r: the set of perturbation structures; N_h: the set of optimization structures; *AL:* acceptance limit of the route.

Figure 6.4: Structure of APM algorithm

In the APM, a set of perturbation structures [*double replace, double cross, triple shift, triple replace, and triple cross*] is randomly run whenever the perturbation is called. In addition to the perturbation move, a local optimization method with previously defined four intra-route neighborhood structures is applied in order to improve the perturbed solution quality. The solution quality of the perturbed solution is significant since a perturbation move that satisfies the vehicle capacity and total route duration limit is always accepted. Moreover, violating moves are accepted as by the shaking operator. The new developed perturbation structures for the APM are defined as follows.

Double Replace is a combination of two times sequential *Replace (1,1)* movements to the same routes which are selected by the *roulette wheel* method. A random client from route 1 is permutated with a random client from route 2; next, another random client from route 1 is permutated with a client from route 2. After intra local search is applied to both route1 and route 2, the total vehicle duration and vehicle loading capacity are checked according to the acceptance limits.

Double Cross applies the *Cross* exchange. Otherwise, it is similar to the *Double Replace* structure.

Triple Shift is a newly developed fast and effective perturbation movement to jump out from local optima. A route (route 1) is randomly selected, and two another routes (route 2 and route 3) are selected by using the defined roulette *wheel* method. Next, similar to the *Shift (0,1)* movement a random client from route 2 is transferred to route 1, and a client from route 1 is transferred to route 3. Similar to double structures, vehicle duration and capacity are checked according to the acceptance limit after intra-local search applied to routes.

Triple Replace (is similar to *Triple Shift* by using the *Replace (1,1)* movement.

Triple Cross is similar to *Triple Shift* by using the *Cross* exchange structure.

As local optimization, a set of intra neighborhood structures [*3-opt, Swap*, *Insertion, 2-opt*] are repeated *z-max* times in a deterministic order. If no acceptable solution is generated after *z-max* attempts in any perturbation structure, the algorithm then tries another perturbation structure.

6.2 Forecasting framework

Forecasting is a method of estimating statements about future events for which actual results have not yet been observed. Forecasting could help decision-makers plan for the future. Parallel to national trade of countries, container throughputs of regional ports have high seasonality and demand fluctuations (Schulze and Prinz 2009; Polat and Uslu 2010). Therefore, reliable and accurate forecasting is needed to help the decision makers plan liner shipping service more effectively and efficiently, since container shipping involves considerable capital investments and huge daily operating costs. In the literature, the proposed models for liner shipping feeder service network design problems consider stable container demand of ports, because of the major complexity of real-world systems. Therefore, in this study, a simulation and artificial neural networks based forecasting framework is developed in order to analyze the impact of seasonal demand fluctuation on the liner shipping feeder service network design.

In developed structure, forecasting a frame consists of three modules (see Figure 6.5). The first decomposition is used to convert yearly maritime statistics to monthly container throughput information. The second artificial neural network (ANN) module is used to reflect trend and seasonality in forecasting monthly container throughput and the third simulation module is used to reflect daily demand fluctuations on container throughput.

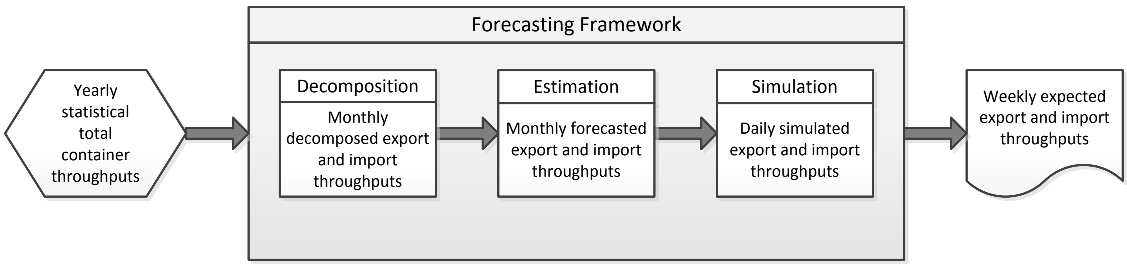


Figure 6.5: Forecasting framework

6.2.1 Decomposition mechanism

Quantitatively oriented literature and databases on international container throughput is quite limited (Schulze and Prinz 2009). In addition, shipping lines and container ports usually just provide yearly market shares and total handling amounts. Therefore, the decomposition module deconstructs yearly throughputs to monthly supply and demand amounts. See Section 7.4.1 for implementation of decomposition mechanism.

6.2.2 Estimation mechanism

ANNs are computational models inspired by the brain and how it processes information. Instead of requiring detailed information about the nature of a system, ANNs try to learn the relationship between the variables and parameters by checking data. ANNs can also handle very complex and large systems with many interrelated parameters. The effectiveness of biological neural systems originates from the parallel-distributed processing nature of the biological neurons. An ANN simulates this system by distributing computations to small and simple processing nodes (artificial neurons) in a network. ANNs have been used in many fields. One major application area is forecasting. Due to the characteristic features, ANNs are an attractive and appreciated alternative tool for both forecasting researchers and practitioners. For comprehensive reviews on the application of ANNs on forecasting, please see Zhang et al. (1998) and Kline and Zhang (2004). Therefore, ANNs are a common tool in forecasting container throughputs of container terminals (See Section 4.4). In developed framework, multi-layer feed- forward networks are trained using back-propagation in order to make estimations for each port's monthly demand and supply throughputs.

Figure 6.6 shows typical multi-layer feed-forward ANN architecture. A typical ANN contains three layers: an input layer, an output layer and, between them, the hidden layers. Each artificial neuron (node) is linked to nodes of the previous layer with weights. A set of these weights creates the knowledge from the system. In order to produce the desired output for a presented input, the network is trained with a learning method through adaptation of the weights. After the training operation, the weights contain meaningful information about the data. The network uses the corresponding input data to produce an output data, which is then compared with the desired output. When there is a difference between desired and produced outputs, the weights continue to adapt in order to decrease difference (error). Until the total error reaches the required limit, the network continues to run in all the input patterns. After reaching the acceptable level, the ANN stops and uses the trained network to make forecasts. For details, please see Zurada (1992) and Bose and Liang (1996) for details of algorithm.

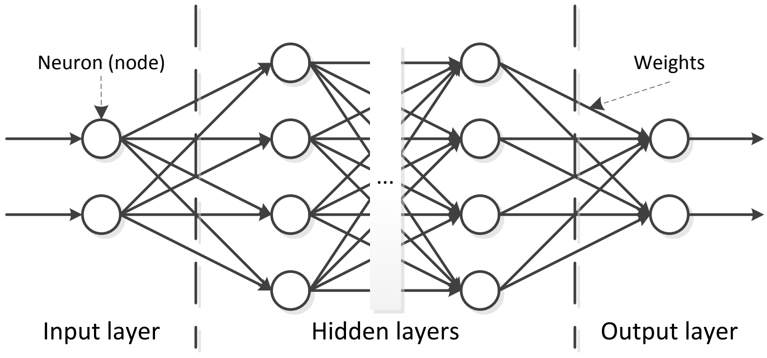


Figure 6.6: Typical ANN architecture

The back-propagation (BP) is a gradient-descent based effective learning algorithm for ANNs (Rumelhart et al. 1986). By adapting the weights with the gradient, PB tries to reduce the total error. The error is calculated with root-mean-square (*E*) value in Equation (6.2), where *t* is produced and o is desired outputs over all patterns (*p*) and nodes (*i*).

$$E = \frac{1}{2}\left[\sum_p \sum_i \left| t_{ip} - o_{ip} \right|^2 \right]^{1/2} \tag{6.2}$$

BP algorithm first assigns random values to all weights in all nodes. Then, the activation (α_{pi}) value is calculated for each pattern and for each node by using the activation function given in Equation (6.3), where *j* refers to all nodes of the previous layer, *i* refers to all node positions of current layer, and x_j and w_{ij} are input and weight terms.

$$\alpha_{pi} = f\left(\sum_j x_j w_{ij}\right) \tag{6.3}$$

After calculating the output of the layer, the error term (δ_{pi}) for each node is also calculated back through the network. The error term measures the changes in the network by using changes in the weight values. The error term is calculated for the output nodes and for the sigmoid activation function as given in Equation (6.4). For hidden layer nodes, the error term is calculated as given in Equation (6.5), where *k* indicates nodes in the downstream layer and *j* is the position of the weight in each node.

$$\delta_{pi} = \left(t_{pi} - \alpha_{pi}\right)\alpha_{pi}\left(1 - \alpha_{pi}\right) \tag{6.4}$$

$$\delta_{pi} = \alpha_{pi}\left(1 - \alpha_{pi}\right)\sum_{k}\delta_{pi} w_{kj} \tag{6.5}$$

In conclusion, incremental change to each weight for each node is calculated as given in Equation (6.6), where ε is learning rate used for weight adaptation in each training iteration and m is momentum, used to change the weight in the previous training iteration $\left(w'_{ij}\right)$. Stopping conditions, maximum iteration number, learning rate and momentum are speed and stability constants defined at the beginning of the training.

$$\Delta w_{ij} = \varepsilon\left(\delta_{pi}\alpha_{pi}\right) + m\left(w'_{ij}\right) \tag{6.6}$$

6.2.3 Simulation mechanism

The Monte Carlo simulation module uses the monthly throughputs estimated by the ANNs module as an input in order to generate daily demand and supply expectations of container terminals. By analyzing these expectations, shipping line planners can obtain realistic predictions for slot capacities, network designs, routes and schedules in the future. Simulation is run many times by using throughput forecasts of ANNs. By the way, different random components of the future demand and supply movements of ports are obtained for shipping line planners. See Section 7.4.1 for implementation of simulation mechanism.

7. Numerical Investigation

The Feeder Service Network Design (FND) related problems are solved in four sections in this chapter. Section 7.1 solves the benchmark instances of the vehicle routing problem with simultaneous pickup and delivery with time limit (VRPSPDTL), which is known as the background problem of the FND. This section proof robustness and effectiveness of the developed Adapted Neighborhood Search (ANS) approach. Section 7.2 solves Containership Routing Problem (FCRP) for a case study from the literature. This problem is the basic version of FND without including sailing season, ship economies, and ships mix and deployment. This section shows effectively implementation of ANS to containership routing problems. Section 7.3 solves the FND problem which aims to simultaneously determine the fleet size and mix, fleet deployment, ship routing and ship scheduling by minimizing total network costs in a sailing season by using a case study from Black Sea region with the help of developed ANS approach. Finally, Section 7.4 estimates container weekly container throughput of ports from Black Sea region under limited historical data with developed simulation and artificial neural networks based forecasting framework and solves the extended FND problem under seasonal demand with the help of developed ANS approach. The related section also handles various service scenarios such as different periodical approaches, different demand allocations, different number of owned ships in the starting of season, different ship owning, chartering, and oil prices in order to better help decision makers of liner shipping providers.

7.1 VRPSPDTL application

The presented mathematical model in Section 5.1 has been programmed by use of the GAMS 23.7 software with the CPLEX 12 solver on an Intel Core-2-Duo T5750 2.0 GHz processor with 3 GB RAM. The proposed metaheuristic approach in Section 6.1 has been coded using Matlab R2009a and executed by using Visual C# 2010 on the same computer.

7.1.1 Benchmark instances

The performance of presented model and proposed metaheuristic are firstly tested on a real case study provided by Min (1989). In this study, a library administration center acts as a depot to 22 client public libraries in a region. The administration center has two homogenous vehicles with 10500 amount capacities. The total delivery amount from depot to client libraries is equal to 20300, and the total pickup amount from the libraries is equal to 19950. Since the original problem is presented as VRPSPD; we added average vehicle speed parameter as 1 distance/unit and time limit parameter as 100 units. Please note that the new added parameters are selected in order to not affect the optimal solution of original problem. The presented model and proposed approach could easily obtain the optimal solution value (88) for the case of Min (1989) under 1 second (Halse 1992). The solutions are turned out to be computationally demanding when problem sizes of the instances are increased in the mathematical model. Therefore the model is not intended for solving large sized problem instances.

The performance of the proposed algorithm is also tested using benchmark instances for the VRPSPDTL from Salhi and Nagy (1999) based on Christofides et al. (1979). This problem set includes 14 problem instances in which client numbers vary between 50 and 199. Salhi and Nagy (1999) manipulated 7 original VRP benchmark problem instances of Christofides et al. (1979) by imposing a maximum time restriction for the vehicles, giving a predefined service time, and splitting the original demand between pickup and delivery loads. The remaining 7 instances were obtained by switching these pickup and delivery loads.

7.1.2 Numerical results

In order to solve benchmark instances, we firstly performed an extensive experimental study on the savings heuristic considering different combinations of parameter values: $\lambda = (1, 0.1, 5)$; $\mu = (0, 0.1, 3)$; $\nu = (0, 0.1, 2)$. In the experimental design it is observed that there is a high interrelation between the savings parameter values and other parameters (vehicle capacity, total duration and service time) of VRPSPDTL problems. As a result, the following settings were found to provide most reasonable initial solutions to general subsets of VRPSPDTL problems: $\lambda = 3.5$, $\mu = 1.6$, $\nu = 1.0$.

As a part of preliminary studies, experiments on the sequence of the shaking operators of the VNS algorithm were conducted in order to determine the most effective sequence of the local neighborhood search set. The results demonstrated the effectiveness of [N1: 3-opt, N2: Swap, N3: Insertion, N4: 2-opt, N5: Exchange (m,n), N6: Cross, N7: Shift (0,1), N8: Replace (1,1)] sequence. The same sequence is used in the local search (VND) part of the VNS algorithm. Therefore, k-max and m-max parameters of the VNS algorithm were set to 8 in the experiments. The total route duration violation acceptance limit is determined as α_1 = 3 and the vehicle capacity violation acceptance limit is determined as α_2 = 1.2 in these experiments.

In addition to construction heuristic parameters, VNS parameters and route violation parameters proposed ANS has two major parameters effect the quality of solutions. These are the APM perturbation counter (p-max) and the ANS termination counter (s-max). In the proposed ANS approach, the perturbation mechanism is executed after p-max iterations counted from the last accepted move. The ANS algorithm is terminated after s-max iterations counted from the last accepted move. In order to determine optimal parameters, an experimental study was conducted with the CMT6X benchmark problem instance of Salhi and Nagy (1999) with service time (Table 7.1).

Table 7.1: Sensitivity analysis results for algorithm parameters

p-max	5#N			2#N			1#N			0.5#N		
s-max	Best	Avg.	T.	Best	Avg.	T.	Best	Avg.	T.	Best	Avg.	T.
1000#N	555.43	556.82	24.1	555.43	556.47	112.1	555.43	555.43	47.1	555.43	556.06	32.7
500#N	556.06	557.17	24.1	555.43	556.47	112.1	**555.43**	**555.43**	**47.0**	555.43	556.06	32.8
250#N	556.06	557.46	24.2	556.06	556.72	64.5	555.43	556.06	40.1	555.43	556.06	32.7
100#N	556.68	558.03	1.5	556.06	557.29	53.9	555.43	556.31	30.6	555.43	556.43	28.1
50#N	556.68	558.57	0.5	556.06	557.58	14.4	555.43	556.78	18.4	555.43	556.48	24.1

#N: number of clients (50); Best: best solution in 10 replications; Avg.: average solution in 10 replication; T: average best solution time in 10 replications

Table 7.1 implies the importance of perturbation mechanism on approaching to optimal solution. As it could be seen in the sensitivity analysis, less perturbation mechanism calling models are working faster but approaching slowly to best known solution and the solutions are non-robust in ten replications. On the other hand, too much perturbation calling models are working a bit slower, approaching fast but the solutions are non-robust. Balanced called models (number of client times) are working slower, approaching to fast, and the solutions are more robust. Hence, the optimal parameter combination for p-max and s-max is 1 (1*50) and 25000 (500*50). Figure 7.1 shows the improvement of the solution with the iteration counter and improvement of the solution with the improvement counter for best solution of CMT13X with service time. Figure 7.1 also implies how perturbation mechanism improves the solution during the iterations by taking from the local optima. The positive effect of the neighborhood structures are also shown in Table 7.2.

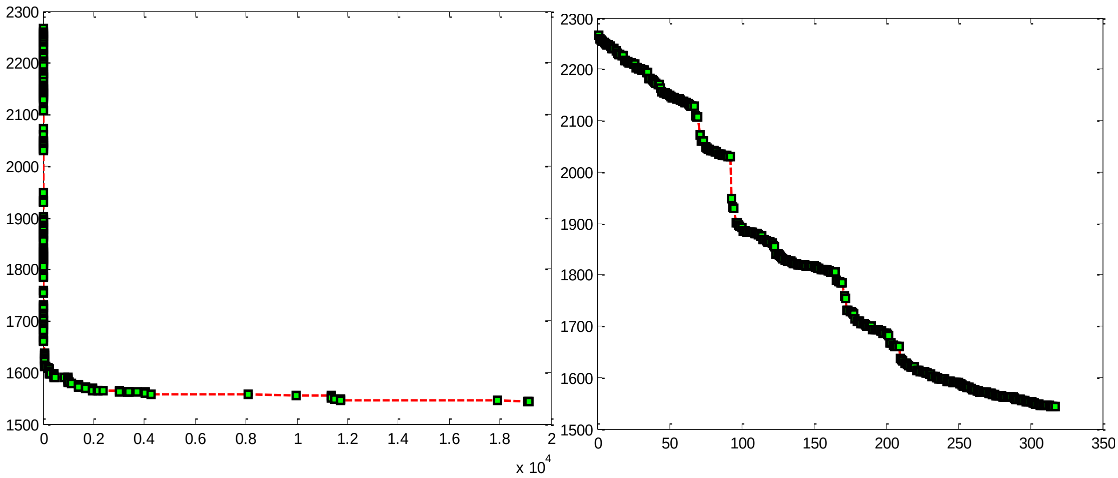


Figure 7.1: Improvement of the solution during the iterations (CMT13X with service time)

Table 7.2: The effect of the neighborhood structures (CMT13X with service time)

		ANS local search structures									
		Pure	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	Sum
ANS Shaking Structures	N_1	5	23	31	30	46	36	6	6	14	197
	N_2	1	5	5	7	11	10	1	2	12	54
	N_3	2	1	4	5	5	6	1	0	6	30
	N_4	1	0	0	1	7	3	0	0	14	26
	N_5	0	0	0	0	0	0	0	2	0	2
	N_6	0	0	0	0	0	1	0	0	0	1
	N_7	0	0	0	2	0	0	0	0	0	2
	N_8	2	0	0	0	2	0	0	0	1	5
	Sum	11	29	40	45	71	56	8	10	47	317

The entities in Table 7.2 show the positive improvement number of neighborhood structures in shaking and local search parts. When the interactions between shaking and local search neighborhood structures are analyzed, the most effective neighborhood combination is N1&N4 and N1&N5. While intra route structures are more effective in early stages, the inter-route structures are more effective in later stages of the proposed ANS. Indeed, the combinations of shaking with intra route structures and local search with intra route structures are more effective in early stages of the proposed ANS. However, though the combinations with inter route structures show a smaller quantitative effect, they play critical roles on route structures. On the other hand, while double perturbation structures are effective in early stages, the triple perturbation structures are more effective in later stages of the solution process.

The proposed ANS heuristic is first compared with the best solutions of Cluster Insertion Heuristics (CIH) by Salhi and Nagy (1999), Insertion Based Heuristics (IBH) by Detholff (2001), Alternating Heuristic Algorithms (ALT) by Nagy and Salhi (2005), Large Neighborhood Search (LNS) by Ropke and Pisinger (2006), Tabu Search (TS) by Montane and Galvao (2006), Reactive Tabu Search (RTS) by Wassan et al. (2008), Iterated Local Search (ILS) by Subramanian and Cabral (2008), Ant Colony System (ACS) by Gajpal and Abad (2009), Particle Swarm Optimization (PSO) by Ai and Kachitvichyanukul (2009), Saving Based Ant Algorithm (SBAA) by Catay (2010), and Nearest Sweep with Perturbation (NSP) by Jun and Kim (2012) for benchmark problem instances with service time of Salhi and Nagy (1999). The detailed results of the comparison of all seven approaches are given in Table 7.3. The proposed ANS algorithm is run ten times with the same seed sets for each parameter combination in order to measure their effectiveness and robustness. The best solutions of the problem types are highlighted using bold type.

Table 7.3: Computational results for the benchmark problem instances with service time

		Best known			ANS				
CMT	#N*	Ref.	#v	BKS	#v	Best	T	Avg.	Gap%
6X	50	ALT, ILS, ACS, NSP	6	555.43	6	**555.43**	47.0	555.43	0.00
7X	75	ACS	-	900.12	11	901.22	70.3	901.22	0.12
8X	100	LNS, ILS, ACS,	9	865.50	9	**865.50**	224.6	865.50	0.00
9X	150	NSP	14	1161.37	14	**1161.37**	484.0	1162.84	0.00
10X	200	ACS	-	1386.29	18	1388.02	1168.8	1390.52	0.12
13X	120	ACS	-	1542.86	11	**1542.86**	332.7	1543.17	0.00
14X	100	ILS, ACS, SBAA, NSP	10	821.75	10	**821.75**	228.5	821.75	0.00
6Y	50	ALT, ACS, NSP	6	555.43	6	**555.43**	47.3	555.43	0.00
7Y	75	ACS	-	900.54	11	901.22	69.8	901.22	0.08
8Y	100	ILS, ACS, SBAA, NSP	9	865.50	9	**865.50**	162.7	865.50	0.00
9Y	150	NSP	14	1161.37	14	**1161.37**	527.7	1162.58	0.00
10Y	200	NSP	18	1392.36	18	**1390.92**	1097.4	1391.95	**-0.10**
13Y	120	ILS, ACS	11	1542.86	11	**1542.86**	375.3	1542.86	0.00
14Y	100	ILS, NSP	10	821.75	10	**821.75**	204.6	821.75	0.00
Avg.	-	-		1033.80		1033.94	360.05	1034.50	0.01

* #N: Number of clients; Ref.: Best solution reference; #v: Number of routes; BKS: Best known solution; Best: Best solution in 10 replications; T: Corresponding CPU time; Avg.: Average solution of replications; %Gap: Percentage difference between the best known and ANS; Avg.: Average of 14 instances

Among 14 instances with service time, the ANS approach could generate a new best solution for the CMT10Y problem instance. In addition, ANS reproduces best-known solutions for 10 instances. For the remaining three instances, the gap between the results of the ANS and the best-known solution is just around 0.10%**.**

Secondly, the proposed ANS heuristic is compared with studies excluding service time. Comparisons with the best solutions of TS by Montane and Galvao (2006), RTS by Wassan et al. (2008) and ILS by Subramanian and Cabral (2008) are listed in Table 7.4. The best solutions of the problem types are highlighted using bold type.

Table 7.4: Computational results for the benchmark problem instances without service time

		Best known			ANS				
CMT	#N*	Ref.	#v	BKS	#v	Best	T	Avg.	Gap%
6X	50	ILS	3	466.77	3	**466.77**	20.16	466.77	0.00
7X	75	RTS	6	663.95	6	668.35	60.08	668.91	0.66
8X	100	TS	5	720	5	**720.32**	58.90	720.55	0.00
9X	150	ILS	7	855.74	7	**855.54**	120.46	855.70	**-0.02**
10X	200	ILS	10	1037.37	10	1042.12	667.91	1043.14	0.46
13X	120	ILS	4	846.85	4	**816.87**	44.41	818.22	**-3.67**
14X	100	RTS	5	644.70	5	663.50	49.38	663.50	2.83
6Y	50	ILS	3	466.77	3	**466.77**	12.67	466.77	0.00
7Y	75	RTS	6	662.50	6	664.40	61.07	664.40	0.29
8Y	100	TS, ILS	5	721.40	6	**721.10**	47.73	721.12	**-0.04**
9Y	150	ILS	7	856.74	7	**855.54**	180.57	855.68	**-0.14**
10Y	200	ILS	10	1036.59	10	1041.12	355.77	1042.55	0.44
13Y	120	ILS	4	848.45	4	**809.18**	54.40	810.12	**-4.85**
14Y	100	RTS	6	659.52	5	662.22	49.13	662.50	0.41
Avg.	-	-	-	749.09	-	746.7	127.33	747.13	**-0.32**

* #N: Number of clients; Ref.: Best solution reference; #v: Number of routes; BKS: Best known solution; Best: Best solution in 10 replications; T: Corresponding CPU time; Avg.: Average solution of replications; %Gap: Percentage difference between the best known and ANS; Avg.: Average of 14 instances

Among 14 instances without service time, the ANS approach could generate new best solutions for five problem instances, namely CMT9X, CMT13X, CMT8Y, CMT9Y and CMT13Y. In addition, ANS reproduces best-known solutions for three instances. For the remaining six instances, the maximum gap between the results of the ANS and the best-known solution to the NSP is around 2.83%**.**

Table 7.5 shows the comparison of approaches for benchmark instances with and without service time. According to these results, ANS shows the best average solution (1033.94) for instances with service time. ANS also provided outstanding average solutions (746.70) for instances without service time. Moreover, ANS has also lowest gap compared with the average of best known solutions for instances with/out service time within all solution approaches. Generally it is difficult to compare CPU times since different approaches are tested on different computers. In order to make a fair comparison of execution times, the computers which are used for all approaches are compared with the help of Passmark Performance Test 7.0 software. Since there are too much factors effecting on CPU times, approximate equivalent computers are used in the benchmark test. See the Appendix (Table A.2) for computer benchmark results.

The average of the computation time for ANS approach is around 6 minutes in the benchmark problem instance of Salhi and Nagy (1999). In the comprehensive comparison with the VRPSPDTL approaches, the scaled average solution time of ANS tolerable worse than others. Despite the effectiveness of repetitive perturbation mechanism, it took fairly more computation time (more than 80%) within ANS approach. We note here that recent effective approaches haven't provided their optimal computation times. Concerning robustness, ANS is the most robust of average solution provided approaches, since ANS gives lowest average for average solutions for all instances. The variance among the average of best results and the average of average results is less than the ones in the other approaches.

Table 7.5: Comparisons of approaches for benchmark instances

	With service time					Without service time				
Name	Avg_b	Avg_a	T_o	T_m	Gap%	Avg_b	Avg_a	T_o	T_m	Gap%
CIH*	1138.50	-	4.9	0.05	0.07821	-	-	-	-	-
IBH	1113.43	-	-	-	0.07714	-	-	-	-	-
ALT	1053.36	-	2.3	0.05	0.01903	-	-	-	-	-
LNS**	1093.85	1115.38	519.77	77.97	0.04176	-	-	-	-	-
TS	-	-	-	-	-	781.86	-	19.17	6.13	0.05082
RTS	1069.78	1074.80	34.41	3.10	0.03491	763.12	-	97.29	8.76	0.02563
ILS	1038.08	1050.83	53.42	37.40	0.00425	754.20	767.99	72.02	50.41	0.01364
ACS	1034.01	1035.65	205.48	63.70	0.00031	-	-	-	-	-
PSO	1065.86	1085.78	-	-	0.03112	-	-	-	-	-
SBAA	1042.20	1049.52	-	-	0.00823	-	-	-	-	-
NSP	1034.95	-	-	-	0.00122	-	-	-	-	-
ANS	**1033.94**	1034.50	360.05	360.05	**0.00024**	**746.70**	747.13	127.33	127.33	**0.00356**
Best***	1033.69	-	-	-	0.00000	744.05	-	-	-	0.00000

*CIH did not provide solutions for 7X and 7Y; **LNS did not provide solutions for 14Y; ***Average of best known solutions for all instances. Avg_b.: Average of best solutions found in benchmark instances; Avg_a.: Average of average solutions found in benchmark instances; T_o: Average of best solution time; T_m: In order to make a fair a comparison between algorithms, original solution times of all approaches are modified according to Table A.2 in Appendix. %Gap: Percentage difference between the best known solution and methods.

The general conclusion that can be drawn from Table 7.3, Table 7.4 and Table 7.5 is that the ANS algorithm produces adequate and robust solutions in reasonable time for the benchmark problems of Salhi and Nagy (1999). The provided best solutions for CMT10Y with service time and CMT13Y without service time are given in the Appendix (Table A.3 and Table A.4).

7.1.3 Concluding remarks

In this section, we proposed a novel hybrid search method called Adaptive Neighborhood Search (ANS) algorithm based on the Savings Algorithm (SA), Variable Neighborhood Search (VNS) and the Adaptive Perturbation Mechanism (APM) to solve the vehicle routing problem with simultaneous pick-up and delivery with time limit (VRPSPDTL). We used eight local neighborhood search structures as shaking and local search operators of the VNS algorithm. A Variable Neighborhood Descent (VND) procedure is used to perform the local search. We use five adaptive perturbation structures in order to escape from local optima. From the numerical results it can be concluded that the proposed ANS algorithm generates efficient and robust solutions compared to existing solution methods for the VRPSPDTL. For 19 out of the 28 benchmark instances with and without service time from Salhi and Nagy (1999), the ANS algorithm could obtain new best solutions or reach the best known solution. The main features of the proposed ANS algorithm are specifically designed sub-procedures as part of the construction heuristic, improvement algorithm and perturbation mechanism to cover the total vehicle duration limit which is not included in the pure VRPSPD solution methods.

7.2 FCRP application

The presented mathematical model in Section 5.2 has been solved with the proposed metaheuristic approach in Section 6.1 coded using Matlab R2009a and executed by using Visual C# 2010 on an Intel Core-2-Duo T5750 2.0 GHz processor with 3 GB RAM. The performance of the proposed algorithm is tested using a real case study from Aegean Islands developed by Sambracos et al. (2004) and generalized by Karlaftis et al. (2009).

7.2.1 Case study

In this case study, the problem is routing of freight vessels from the port of Piraeus to a set of 25 islands in the Aegean Sea. See details of the problem at Table A.5 in the Appendix. The homogenous vessel capacity is 100 small containers, average ship speed is 12 knots, the total delivery amount equals to 464, and the total pickup amount is 235. The service time to vessels is different in each island and time dead line for vessel is used as 40 hours. The authors used time limit as soft deadline for supplying islands with goods. The authors also used a tolerance for approaching an island later than this time deadline. Such routes are penalized with 5% of the delays.

7.2.2 Numerical results

In order to solve the defined case study, we performed an extensive experimental design for savings heuristic considering different combinations of parameter values: $\lambda = (1: 0.1: 5)$; $\mu = (0: 0.1: 3)$; $\nu = (0: 0.1: 2)$. In the experimental design it is observed that there is a high relationship between the parameter values savings and parameters (vehicle capacity, total duration and service time) of FCRP. Therefore, following setting is observed to provide ideal initial solutions on general subset of FCRP: $\lambda = 3.5$; $\mu = 1.6$; $\nu = 1.0$.

As a part of preliminary studies, experiments on the sequence of the shaking operators of the EVNS algorithm were conducted in order to determine the most effective sequence of the local neighborhood search set. The results demonstrated the effectiveness of [N_1: *3-opt*, N_2: *Swap*, N_3: *Insertion*, N_4: *2-opt*, N_5: *Exchange (m,n)*, N_6: *Cross*, N_7: *Shift (0,1)*, N_8: *Replace (1,1)*] sequence. The same sequence is used in the local search (VND) part of the EVNS algorithm. Therefore, k_{max} and m_{max} parameters of the EVNS algorithm set to 8 in the experiments. The vehicle capacity violation acceptance limit is determined as $\alpha = 1.2$ in these experiments.

In addition to construction heuristic parameters, EVNS parameters, and route violation parameters, proposed ANS have two algorithm parameters effecting on the quality of solutions. These are perturbation counter (p-max) and ANS termination counter (s-max). In the proposed ANS approach, the perturbation mechanism is called after p-max iterations counted from the last accepted move. The ANS algorithm is terminated after s-max iterations counted from the last accepted move. A sensitivity analysis performed in order to determine optimal algorithm parameters. The proposed ANS algorithm is run ten times with same seed sets for each parameter combination in order to measure their effectiveness and robustness. Table 7.6 shows that optimal (fast and robust) parameter combination for p-max and s-max is 25 (≈1*25) and 2500 (=100*25).

The proposed ANS approach is also compared with the best solutions of the GA by Karlaftis et al. (2009) for the Aegean Islands case study. The case study is also solved with hard deadline which do not allow delays for approaching an island. In order to make fair comparison, the case study with both soft and hard deadline is also solved with EVNS (without perturbation mechanism). Moreover, the GA developed by Karlaftis et al. (2009) are reprogrammed and validated in order to solve the case study with hard deadline (GA-2). The detailed results of the comparison of algorithms are given in Table 7.7 and best set of routes are shown in Figure 7.2. Please see Table A.6 and Table A.7 in the Appendix for details of the best solutions.

Table 7.6: Sensitivity analysis results for algorithm parameters

p-max		10#N			4#N			2#N			1#N	
s-max	Best	Avg.	T.	Best	Avg.	T.	Best	Avg.	T.	Best	Avg.	T.
1000#N	253.96	253.97	147.77	253.96	253.96	98.16	253.96	253.96	116.50	253.96	253.96	33.03
500#N	253.96	253.98	77.80	253.96	253.96	98.16	253.96	253.96	116.50	253.96	253.96	33.03
250#N	253.96	253.98	47.99	253.96	253.97	64.51	253.96	253.97	75.74	253.96	253.96	33.03
100#N	254.00	254.00	19.88	253.96	254.21	14.38	253.96	254.44	10.06	**253.96**	**253.97**	**23.36**
50#N	254.00	254.67	6.47	253.96	254.22	6.70	253.96	254.44	11.27	253.96	253.98	19.32
p-max		0.5#N			0.25#N		0.125#N				No	
1000#N	253.96	253.96	116.86	253.96	253.96	179.87	253.96	254.05	139.66	254.00	254.67	2.02
500#N	253.96	254.05	72.72	253.96	253.97	129.47	253.96	254.06	89.05	254.00	254.67	2.02
250#N	253.96	254.07	21.53	253.96	254.06	39.36	253.96	254.07	53.85	254.00	254.67	2.02
100#N	253.96	254.07	19.15	253.96	254.07	25.82	254.00	254.08	25.36	254.00	254.67	2.02
50#N	253.96	254.21	10.72	253.96	254.22	7.29	254.00	254.97	8.76	254.00	254.67	2.02

#N: number of clients (25 islands); Best: best solution in 10 replications; Avg.: average solution in 10 replication; T: average best solution finding time in 10 replications

Table 7.7: Comparisons of algorithms

Algorithms	Dead line	Number of routes	Best Fitness Function value[1]	Average solution value[2]	Avg.Best solution time (s)[3]
GA	Soft	5	260.22	-	97.5[4,5]
GA-2	Hard	5	264.00	265.39	33.68
EVNS	Soft	5	254.00	254.67	2.02
EVNS	Hard	5	258.12	259.48	1.12
ANS	Soft	5	**253.96**	253.97	23.36
ANS	Hard	5	**256.00**	256.07	5.57

[1] best solution in 10 replication; [2] average of best solutions in 10 replication; [3] average of best solution finding time in 10 replication; [4] best solution of in 1 replication; [5] "Intel Core 2 Duo T5750 2.0 GHz processor with 2 Gb RAM" is around 4.4 times faster than Karlaftis et al. (2009)'s "Intel Pentium 4 2.53 GHz processor with 512 Mb RAM" according to Passmark Performance Test 7.0 software. Therefore, in order to make a fair a comparison between algorithms, original solution time of Karlaftis et al. (2009) is modified.

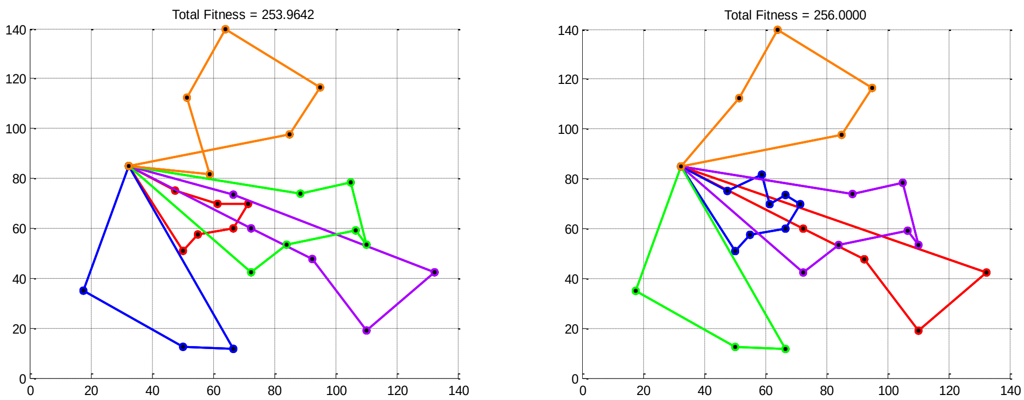


Figure 7.2: Best solution networks for soft and hard time deadline

The proposed ANS algorithm could find the new best solution for the Aegean Islands case study for both soft and hard deadline restriction. On the other hand, EVNS approach could get results faster solutions; however it is stuck in local optima. The solutions provided for hard deadline case are more robust and faster than soft dead line case, since hard line case does not allow time violation for serving islands.

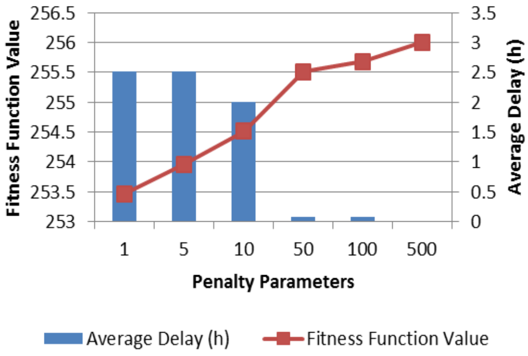
Container transportation capacity of feeder containerships and time deadlines for delivering containers to feeder ports are main parameters for FCRP. In addition to sensitivity analysis for algorithm parameters, further sensitivity analysis performed in order to analyze effect of problem parameters (see Table 7.8).

Table 7.8: Sensitivity analysis results for problem parameters

Deadline		30			35			40			45	
Capacity	Best S.	#Routes	Delay	Best S.	#Routes	Delay	Best S.	#Routes	Delay	Best S.	#Routes	Delay
75	310.71	7	2.74	310.03	7	0.81	309.67	7	0.01	309.67	7	0.00
100	255.45	5	8.46	254.70	5	5.46	253.96	5	2.52	253.70	5	1.45
125	226.38	4	16.80	225.63	4	12.33	224.88	4	8.58	224.31	4	5.70
150	219.64	4	17.36	218.89	4	13.61	218.14	4	9.86	217.39	4	6.11
175	205.23	3	25.96	204.48	3	20.96	203.73	3	15.96	202.98	3	10.96

According to results of sensitivity analysis for problem parameters, as it expected, fitness value of solution, the number of routes decreases when capacity of barge containerships and time deadline are simultaneously increased. On the other hand, the decrease of fitness value and number of routes increase the average delay on approaching of containerships to feeder ports. Short delays are considered tolerable in FCRP since uncertain nature of maritime transportation and feeder ports. However, increase on containership capacity causes inadmissible delays on approaching since soft time deadline which directs algorithm to use less containership number. In this context, selection of barge containership type is purely related to tolerance of time deadlines which is related to type of transported goods. Therefore, penalty value for penalizing delays on approaching of containerships to feeder ports is another relevant parameter. Penalty value is used low for more perishable product transportation and high for less perishable product transportation. Figure 7.3 shows effect of penalty parameter on solution of the problem (Capacity 100 TEU and time deadline 40 hour).

According to results of penalty parameter analyze, as expected, fitness value of solution is increased and average delay is decreased when penalizing value (%) is increased. While problem is less sensitive to time deadline in lover penalizing value, it is more sensitive to time deadline in higher values. After 500% penalizing value, problem is starting to use deadline as hard time deadline for approaching of containerships to feeder ports. However, in our experience, total number of routes is not affected by increase of penalizing value, since current time deadline is adequate for feeder containerships.



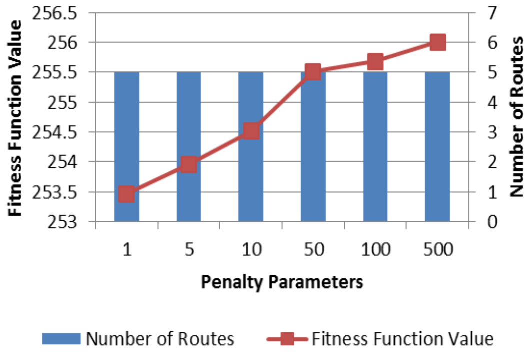


Figure 7.3: Sensitivity analysis results for penalty parameter

7.2.3 Concluding remarks

In this section, we proposed a novel hybrid search method called adaptive neighborhood search (ANS) which uses the savings algorithm, enhanced variable neighborhood search and perturbation mechanism in order to solve to the feeder containership routing problem (FCRP). We used eight local neighborhood search structures as shaking and local search operators of the algorithm. The proposed approach is tested on a case study from Aegean Islands and solutions are improved around %3. Moreover, a range of scenarios and parameters values used in order to test the robustness of the approach through sensitivity analysis. From the numerical results it can be concluded that the proposed ANS algorithm generates efficient and robust solutions for the FCRP.

7.3 FNDP application

The FND problem presented in Section 5.3 is a highly complex combinatorial optimization problem and thus hard to solve by use of standard optimization software. Exact methods for solving the FND problem are generally not practical for large instances because of the problem complexity. We therefore employ an adaptive neighborhood search (ANS) heuristic which has shown to be very efficient for solving the VRPSPDTL (see Section 7.1). In this section we address the strategic choice of the hub port, decisions on the size and composition of the fleet of containerships, and ship routing and scheduling as an integrated planning problem. We consider the Black Sea region as an application example to analyze the design problem of container feeder networks from the perspective of a feeder shipping company commencing its services from a newly constructed port.

7.3.1 Implementation

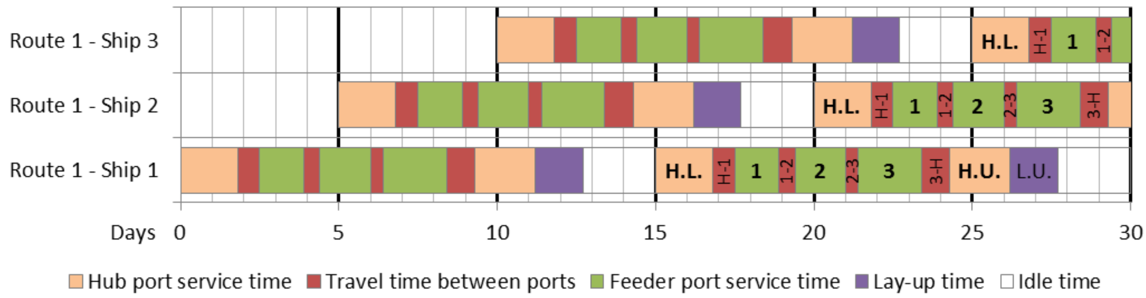
The presented mathematical model in Section 5.3 has been solved with the proposed ANS approach in Section 6.1 coded using Matlab R2009a and executed by using Visual C# 2010 on an Intel Core-2-Duo T5750 2.0 GHz processor with 3 GB RAM.

The candidate networks created by the ANS are evaluated using a fitness function. Since ANS is originally intended to solve the VRPSPDTL with homogenous vehicles under the objective to minimize the total travel distance within the network, it is necessary to adjust the fitness function of the ANS. In our implementation of the ANS total operation costs of all routes for the entire sailing season according to the cost functions (5.25) and (5.26) of Section 5.3 are used as fitness function. The respective procedure for calculating the fitness values is summarized in Figure 7.4. In the VRPSPDTL application candidate routes are generated with the help of neighborhood structures. In this step constraints (5.29) - (5.39) of the optimization model are checked in order to achieve feasible solutions.

```
procedure: fitness function for ANS
input: candidate network
output: total network costs of candidate network (dNC)
start
  for each route (r) in the candidate network
    initialize a big number for total route cost (RC_r)
    for each ship type (s)
      if (hub and each feeder port departure and arrival loads are feasible for ship type s on
         route r) [Eq. (5.35), (5.36), (5.37)]
        calculate voyage cycle time of route r with ship type s specifications [Eq. (5.28)]
        if (voyage cycle time is feasible by considering maximum voyage dur. limit) [Eq. (5.38)]
          calculate required ship number of ship type s for route r [Eq. (5.27)]
          calculate variable costs for route r operated with ship type s [Eq. (5.26)]
          calculate fixed costs for route r operated with ship type s [Eq. (5.25)]
          calculate total costs of route r operated with ship type s (dRC_r)
          if (dRC_r < RC_r )
            update RC_r with dRC_r
          end if
        end if
      end if
    end for
  end for
  calculate total network costs of candidate network (dNC = ∑_r RC_r) [Eq. (5.24)]
end
```

Figure 7.4: Calculation of the FNDP fitness function

Apart from the network routes the ANS determines the fleet mix, the number of required ships according to Equation (5.27) and their deployment to routes in the candidate network. Based on these data the total voyage cycle of a ship on a route is achieved as given by Equation (5.28), i.e. considering the related port service times, travel times between ports, lay-up times etc. Figure 7.5 shows an example of a route-ship-port schedule for 30 days of operation with 5 days service frequency, 3 feeder ports in sequence, and 3 required ships for a route in the network.



*H.L: loading time at hub port; H-1, 1-2, 2-3, 3-H: port-to-port travel time; 1, 2, 3: feeder port service time including, loading, unloading and set-up times; H.U: unloading time at hub port; L.U.: lay-up time of ship for next voyage

Figure 7.5: An example of a route-ship-port schedule

7.3.2 Case study

The fact that the considered region is surrounded by several seas – the Black Sea, Mediterranean Sea, Adriatic Sea, Ionian Sea, Aegean Sea, and Marmara Sea – makes maritime shipping a prime area for sustained growth (see Figure 7.6). Container feeder shipping lines offer crucial transport connections between the hinterland of this region and global trunk shipping lines. The feeder shipping dynamics of the region are mainly related to container transportation volumes of the trunk shipping lines between Far East and Europe. In recent years, parallel to the increase of container transportation volumes on the global trunk shipping lines, an increase of the total container handling volume is observed in the regional feeder ports. This is particularly true for ports in the Black Sea region. Hence, the outlook for the maritime transportation market in the region is very promising (Varbanova 2011a).

Turkey's ideal location between Asia and Europe gives its ports a competitive advantage and opportunity to develop into major transhipment hub ports. However, so far Turkish ports primarily serve their national needs and remain outside the major trunk lines (Kulak et al. 2013). This situation results in maritime container transport mainly executed by feeder lines that serve the Turkish ports from the East Mediterranean hub ports. In this regard, Turkey has significant potential for getting stronger involved in regional maritime transport and consequently several projects for the development of intermodal transport are being initiated. One of these projects is the construction of a hub port in Izmir's Candarli district in order to improve Turkey's hub port potential in the East Mediterranean and especially in the Black Sea region. According to the project plan, the Northern Aegean Candarli port will take its place among the world's largest ports after its first part is completed in 2013 and it will be able to handle 12 million tons of container freight annually in its ultimate configuration. The potential market areas of Candarli as a hub port can be categorized into four sub-regions: the Black Sea, the Marmara Sea, the East Mediterranean and the Aegean Sea.

Figure 7.6: Regional feeder and hub ports

A particular feeder liner shipping company currently operates a feeder network with a hub port at Port Said in Northern Egypt. However, after opening of the new Candarli port, the company will possibly redesign its current feeder network with Candarli as a new hub port. Therefore, in this study three different strategic options for hub ports are considered.

- *The first strategic option* corresponds to the current configuration with Port Said as hub for feeder ports in the Black Sea region. The main advantage of this option is the closeness to the Suez Canal through which almost all of the Asia-Europe shipping routes pass.
- In *the second strategic option* the new Candarli port replaces Port Said as a hub port for the Black Sea region. This option is based on the assumption that Candarli will be a firm part of the global shipping routes.
- *The third strategic option* is a mixed case in which two hub ports are established. Namely Port Said serves as a link to the main global shipping lines and at the same time as regional hub port for the East Mediterranean ports. Candarli will serve as a second regional hub port for the Black Sea, the Sea of Marmara and the Aegean Sea ports and with daily direct connections to Port Said via mid-sized ships.

These strategic options are tested under different time deadline and service frequency conditions for a 52-week sailing season. In this region, the concerned feeder liner company has 36 contracted container terminals at 26 feeder ports which have a total daily demand of 3321 TEU and a total daily supply of 2151 TEU on average (see Table A.8 in the Appendix for details of the ports). Because of the limited berth depth at some regional ports and well-known traffic bottlenecks at the Bosporus and Dardanelles straights, ships of three different sizes are considered in the numerical experiment. The major cost parameters for all ship types are shown in Table 7.9.

7.3.3 Numerical results

In order to provide decision support for the feeder network design problem faced by the Turkish company, we proceed with our experiments in the following order. First the strategic options for choosing the hub port are evaluated (Section 7.3.3.1). Second, the impact of different scenarios for the long-term development of transportation volume in the Black Sea region is analyzed (Section 7.3.3.2).

Table 7.9: Parameter values for ship types

Parameter	Unit	Ship1	Ship 2	Ship 3
Capacity	TEU	4300	2600	1200
Operating speed	(knots)	22.60	19.90	17.40
Fuel consumption (on sea)	(tons/hour)	5.26	2.82	1.51
IFO 180 price (on sea)	($/ton)	647.50	647.50	647.50
Fuel consumption (at port)	(tons/hour)	0.26	0.14	0.08
MGO price (at port)	($/ton)	890.00	890.00	890.00
Chartering cost	($/day)	12772.00	7579.00	5866.00
Operating costs	($/day)	11520.00	8887.00	6023.00
Port charges	($/call)	35000.00	29000.00	22000.00
Lay-up time	(hour/call)	28.80	24.00	16.80
Set-up time	(hour/port)	2.00	1.80	1.50
Planning period	Days	364	364	364

Sources: Stopford (2009), VHSS (2013), BunkerIndex (2012)

7.3.3.1.Strategic options for feeder networks

The three basic strategic options to be considered are the locations of hub port in Port Said and Candarli, respectively, and a combined network design with these two transhipment hubs connected by a shuttle service of feeder ships. In the experiments two additional network design parameters are evaluated. As for *shipping frequencies* we compare the departure of services every 7 or 3.5 days, respectively. For each frequency the *time deadline* for voyages is varied between 3 and 4.5 weeks.

The specific research issues addressed in our numerical investigation are the following:

- Does the time deadline imposed on the voyages represent a major factor in the design of the network configuration?
- How does the voyage frequency impact the cost performance of the various network configurations?
- Which of the three strategic options for hub ports would be favourable in terms total yearly costs?

The perturbation mechanism is called after $1 * \textit{feeder port number}$, i.e. 36, iterations counted from the last accepted move. The total route duration and the vehicle capacity violation acceptance limit (α_1 and α_2) are used as 10%. This rule aims to allow customers to join another route for possible future improvements. The termination condition of the ANS algorithm is used as maximum number of iterations between two improvements of the best solution. The termination condition is set to $100 * \textit{feeder port number}$

iterations without improvement. The proposed ANS algorithm is run ten times with different random seeds in order to measure its robustness.

Table 7.10 shows the total costs of the current and alternate hub port options under various time deadline and service frequencies. Total costs include chartering costs, operating costs, administration costs, on-sea bunker costs, on-port bunker cost and port charges for a 52-week sailing season. Computational times depending on the structure of the feeder network varied between 10 and 60 seconds.

Table 7.10: Scenario results for alternative hub port locations

Scenario	Hub	Frequency (days)	Deadline (days)	Minimum total cost (x1000)	Average total cost (x1000)	Average CPU time
1	Port Said	7	3x7	286548.47	286978.61	56.38
2	Port Said	7	3.5x7	286911.48	287691.02	58.60
3	Port Said	7	4x7	**286420.04**	287616.77	39.80
4	Port Said	7	4.5x7	287388.27	287893.72	51.95
5	Port Said	3.5	3x7	339726.79	342734.19	25.03
6	Port Said	3.5	3.5x7	339726.79	341642.78	31.06
7	Port Said	3.5	4x7	339726.79	341565.97	23.73
8	Port Said	3.5	4.5x7	339726.90	342141.54	18.43
9	Candarli	7	3x7	257526.74	258052.94	36.43
10	Candarli	7	3.5x7	255733.20	257470.14	50.02
11	Candarli	7	4x7	**255341.87**	257051.03	30.97
12	Candarli	7	4.5x7	255341.87	257647.93	38.38
13	Candarli	3.5	3x7	296789.81	298547.32	42.07
14	Candarli	3.5	3.5x7	298157.27	300052.71	20.21
15	Candarli	3.5	4x7	296831.31	299795.88	17.26
16	Candarli	3.5	4.5x7	296789.81	297920.09	29.81
17	Mixed	7	3x7	368529.88	369673.02	17.07
18	Mixed	7	3.5x7	367462.31	369468.74	17.64
19	Mixed	7	4x7	**367099.69**	369206.60	23.37
20	Mixed	7	4.5x7	367462.31	368277.30	30.25
21	Mixed	3.5	3x7	403355.76	405330.18	10.36
22	Mixed	3.5	3.5x7	401789.60	402769.03	14.50
23	Mixed	3.5	4x7	401789.60	401818.82	15.93
24	Mixed	3.5	4.5x7	401789.60	402453.47	12.12

The first conclusion that can be drawn from the results displayed in Table 7.10 is that the effect of the time deadline is practically negligible. Even the largest deviation observed for Candarli and the 7-days frequency options (no. 9-12) are less than 1%.

However voyage frequencies have a major impact on the cost performance. Reducing the voyage frequency for Port Said from 7 to 3.5 days causes a cost increase of 18.65%. Respective values are 16.2% for Candarli and 9.44% for the configuration with two hubs.

The main research question addresses the choice of the hub location. It can be seen from the results shown in Table 7.10 that the mixed hub option causes total costs of

$367,099,690 (option no. 19 with 7-day service frequency and 4 weeks deadline) and thus is clearly outperformed by the single-hub configurations. This cost disadvantage is mainly due to the additional transhipment operations at Candarli. As for the single-hub configurations the existing hub port option of Port Said shows minimum total costs of $286,420,040 (option no. 3 with 7-day service frequency and 4 weeks deadline) while the projected hub port of Candarli achieves minimum total cost of $255,341,870 (option no. 11 with 7-day service frequency and 4 weeks deadline). Considering only network-wide cost figures the Candarli option would allow cost savings of 12.2% compared to the existing feeder network configuration with Port Said as hub. The resulting feeder routes for Port Said (option no. 3) and Candarli (option no. 11) are shown in Figure 7.7.

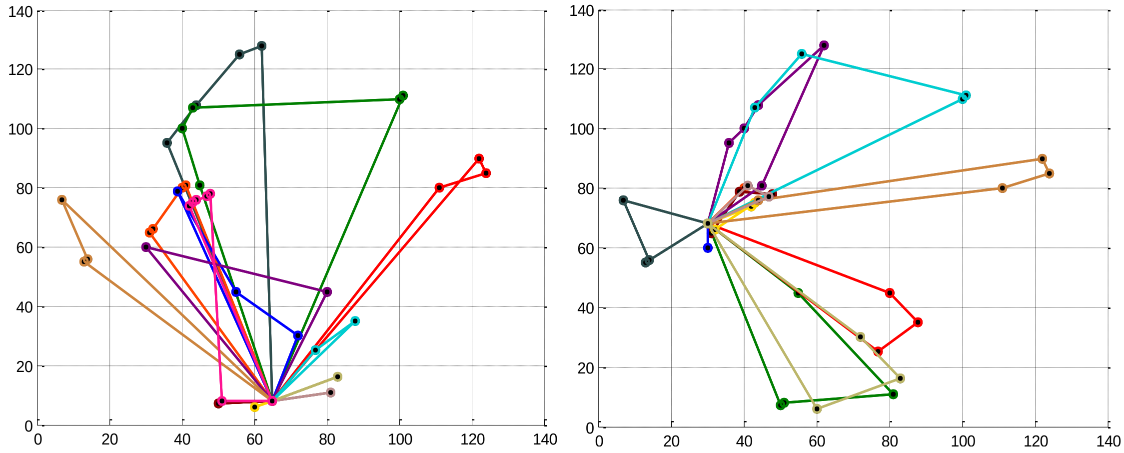


Figure 7.7: Feeder route networks for Port Said (left) and Candarli port (right)

Table 7.11 presents a comparison of costs, fleet and voyage characteristics of the two single-hub configurations. As in global trunk lines, feeder shipment is highly sensitive to bunker fuel costs as they represent 26.67% (Port Said) and 20.83% (Candarli) of total costs. However, these shares are significantly lower compared to global trunk lines due to the density of the network and the relatively short transportation distances. In turn feeder networks show a higher share of ship based fixed costs such as chartering, operating and port charges. Since Candarli has shorter distances to regional feeder ports, relatively small containerships are employed. In contrast, the Port Said based feeder network utilizes slightly more mid-sized containerships. Large-sized feeder ships of 4300 TEU are not appropriate for both hub alternatives because of the relatively high fixed costs. It could be expected, however, that in case the network dimension is enlarged and total demand increases, larger ships will become more attractive in order to meet the balance between fixed and variable costs. It is also shown in Table 7.11 that total voyage durations of 297.23 hours are slightly lower for the Port Said option compared to Candarli with 308 hours. In both cases the major share of the voyage durations of more than 60% occurs for the stay in the hub and in the feeder ports. As expected the on-sea voyage duration is lower for the Candarli option due to its geographical location closer to the Black Sea region. The best solution achieved for Candarli is given in detail in Table A.9 in the Appendix.

Table 7.11: Feeder network comparison of the Port Said and Candarli port options

	Parameter	Port Said	Candarli
Costs	Total costs (´000 $)	286,420.04	255,341.87
	Chartering costs	20.80%	22.30%
	Operating costs	23.62%	25.42%
	Bunker costs (on sea)	26.67%	20.83%
	Bunker costs (at port)	4.83%	5.38%
	Port charges	24.09%	26.07%
Fleet	Number of routes	13	12
	Total number of ships	23	22
	1200 TEU	20.44%	27.27%
	2600 TEU	79.56%	72.73%
	4300 TEU	0.00%	0.00%
Voyages	Total avg. duration (Hour)	297.23	308.00
	On sea	23.71%	17.69%
	In feeder ports	41.31%	43.17%
	In hub port	20.39%	21.27%
	Lay-up times	6.96%	6.82%
	Idle times	7.64%	11.06%

A specific drawback of the Candarli option compared to Port Said is certainly its location of about 220 nautical miles farther away from the main global shipping lines. Under one daily East-Westbound and West-Eastbound service assumption, the extra costs for operating this transhipment service would almost compensate the saving in operational costs.

7.3.3.2.Demand scenarios

For the future development of the feeder network the expected growth of the transportation market in the Black Sea region is an essential factor. According to forecasting reports of Ocean Shipping Consultants (2011), container handling demand in the region will continue to increase yearly by 25% till 2025. Therefore, a sensitivity analysis is performed to assess the influence of this factor on the cost performance of the Port Said and Candarli network configurations. Based on this expectation for four subregions, 16 different market scenarios are created in order to evaluate the network costs for exchanging the current hub port. Scenario 1 corresponds to the current market situation. In the further scenarios combinations of market volume increase in one, two and three regions, respectively, are assumed. Finally, scenario 16 corresponds to a 25% market volume increase in all four regions.

Results of the sensitivity analysis summarized in Table 7.12 show network costs for the two candidate hub ports under equivalent demand increase assumptions. According to the results of the sensitivity analysis, Candarli outperforms Port Said in all demand scenarios because of its advantageous geographical position. Candarli's superiority, however, is considerably smaller when only a market volume increase in the East Mediterranean and the Aegean Sea region is assumed. Otherwise, Candarli benefits from increased market volumes in the Black Sea and the Sea of Marmara region.

Table 7.12: Sensitivity analysis of market volume increase

	Assumed market volume increase*				Total costs for alternative hub ports**		
Scenario no.	Black Sea region	Sea of Marmara	Aegean Sea region	East Med. sea region	Port Said (´000 $)	Candarli (´000 $)	Difference (´000 $)
1	**o**	**o**	**o**	**o**	286,420.04	255,341.87	31,078.17
2	+	**o**	**o**	**o**	309,076.85	269,818.90	39,257.95
3	**o**	+	**o**	**o**	298,126.92	268,435.94	29,690.98
4	**o**	**o**	+	**o**	295,888.30	264,097.58	31,790.72
5	**o**	**o**	**o**	+	298,868.95	273,022.57	25,846.38
6	+	+	**o**	**o**	323,199.03	283,684.09	39,514.94
7	**o**	+	+	**o**	310,919.54	275,603.45	35,316.09
8	**o**	**o**	+	+	306,960.82	280,852.65	26,108.17
9	+	**o**	+	**o**	318,259.61	279,308.36	38,951.25
10	+	**o**	**o**	+	320,500.69	288,631.05	31,869.64
11	**o**	+	**o**	+	312,501.39	283,657.26	28,844.13
12	+	+	+	**o**	332,576.84	291,443.00	41,133.84
13	**o**	+	+	+	322,131.10	291,084.21	31,046.89
14	+	+	**o**	+	334,665.42	299,057.31	35,608.11
15	+	**o**	+	+	333,242.55	295,495.20	37,747.35
16	+	+	+	+	344,605.35	308,725.32	35,880.03

*o indicates that the company will maintain its current market share; + indicates that the company will increase its current market share in the region by 25%. ** The results show the best of 10 replications of the heuristic for alternative hub ports with 4 weeks deadline and 7 days service frequency for a 52 week sailing season.

7.3.4 Concluding remarks

In this section, we focus on the potential hub role of a new port (Candarli) in the East Mediterranean and Black Sea region and apply a heuristic procedure to solve the feeder network design problem faced by a short-sea shipping company. Based on the container transportation demand at feeder ports, the feeder network and fleet mix, the composition of routes and the schedule of the vessels operating on these routes are determined by minimizing total operational costs. A mathematical model of the feeder network design problem has been developed. Because of the complexity of the optimization problem an efficient heuristic solution procedure was applied.

In the numerical investigation the cost performance of three strategic options for hub port configurations has been compared. From the numerical results it can be concluded that Candarli as a new hub port offers significant cost savings compared to Port Said which is currently used as a hub port by the considered company. However, these cost savings would be compensated with additional transhipment cost for the Port Said - Candarli services which are needed to connect Candarli to the global trunk shipping lines. Therefore, additional factors like service quality and handling efficiency at the hub ports as well as waiting time in the queue of the hub ports play an important role in the development of the company's feeder network configuration. Certainly, the new Candarli port has great market potential as long as port authorities keep container handling costs and service quality at a favourable level.

7.4 LSND under unstable demand environments

The LSND problem presented in Section 5.4 is a highly complex combinatorial optimization problem and is thus hard to solve with the use of standard optimization software. Exact methods for solving the LSND problem are generally not practical for large instances because of the problem complexity. We therefore employ a simulation-optimization based solution framework which contains a hybrid solution heuristic called Adaptive Neighborhood Search (Section 6.1) and a simulation and artificial neural networks based forecasting model (Section 6.2) is proposed to solve the joint problem.

In this section, we consider the Black Sea region as an application example to analyze the design problem of liner shipping networks under unstable demand environments from the perspective of a feeder shipping company commencing its services from a newly constructed port. The design of the service network is revised at the beginning of every period in response to changes in demand patterns for a season estimated with a simulation based forecasting framework. Changes to the service network may include introducing new routes, and schedules as well as fleet deployments which could contain chartering in new ships or chartering out unnecessary ships. This section also employs various service scenarios in order to better help decision makers of liner shipping providers. These scenarios contain different periodical approaches, different demand allocations, different numbers of owned ships at the start of sailing season, and different ship prices to provide a very high degree of flexibility for planning decisions under unstable demand environments.

7.4.1 Implementation

The mathematical model presented in Section 5.4 has been solved with the proposed ANS approach in Section 6.1 coded using Matlab R2009a and executed by using Visual C# 2010 on an Intel Core-2-Duo T5750 2.0 GHz processor with 3 GB RAM.

The candidate networks created by the ANS according to periodical demands estimated by forecasting framework are evaluated using a fitness function. Since ANS is originally intended to solve the VRPSPDTL with homogenous vehicles under the objective to minimize the total travel distance with stable demands in the network, it is necessary to adjust the fitness function of the ANS according to the unstable demand environment of the LSND problem. In our implementation of the ANS total operation costs of all routes and all periods for the entire sailing season according to the cost functions (5.41) and (5.42) of Section 5.4 are used as the fitness function. The respective procedure for calculating the fitness values is summarized in Figure 7.8. In the VRPSPDTL application candidate routes are generated with the help of neighborhood structures. In this step constraints (5.45) - (5.57) of the optimization model are checked in order to achieve feasible solutions. The regret value represents the difference between the ship types and deployments. The assignment with the highest regret value is assigned to the related route by considering on hand ship numbers. After assigning on hand ships to routes, the remaining empty routes are operated with charter ships. The idle on hand ships are chartered out to the market.

Apart from the network routes the ANS determines the fleet mix, the number of required ships according to Equation (5.43) and their deployment to routes in the candidate network under unstable demand environment for each period. Based on these data the total voyage cycle of a ship on a route is achieved as given by Equation (5.44), i.e. considering the related port service times, travel times between ports, lay-up times etc.

```
procedure: fitness function for ANS
input: candidate network
output: total network costs of candidate network (dNC)
start
  for each route (r) in the candidate network
    initialize a big number for total route cost (RC_r)
    for each ship type (s)
      if (hub and each feeder port departure and arrival loads are feasible for ship type s on
        route r)
        calculate voyage cycle time of route r with ship type s specifications
        if (voyage cycle time is feasible by considering maximum voyage dur. limit)
          calculate required ship number of ship type s for route r
          calculate variable costs for route r operated with ship type s
          calculate fixed costs for route r operated with chartered ship type s
          calculate fixed costs for route r operated with owned ship type s
          calculate total costs of route r operated with chartered ship type s (dRC_rs1)
          calculate total costs of route r operated with owned ship type s (dRC_rs2)
        end if
      end if
    end for
  end for
  create regret value index (variance) matrix between (dRC_rs1) and (dRC_rs2)
  sort rows and columns and rows of the matrix in descending order
  assign on hand ships to routes by considering on hand ship number and regret value
  charter in necessary ships
  charter out unnecessary ships
  calculate total network costs of candidate network (dNC)
end
```

Figure 7.8: Calculation of the LSND fitness function

7.4.2 Case study

The fact that the considered region is surrounded by several seas – the Black Sea, Mediterranean Sea, Adriatic Sea, Ionian Sea, Aegean Sea, and Marmara Sea – makes maritime shipping a prime area for sustained growth (see Figure 7.10). Container feeder shipping lines offer crucial transport connections between the hinterland of this region and global trunk shipping lines. The feeder shipping dynamics of the region are mainly related to container transportation volumes of the trunk shipping lines between the Far East and Europe. In recent years, parallel to the increase of container transportation volumes on the global trunk shipping lines, an increase of the total container handling volume has been observed in the regional feeder ports. This is particularly true for ports in the Black Sea region. Hence, the outlook for the maritime transportation market in the region is very promising (Varbanova 2011a).

Figure 7.9: Regional ports

In this region, a particular feeder liner shipping provider would like to design its service feeder network with a new hub port at Candarli in Turkey. Since liner shipping has been directly affected by financial, political and seasonal conditions, the provider would like to design its service networks by considering the seasonal demand fluctuations in this region.

The considered problem is tested under a four-week service time deadline and seven-day service frequency conditions for a 52-week sailing season. In this region, the concerned feeder liner shipping provider has 36 contracted container terminals at 26 feeder ports in 12 countries. Table A.10 in the Appendix shows detailed information about the terminals, including country and sub-region information, market share of a shipping line provider in related terminals, operation efficiency of terminals, and yearly total throughputs of related terminals between 2005 and 2011.

Because of the limited berth depth at some regional ports and well-known traffic bottlenecks at the Bosporus and Dardanelles straights, ships of three different sizes are considered in the numerical experiment. The major cost parameters for all ship types are shown in Table 7.13.

Table 7.13: Extended parameter values for ship types

Parameter	Unit	Ship1	Ship 2	Ship 3
Capacity	TEU	4300	2600	1200
Operating speed	(knots)	22.60	19.90	17.40
Fuel consumption (on sea)	(tons/hour)	5.26	2.82	1.51
IFO 180 price (on sea)	($/ton)	647.50	647.50	647.50
Fuel consumption (on port)	(tons/hour)	0.26	0.14	0.08
MGO price (on port)	($/ton)	890.00	890.00	890.00
Chartering costs (charter in)	($/day)	12772.00	7579.00	5866.00
Amortization costs (on hand)*	($/day)	6386.00	3789.50	2933.00
Rent price (charter out)**	($/day)	9579.00	5684.25	4399.50
Operating costs	($/day)	11520.00	8887.00	6023.00
Port charges	($/call)	35000.00	29000.00	22000.00
Lay-up time	(hour/call)	28.80	24.00	16.80
Set-up time	(hour/port)	2.00	1.80	1.50
Planning period	Days	364	364	364

Sources: Stopford (2009), VHSS (2013), BunkerIndex (2012),* Amortization cost used as 50% of charter in cost, ** Charter out price used as 75% of charter in cost.

7.4.3 Demand estimation

In this region, the statistical databases on container throughput of the ports are scare and hard to handle seasonal throughputs from the port authorities. For that reason, yearly throughputs of regional container terminals are firstly decomposed into monthly supply and demand amounts by using monthly import and export foreign trade rates of related port countries. Table A.11 in the Appendix shows monthly import and export foreign trade volumes of related countries between 2005 and 2011. Table 7.14 shows an example decomposition of the Odessa container terminal in 2011. The percentages of monthly export and import trades in yearly total foreign trade volumes are calculated. Then the percentages are used in order to find the monthly statistics of related ports.

Secondly, decomposed monthly statistics are used in the proposed ANNs approach in order to forecast monthly demand and supply throughputs of terminals. Figure 7.10 shows monthly decomposed demand and supply throughputs of the Odessa container terminal between 2005 and 2011, and monthly forecasted throughputs for 2012.

Table 7.14: An example of monthly throughputs decomposition

	1	2	3	4	5	6	7	8	9	10	11	12	Total
Trade Export ($ Million)*	4621	5379	5382	5603	5969	5889	5365	5769	5974	5716	6283	6459	68409
Trade Import ($ Million)*	5037	6463	7016	6298	6766	6772	6522	7208	7412	7545	7675	7892	82606
Export in foreign trade (%)	3.06	3.56	3.56	3.71	3.95	3.90	3.55	3.82	3.96	3.79	4.16	4.28	45.3
Import in foreign trade (%)	3.34	4.28	4.65	4.17	4.48	4.48	4.32	4.77	4.91	5.00	5.08	5.23	54.7
Container export (TEU)	13883	16160	16169	16833	17933	17693	16118	17332	17948	17173	18876	19405	205523
Container import (TEU)	15133	19417	21078	18921	20327	20345	19594	21656	22269	22669	23058	23710	248177

*Source: Ukraine's monthly foreign trade in goods (2011), Total throughputs of the Odessa container terminal is 453700 TEU in 2011.

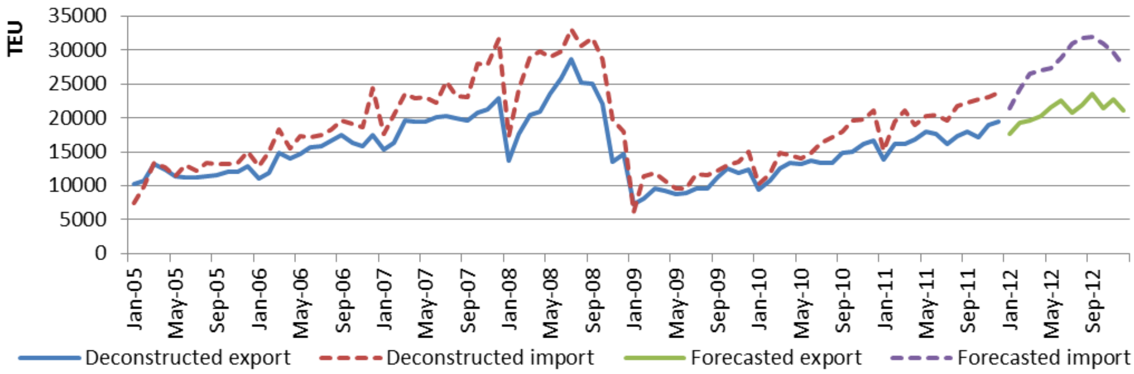


Figure 7.10: An example of monthly throughputs estimation

In order to reflect fluctuations in daily operations, a Monte Carlo simulation framework is designed according to expert opinions from the port and shipping authorities. The designed framework contains two sub-modules, which create a final fluctuation coefficient. For each month, the ordinary day throughputs (forecasted throughput amount of the month / the number of days in the month) are fluctuated with this coefficient. In the designed framework, the first module is used to reflect fluctuations within weekdays and the second module is used to reflect fluctuations within month days. Table 7.15 and Table 7.16 show designed simulation coefficients for week and month days according to expert opinions. In the tables, coefficients represent operation workload expectations of the days, and workload ratios represent situations of that day compared to an ordinary day. Table 7.17 shows an example calculation for fluctuation coefficients of ordinary days.

Table 7.15: Simulation coefficients for week days

Days	Low (0.8)	Mid (1)	High (1.2)
Monday	20%	40%	40%
Tuesday	30%	60%	10%
Wednesday	40%	40%	20%
Thursday	40%	50%	10%
Friday	10%	30%	60%
Saturday	10%	50%	40%
Sunday	50%	40%	10%

Table 7.16: Simulation coefficients for month days

Days	Low (0.7)	Mid (1)	High (1.3)
First 5 days	10%	50%	40%
Mid-days	40%	40%	20%
Last 5 days	10%	20%	70%

Table 7.17: An example of daily throughputs fluctuation

Date	Day	Random number	Week day coef-ficient	Random number	Month day coefficient	Final fluctuation coefficient	Ordinary day demand	Fluctu-ated demand
05 October 2011	Wed.	0.00543	0.80	0.85504	1.30	1.04	6405	6661
06 October 2011	Thu.	0.66611	1.00	0.93674	1.30	1.30	6405	8327

Thirdly, the proposed fluctuation simulator is run 100 times for each day of each month by using forecasted throughputs. In addition, different random components of the future demand and supply throughput expectations of terminals are obtained. Figure 7.11 shows average daily fluctuated demand and supply throughputs of the Odessa container terminal for a 364-day sailing season in 2012. Since the considered problem is tested under seven-day service frequency, the daily throughputs are collected into weekly throughputs.

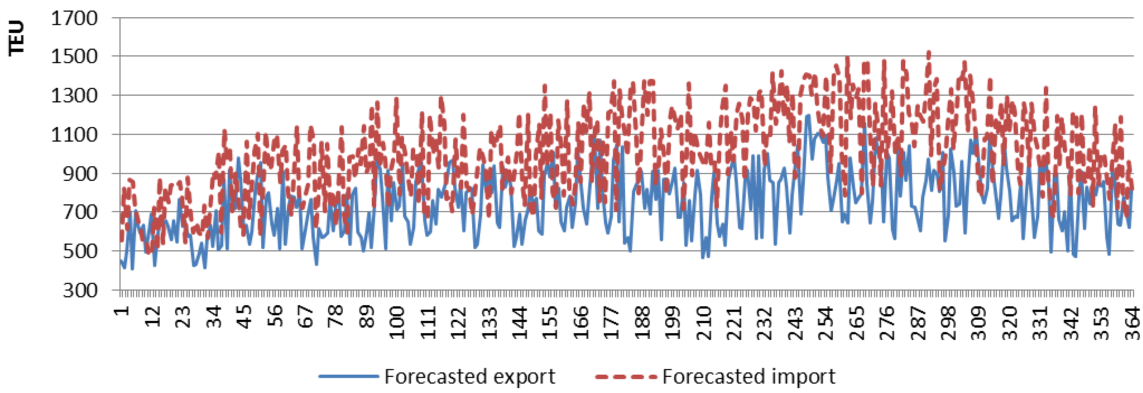


Figure 7.11: An example of daily throughputs simulation

Figure 7.12 shows weekly expected demand and supply throughputs of the Odessa container terminal and total demand and supply throughputs of the region for a 52-week sailing season in 2012. These weekly throughput estimations are used in the case study to design feeder service networks under unstable demand environments.

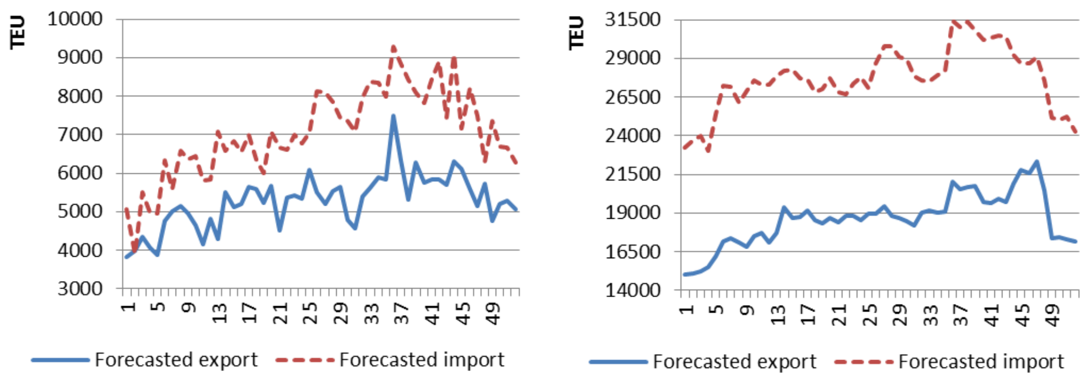


Figure 7.12: Examples of weekly demand estimations of the Odessa container terminal (right) and whole region (left)

7.4.4 The impact of seasonal demand fluctuations

In order to analyze how the seasonal demand fluctuations are affecting the service networks of shipping lines, the developed ANS algorithm is run ten times with different random seeds for each week during a 52-week sailing season by using the forecasted demands. Figure 7.13 shows the region's minimum total cost, which includes chartering costs, operating costs, administration costs, on-sea bunker costs, on-port bunker cost and port charges for a 52-week sailing season. In other words, the figure shows how seasonality and demand fluctuations on throughputs are affecting the total service cost of the region. The optimal total cost of the region changes from \$238,940,000 to \$320,690,000 meaning that there is a 34.21% cost difference between the 1st and 38th weeks of the sailing season. Please note that these total cost figures represent total cost of the entire planning horizon by using related week's demand.

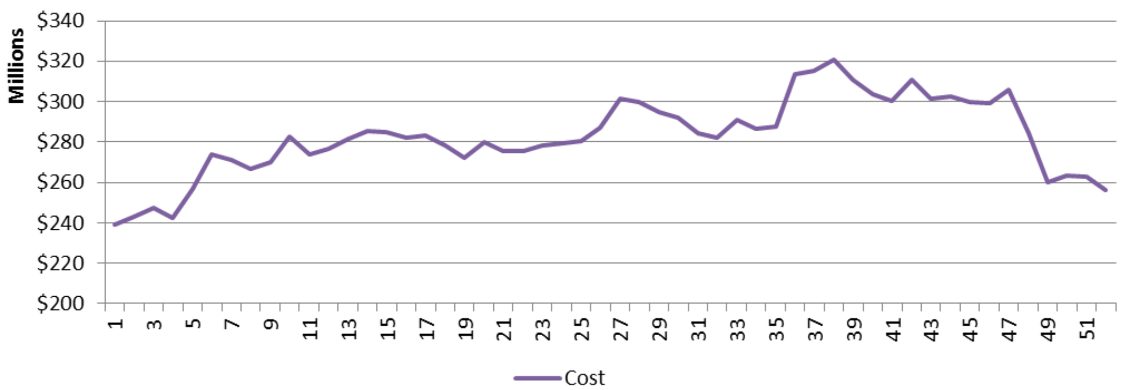


Figure 7.13: Minimum total cost of the region for a 52-week sailing season

Since total voyage distances of feeder networks are less than those of trunk networks, total network costs contain more ship based fixed costs, such as chartering, operating and administration (Polat et al. 2013). Therefore, the cost difference within weeks mainly results from the number of service routes, the number of necessary ships and the types of these ships. Figure 7.14 and Figure 7.15 show how these parameters change during the season.

In Figure 7.14, the optimal route number of the network changes from 13 to 17. Since hub port Candarli has shorter distances to feeder ports, small and mid-sized containerships are employed in low demand seasons; relatively mid-sized containerships are employed in regular demand seasons; and big ships only start to be employed in high demand seasons. Consequently, 34.70% of the routes are serviced by small ships, 64.78% by mid-sized ships, and 0.53% by big ships. On the other hand, the total slot capacity of the routes changes parallel with the total import of the region. Out of these slots, 19.61% are owned by small ships, 79.32% by mid-sized ships, and 1.07% by big ships. The necessary slot capacity fluctuates between 25,400 TEU (28.35% by small and 71.65% by mid-sized ships) and 37,500 TEU (19.20% by small, 69.33% by mid-sized and 11.47% by big ships). This means that there is a 47.64% necessary slot capacity difference between the 1st and 37th weeks of the sailing season.

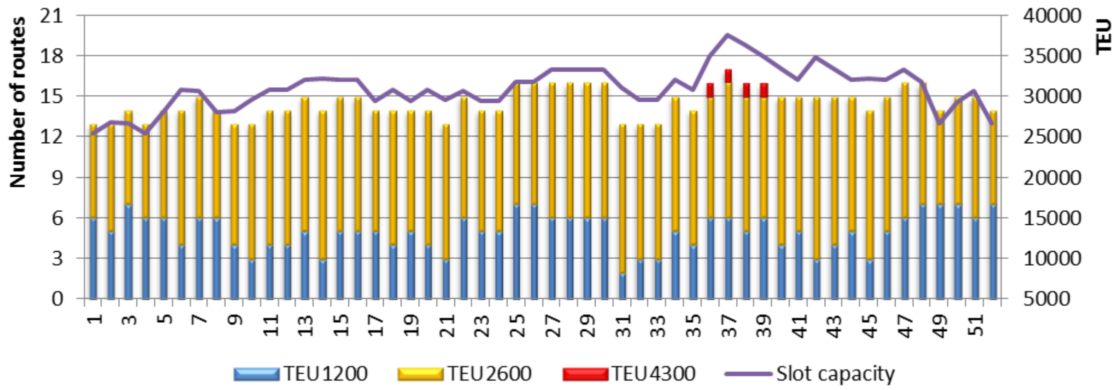


Figure 7.14: Necessary number of routes with ship types and slot capacity

In Figure 7.15, the necessary ship size and mix of the service network changes from 23 ships (39.13% by small and 60.87% by mid-sized) to 30 ships (30.00% by small, 63.33% by mid-sized, and 6.67% by big sized). This number determines the minimum number of ships required to service the region, with seven-day frequency, according to the related week's demand expectation for a 52-week sailing season. Therefore, the number of required ships is more critical than the number of routes for the total cost of the network. The slot capacity of ships fluctuates between 47,200 TEU (22.88% by small, and 72.12% by mid-sized ships) and 71,800 TEU (8.36% by small, 79.67% by mid-sized, and 5.99% by big ships). This means that there is a 47.64% necessary slot capacity difference between the 1st and 38th weeks of the sailing season. On the other hand, the utilization ratio of total slot capacity fluctuates between 68.71% and 80.04%, which is mainly the result of import - export imbalances (avg. 1.49) in the region.

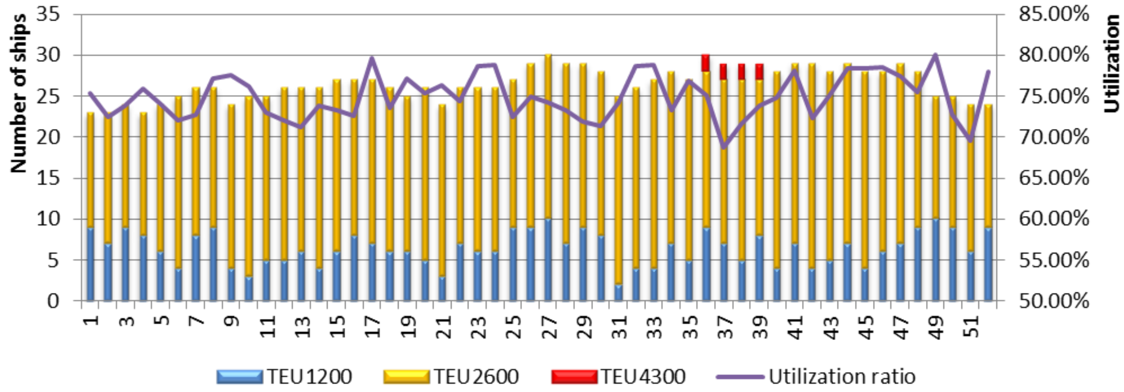


Figure 7.15: Necessary minimum number of ships with types and capacity utilization

The decisions in tactical planning operations of liner shipping, such as fleet size and mix, fleet deployment, ship routing and scheduling are made according to container throughput estimations. However, these throughputs are highly affected by unstable financial, political and seasonal conditions. In this study, we focus on developing a Monte Carlo simulation and artificial neural networks based forecasting frame to analyze the impact of these conditions on the liner shipping feeder service network design. The proposed model implementation has been tested for the liner shipping feeder service in the Black Sea region. The optimal feeder networks are calculated according to the forecasted throughputs of the region terminals for each week during a 52-week sailing season. The results show that the total cost of the region service network is affected around 34.21%, the total slot capacity is affected around 47.64%, and utilization of the slot capacity, the necessary ship type and mix is highly affected by these unstable conditions. These figures show the importance of dynamic and flexible feeder service network designs in liner shipping in making effective and efficient plans.

7.4.5 Experimental design

The previous section assumes that shipping line providers allow weekly service network design change. However in practice, due to market service restrictions, providers of shipping lines could change their service networks only a couple of times within a yearly planning horizon. In this section, we therefore evaluate service network designs by allowing a limited number of changes in the service network. In the content of this study, we use monthly, bi-monthly, quarterly, trimester, semi-annual, and annual seasonal periods in order to update demand figures and service network designs. Table 7.18 shows these seasons and shows week allocations to these seasons, thus demonstrating how many weeks each season contains.

Table 7.18: Seasonal week allocations to periods (Scenario A)

<table>
<tr><th>Approach</th><th>Number of periodical seasons</th><th>Jan.</th><th>Feb.</th><th>Mar.</th><th>Apr.</th><th>May</th><th>Jun.</th><th>Jul.</th><th>Aug.</th><th>Sep.</th><th>Oct.</th><th>Nov.</th><th>Dec.</th></tr>
<tr><td>1</td><td>12</td><td>5</td><td>4</td><td>4</td><td>4</td><td>4</td><td>5</td><td>5</td><td>4</td><td>4</td><td>4</td><td>4</td><td>5</td></tr>
<tr><td>2</td><td>6</td><td colspan="2">9</td><td colspan="2">8</td><td colspan="2">9</td><td colspan="2">9</td><td colspan="2">8</td><td colspan="2">9</td></tr>
<tr><td>3</td><td>4</td><td colspan="3">13</td><td colspan="3">13</td><td colspan="3">13</td><td colspan="3">13</td></tr>
<tr><td>4</td><td>3</td><td colspan="4">17</td><td colspan="4">18</td><td colspan="4">17</td></tr>
<tr><td>5</td><td>2</td><td colspan="6">26</td><td colspan="6">26</td></tr>
<tr><td>6</td><td>1</td><td colspan="12">52</td></tr>
</table>

Since each service week has different demand levels, it is necessary to assign common supply and demand figures to related seasons. In this study, we compared five different approaches in order to assign supply and demand figures to seasons (Table 7.19). The first approach assigns each terminal's maximum demanded (demand or supply) week figure as seasonal demand for the terminal. The second approach assigns the maximum total demanded week's figures as seasonal demand for each terminal. The third approach assigns each terminal's minimum demanded week figure as seasonal demand for the terminal. The forth approach assigns the minimum total demanded week's figures as seasonal demand for each terminal. The fifth approach assigns seasonal demand according to the average seasonal demand of each terminal in the season.

Table 7.20 shows an example of seasonal demand assignments according to demand and supply of four ports and four weeks.

Table 7.19: Seasonal demand assignment approaches (Scenario B)

No	Approach
1	According to maximum demanded week of each terminal in the season
2	According to maximum total demanded week of the season
3	According to minimum demanded week of each terminal in the season
4	According to minimum total demanded week of the season
5	According to average seasonal demand of each terminal in the season

Table 7.20: Example of seasonal demand assignments

	Terminal A		Terminal B		Terminal C		Terminal D	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
Week 1	40	30	35	31	34	45	21	12
Week 2	47	32	31	30	28	42	20	16
Week 3	40	24	28	25	30	50	12	8
Week 4	34	20	24	15	25	40	14	10
Approach 1	47	32	35	31	30	50	21	12
Approach 2	40	30	35	31	34	45	21	12
Approach 3	34	20	24	15	25	40	12	8
Approach 4	34	20	24	15	25	40	14	10
Approach 5	40	27	30	25	29	44	17	12

Another strategic decision on feeder lines is the ratio between owned and chartered ships in the fleet. Feeder lines usually operate a small fixed number of owned ships and balance their requirements with chartered ships. This could decrease their capital costs and make their network more flexible to changes in trade. However, if there is a stable or increasing demand trend in the market, operating with a high number of charter ships could be couple of times more costly than operating with owned ships. Therefore, it is crucial for feeder lines to define the minimum number of owned feeder ships for long term efficiency.

In this study, we compared six different approaches in order to determine owned ship numbers at the start of planning horizon (Table 7.21). The first approach starts with no owned ship and uses only charter in ships during the planning horizon. The second approach assigns ships according to maximum slot demanded season of the planning horizon in the no owned ship approach. This approach guarantees that all demand and supply on the market will be satisfied by the shipping lines. However, it could result in overcapacity in the total transportation slots. During the planning periods, when the ships become idle, they could be chartered out. The third approach defines owned ship numbers according to the maximum necessary ship numbers from each type of ship from all seasons which is calculated in the no owned ship approach. This approach also guarantees satisfaction of the customer demand, but could decrease utilization of the owned on hand ships. The forth approach assigns ships according to minimum slot capacity demanded season of the planning horizon in the no owned ship approach. This approach does not guarantee the satisfaction of the demand of the ports, but increases the utilization of the ships and charter in ship numbers. The fifth approach defines owned ship numbers according to the minimum necessary ship numbers from each type of ship from all seasons which is calculated in the no owned ship approach. This approach also does not guarantee satisfaction of the customer demand, but could decrease total owned ship costs and increase charter in ship numbers. The sixth approach defines on hand ships according to average necessary ship numbers from each type of ship during the planning horizon which is defined in the no owned ship number approach.

Table 7.22 shows an example of owned ship number determination approaches for four periods and three ship types.

Table 7.21: Owned ship number determination approaches (Scenario C)

No	Approach
1	No owned ship
2	According to maximum slot demanded season of the network in all seasons
3	According to maximum necessary ship numbers from each type of all seasons
4	According to minimum slot demanded season of the network in all seasons
5	According to minimum necessary ship numbers from each type of all seasons
6	According to average necessary ship numbers from each type of all seasons

Table 7.22: Example of owned ship number determination approaches

		Ship 1 (4300)		Ship 2 (2600)		Ship 3 (1200)		Slot capacity
	Charter	in	out	in	out	in	out	TEU
Approach 1	On hand	0		0		0		0
	Period 1	0	0	4	0	10	0	22400
	Period 2	0	0	5	0	5	0	19000
	Period 3	1	0	6	0	9	0	30700
	Period 4	0	0	3	0	6	0	15000
Approach 2	On hand	1		6		9		30700
	Period 1	0	1	0	2	1	0	22400
	Period 2	0	1	0	1	0	4	19000
	Period 3	0	0	0	0	0	0	30700
	Period 4	0	1	0	3	0	3	15000
Approach 3	On hand	1		6		10		31900
	Period 1	0	1	0	2	0	0	22400
	Period 2	0	1	0	1	0	5	19000
	Period 3	0	0	0	0	0	1	30700
	Period 4	0	1	0	3	0	4	15000
Approach 4	On hand	0		3		6		15000
	Period 1	0	0	1	0	4	0	22400
	Period 2	0	0	2	0	0	1	19000
	Period 3	1	0	3	0	3	0	30700
	Period 4	0	0	0	0	0	0	15000
Approach 5	On hand	0		3		5		13800
	Period 1	0	0	1	0	5	0	22400
	Period 2	0	0	2	0	0	0	19000
	Period 3	1	0	3	0	4	0	30700
	Period 4	0	0	0	0	1	0	15000
Approach 6	On hand	0		5		8		22600
	Period 1	0	0	0	1	2	0	22400
	Period 2	0	0	0	0	0	3	19000
	Period 3	1	0	1	0	1	0	30700
	Period 4	0	0	0	2	0	2	15000

In addition to the previous experiments, a comprehensive numerical investigation is presented to evaluate how the general change in ship prices (owning, charter in, charter out) impacts on the design of the service network configuration.

Table 7.23: The change in the ship prices (Scenario E)

No	Approach
1	50% decrease in ship prices
2	25% decrease in ship prices
3	No change in ship prices
4	25% increase in ship prices
5	50% increase in ship prices
6	100% increase in ship prices

In order to evaluate the performance of the week allocation approaches, owned ship number approaches, and demand allocation approaches with service environment parameters an experimental design framework is conducted. The conducted experimental design consists of four test families by using four design and environment scenarios (Table 7.24).

Table 7.24: Designed experimental tests

Test	Scenario A	Scenario B	Scenario C	Scenario D
1	1-2-3-4-5-6	2	1	3
2	1-2-3-4-5-6	1-2-3-4-5	1	3
3	1-2-3-4-5-6	2	1-2-3-4-5-6	3
4	3	2	1-2-3-4-5-6	1-2-3-4-5-6

7.4.6 Numerical results

The designed experimental tests in the previous section are solved by using the developed ANS algorithm for a 52-week sailing period with the forecasted demands in Section 7.4.3 Please see Total throughput of **related container terminals, the operation amount of interested feeder shipping line could be calculated by using market share ratios in** Table A.10.

Table A.13 in the Appendix for the detailed results of the experiments. Figure 7.16 shows how the weekly network costs of a different number of periodical seasons change during the sailing period. According to the results, as long as the periodical change number increases, the flexibility of the service network increases in order to adapt itself to seasonal demand fluctuations. The total cost of the network therefore increases when the seasonal period number is decreased in a sailing period. When monthly change in the service network is allowed, the total network cost for a sailing season is around 309 million dollars. Total network cost is around 316 million dollars for bi-monthly change, 320 million dollars for quarterly change, 323 million dollars for trimester change, 324 million dollars for semi-annual change, and 340 million dollars for annual seasonal change to update demand figures and service network designs. Figure 7.17 shows how the slot utilization of the ships changes for different numbers of periodical seasons during weeks in the sailing season. As long as the number of change periods is increased, the utilization ratio of the ship slots increases as well. Both cost and utilization figures show the importance of flexible and demand dependent service network designs. However, despite the advantage of changing the design of service networks more frequently, it is not practical to change service networks every two months or sooner. Therefore under assumptions of this scenario changing a service network quarterly is the most effective approach for shipping lines under demand fluctuations.

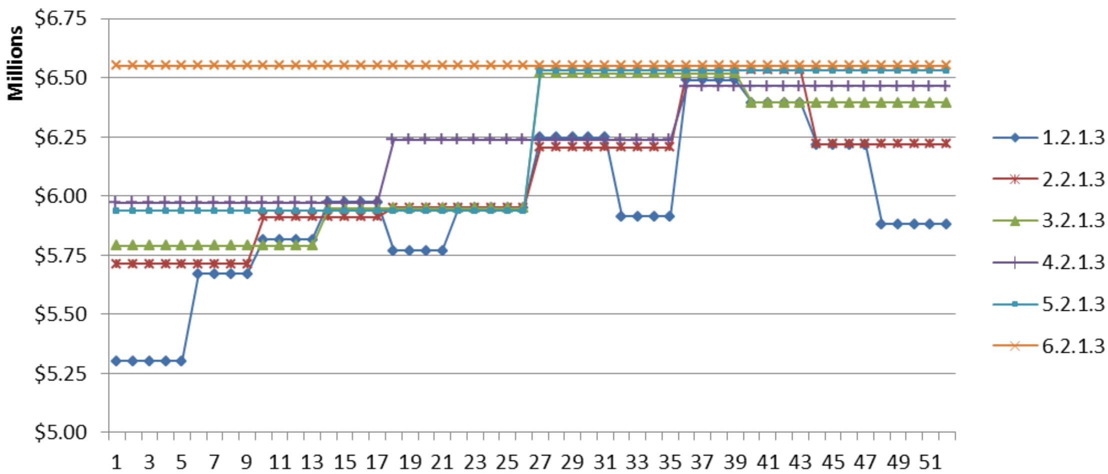


Figure 7.16: Effect of seasonal change number on the weekly total cost of the network (Test 1)

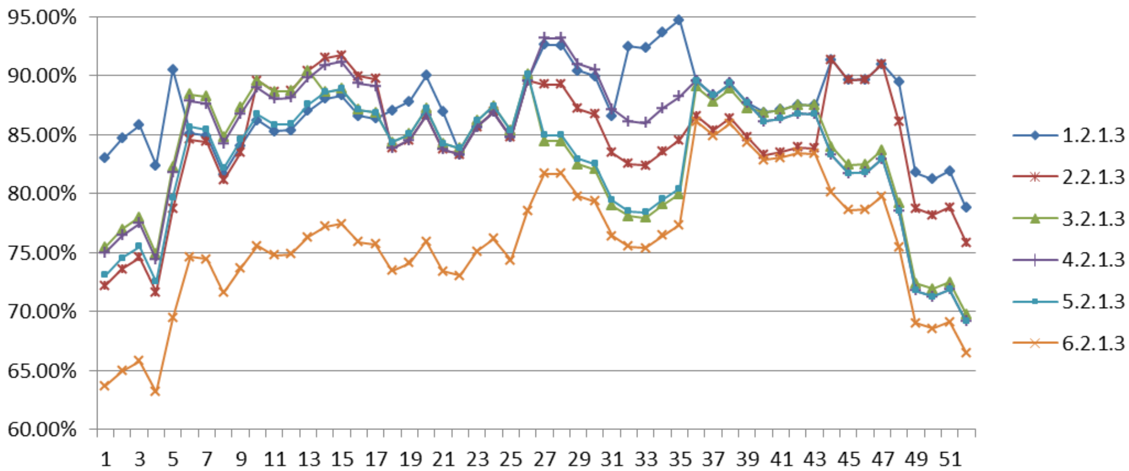


Figure 7.17: Effect of seasonal change number on the weekly capacity utilization of the network (Test 1)

Figure 7.18 shows the result of the second test family which evaluates the dual impact of different numbers of periodical seasons and different seasonal demand assignment approaches by considering other scenarios fixed. Figure 7.19 shows how the slot utilization of the ships changes for different demand assignments during weeks in the sailing season by considering quarterly service network change. In these figures, the network cost of rule 1 and rule 2, which use maximum based demand approaches, highly increases as the number of network changes is decreased because of the usage of high demanded week's rates. Since these approaches are allocating more slots to terminals, they require more ships during the planning periods. By designing according to maximum demanded week's values, the network design ensures that there will be no overcapacity during the weeks. But this will come with respectively low utilization rates. On the other hand in minimum based demand approaches (3 and 4), the total network cost decreases as the number of network change is decreased because of the usage of low demanded week's values. Since these approaches are allocating fewer slots to terminals, they require fewer ships during the planning periods. By designing according to minimum demanded week's values, the network design aims to increase utilization rates during the weeks. However this could result in overcapacity in rush weeks. Although the third approach, which assigns the minimum demanded week of each terminal in the season as seasonal demand, has the lowest network costs of all seasonal change approaches, its utilization rate is always more than 100% which could result in lost sales during the periods. The forth approach which assigns minimum total demanded week's values as seasonal demand also has correspondingly low total network costs. But its utilization rate is generally more than 100% which could also cause lost sales during the planning horizon. The cost of the fifth demand assignment approach is almost the same in all seasonal change approaches. However robustness of it disappears when the change number is decreased. It starts to become more over capacity. The approach also generally has more than 90% capacity utilization which increases the risk of overcapacity. In practice, the expected capacity utilization is around 90% in order to handle other unexpected demand fluctuations and irregular container types. Therefore it could be suggested that the second demand assignment approach, which assigns according to maximum total demanded week of the season, has more robust conditions to handle demand fluctuations within the season. Thus, demand change scenario 2 and seasonal change scenario 3 is the most effective and robust combination under these experimental conditions.

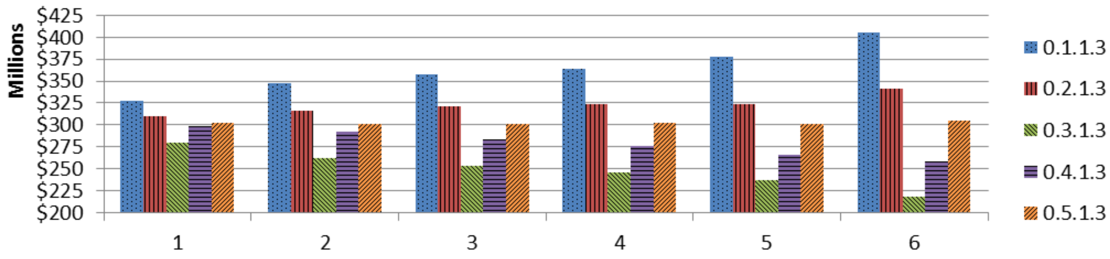


Figure 7.18: Impact of seasonal change number and demand assignment (Test 2)

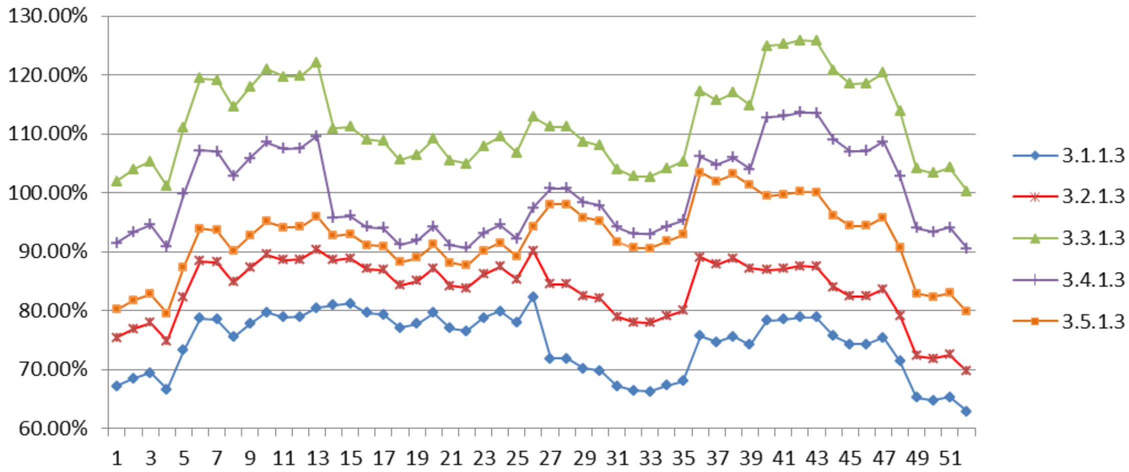


Figure 7.19: Impact of demand assignment on the weekly capacity utilization of the network (Test 2)

Figure 7.20 shows the result of the third test family which evaluates the dual impact of different numbers of periodical seasons and different starting owned ship number determination approaches by considering other scenarios fixed. The figure clearly shows the importance of owned ship number on decreasing total cost of the network. In all service network change approaches, the no owned ship approach has an almost 20% cost disadvantage compare to other approaches which use different owned ship strategies. As the service network change number decreases, the impact of owned ship number also decreases in these configurations. Within owned ship number approaches, maximum ship and slot based approaches (2 and 3) have the lowest total network costs. On the other hand, the network cost is slightly diverse between maximum and minimum based approaches. Therefore, the minimum demanded slot based owned ship approach could be used in order to decrease capital investment and become flexible to fluctuations in the seasonal demands. Please note that the approaches in this test assume that there is a broad market to charter in and out ships with no trouble.

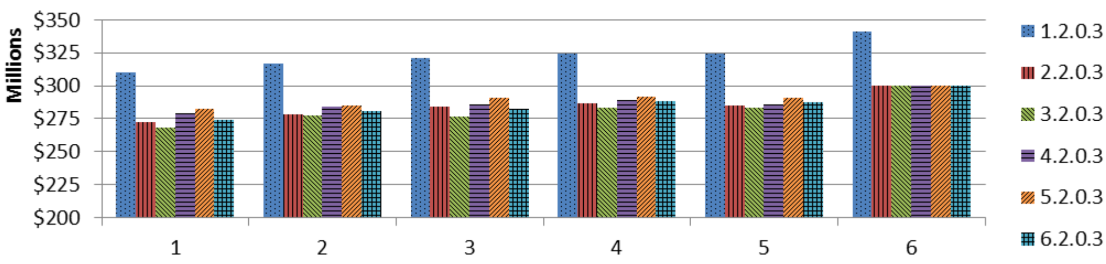


Figure 7.20: Impact of seasonal change number and owned ship number (Test 3)

Figure 7.21 shows the result of the fourth test family which analyzes the dual effect of different starting owned ship number determination approaches and the change in the ship prices by considering other scenarios fixed. The rates in the figures show that as long as ship prices increase the impact on owned ship number increases in the total network cost. With low ship prices the total network cost starts to be less ship cost oriented and the number of owned ships loses its importance. On the other hand, the total network cost is more ship price oriented under high ship prices.

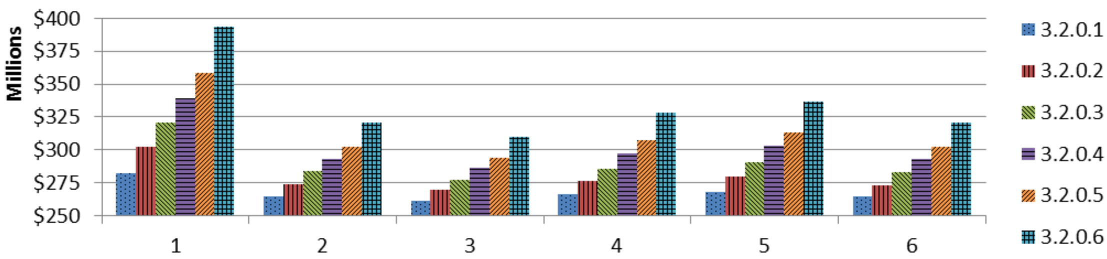


Figure 7.21: Impact of the owned ship number and ship price (Test 4)

7.4.7 Concluding remarks

The decisions in tactical planning operations of liner shipping, such as fleet size and mix, fleet deployment, ship routing and scheduling are made according to container throughput estimations. However, these throughputs are highly affected by unstable financial, political and seasonal conditions. Therefore in this study, an adaptive neighborhood search approach is used to determine the feeder ship fleet size and mix, fleet deployments, service routes and voyage schedules to minimize operational costs for dynamic sailing seasons. A Monte Carlo simulation and an artificial neural networks based forecasting framework are also used to estimate unstable throughput demands of regional ports. In our case study investigation, we assume the feeder network design problem of a Turkish short-sea shipping company in view of the opening of the new Candarli port near Izmir. The cost performance of alternate feeder network configurations serving the Black Sea region is compared under unstable demand environments.

The optimal feeder networks are calculated according to the forecasted throughputs of the region terminals for each week during a 52-week sailing season. The results show that the total cost of the region service network is affected around 34.21%, the total slot capacity is affected around 47.64%, and utilization of the slot capacity, the necessary ship type and mix are highly affected by these unstable conditions. These figures show the importance of dynamic and flexible feeder service network designs in liner shipping in making effective and efficient plans. This study could be extended by developing liner shipping service network designs under unstable freight rate and oil price environments.

8. Summary

The introduction of mega containerships on the main international sea routes between major seaports made it necessary to temporarily store containers in a specific region and to distribute them on short-sea routes. Therefore in addition to the location of hub ports, regional feeder containership service is a critical issue in designing global networks of shipping lines. In conceptual terms, the feeder containership service collects and drops containers in a specific region with small and medium sized containerships and feeds mega containerships so as to avoid their calling at too many ports. It was the containership feeder line that made the entire container service economically rational, efficient, more profitable, and consequently cheaper and timely for the end users. Hence developments of effective service network designs are essential in order to better help decision makers of liner shipping providers in different environments. In a sailing season, an effective service network includes joint solution of tactical planning decisions, such as fleet size and mix, fleet deployment, ship routing and scheduling. The container feeder network design depends on the characteristics of feeder ships, the feeder ship ports, the operating and chartering costs of the ships and bunker costs, as well as container demand throughputs of the ports.

The decisions in tactical planning operations of liner shipping, such as fleet size and mix, fleet deployment, ship routing and scheduling are made according to container throughput estimations. Container demand throughputs of ports are therefore one of the main design parameters of service networks. Nevertheless, they have been directly affected by unexpected local and global demand fluctuations as well as seasonal conditions. Therefore, forecasting container throughputs of ports is playing a critical role at all the levels of planning decisions of liner shipping lines. Since liner shipping involves considerable capital investment and huge daily operating costs, the appropriate throughput demand estimation of a whole sailing season will state the development of service network design. In order to cope with the dynamic nature of shipping markets, it is also important to design more agile and flexible feeder service networks by allowing seasonal service network changes within a planning horizon.

Changes to the service network may include introducing new routes, and schedules as well as fleet deployments which could contain chartering in new ships or chartering out unnecessary ships. This thesis also employs various service scenarios in order to better help decision makers of liner shipping providers. These scenarios contain different periodical approaches, different demand allocations, different numbers of owned ships at the start of sailing season, and different ship prices to provide a very high degree of flexibility to planning decisions under unstable demand environments.

In Chapter 2 the reader is introduced to container shipping and especially to containerization history, terminology and standards, orientation of liner shipping, leading shipping lines and freight rates, and common service network designs.

Detailed information about the background of liner shipping feeder services, advantages and disadvantages of feeder services, the role of feeder services in modern global service networks, design parameters of feeder service networks, characteristics of feeder lines, the reasons for demand fluctuations in feeder services, and general problem types in different planning levels are presented in Chapter 3.

In Chapter 4 the relevant literature is summarized in order to underline potential gaps in liner shipping network designs, feeder services, vehicle routing problems, container throughput estimation, and liner shipping under unstable demand environments.

The feeder service network design (FND) problem is mathematically modeled in four parts in Chapter 5. While Section 5.1 handles the problem as the vehicle routing problem with simultaneous pick-up and delivery with time limit (VRPSPDTL), Section 5.2 handles the problem as feeder containership routing problem (FCRP) which is the basic version of FND without including sailing season, ship economies, and ship mix and deployment. Section 5.3 handles the basic FND problem for a stable sailing horizon for reducing the total transportation costs and Section 5.4 approaches the problem more realistically by considering varying forecasted throughput demands for a dynamic sailing season and vessel charter operations.

Two frameworks for the feeder service network design problems are provided in Chapter 6. The first framework proposes an Adaptive Neighborhood Search (ANS) combined with the classic savings heuristic as an initial solution construction algorithm, variable neighborhood search in order to improve the initial solution, and a perturbation mechanism to escape from local optima. The second framework provides a Monte Carlo simulation and an artificial neural networks based forecasting frame in order to analyze the impact of seasonal demand fluctuation on the liner shipping feeder service.

Numerical results of FND related problems are presented in four sections in Chapter 7. In Section 7.1, well known benchmark problem instances of the vehicle routing problem with simultaneous pick-up and delivery with time limit (VRPSPDTL) are solved with the developed ANS approach. From the numerical results it can be concluded that the proposed ANS algorithm generates efficient and robust solutions compared to existing solution methods for the VRPSPDTL. The ANS approach could obtain new best solutions or reach the best known solution for 19 out of the 28 benchmark instances with and without service time. This section proved the robustness and effectiveness of the developed ANS approach for vehicle routing problems. The proposed ANS algorithm can be adapted to consider heterogeneous fleet conditions and the dynamic environment of the VRPSPDTL.

In Section 7.2, FCRP with a case study from the Aegean Islands are solved with the developed ANS approach. The solutions existing in the literature improved around 3% by using the developed approach. Moreover, a range of scenarios and parameter values are used in order to test the robustness of the approach through sensitivity analysis. From the numerical results it can be concluded that the proposed ANS algorithm generates efficient and robust solutions for the FCRP. This section shows effective implementation of ANS to containership routing problems. The proposed ANS algorithm can be adapted in order to consider heterogeneous fleet conditions, multi depot characteristics, and dynamic environments of the FCRP.

In Section 7.3, the FND problem which aims to simultaneously determine the fleet size and mix, fleet deployment, ship routing and ship scheduling by minimizing total network costs in a sailing season are solved by using the developed ANS approach. In this section, we focus on the potential hub role of a new port (Candarli) in the East Mediterranean and Black Sea region for a short-sea shipping company. In the numerical investigation the cost performance of three strategic options for hub port configurations has been compared. From the numerical results it can be concluded that Candarli as a new hub port offers significant cost savings compared to Port Said which is currently used as a hub port by the considered company. However, these cost savings would be compensated with additional transhipment cost for the Port Said - Candarli services which are needed to connect Candarli to the global trunk shipping lines. Therefore, additional factors like service quality and handling efficiency at the hub ports as well as waiting time in the queue of the hub ports play an important role in the development of the company's feeder network configuration. Certainly, the new Candarli port has great market potential as long as port authorities keep container handling costs and service quality at a favourable level.

Finally, Section 7.4 considered the service network design problem of liner shipping networks under unstable demand environments from the perspective of a feeder shipping company commencing its services from a newly constructed port. The design of service networks is revised at the beginning of every period in response to changes in demand patterns for a season estimated with a simulation based forecasting framework. The proposed model implementation has been tested for a liner shipping feeder service in the Black Sea region. The optimal feeder networks are designed by using the forecasted throughputs of the region terminals for each week during a 52-week sailing season with the help of the developed ANS approach. The results show that the total cost of the region service and the total slot capacity is highly affected by unstable demand conditions. The related section also handles various service scenarios such as different periodical approaches, different demand allocations, different number of owned ships at the start of sailing season, and different ship owning, chartering, and oil prices in order to better help decision makers of liner shipping providers. These figures show the importance of dynamic and flexible feeder service network designs in liner shipping to make effective and efficient plans. This study could be extended by developing liner shipping service network designs under unstable freight rates and oil prices and environmental routing conditions.

A. Appendices

Table A.1: The top 100 liner shipping operators in 2013

Rank	Shipping Line Operator	Slot TEU	World Share	Total Ships	Average TEU
1	APM-Maersk	2,581,417	15.68%	593	4353.15
2	Mediterranean Shg Co	2,295,334	13.94%	473	4852.71
3	CMA CGM Group	1,421,398	8.63%	419	3392.36
4	COSCO Container L.	730,598	4.44%	158	4624.04
5	Evergreen Line	721,684	4.38%	184	3922.20
6	Hapag-Lloyd	652,750	3.96%	141	4629.43
7	APL	607,326	3.69%	128	4744.73
8	Hanjin Shipping	602,536	3.66%	114	5285.40
9	CSCL	569,186	3.46%	139	4094.86
10	MOL	499,893	3.04%	108	4628.64
11	OOCL	461,259	2.80%	98	4706.72
12	NYK Line	414,299	2.52%	95	4361.04
13	Hamburg Süd Group	413,498	2.51%	102	4053.90
14	K Line	352,106	2.14%	71	4959.24
15	Yang Ming Marine	350,646	2.13%	81	4328.96
16	Hyundai M.M.	346,097	2.10%	58	5967.19
17	Zim	320,018	1.94%	82	3902.66
18	PIL (Pacific Int. Line)	300,133	1.82%	146	2055.71
19	UASC	279,460	1.70%	49	5703.27
20	CSAV Group	255,536	1.55%	55	4646.11
21	Wan Hai Lines	162,501	0.99%	71	2288.75
22	HDS Lines	86,320	0.52%	21	4110.48
23	X-Press Feeders Group	76,466	0.46%	60	1274.43
24	NileDutch	67,482	0.41%	31	2176.84
25	TS Lines	67,342	0.41%	34	1980.65
26	SITC	65,892	0.40%	64	1029.56
27	KMTC	54,936	0.33%	39	1408.62
28	RCL (Regional Con-	50,209	0.30%	36	1394.69
29	CCNI	43,846	0.27%	17	2579.18
30	STX Pan Ocean (Con-	42,722	0.26%	22	1941.91
31	Grimaldi (Napoli)	39,944	0.24%	39	1024.21
32	UniFeeder	39,821	0.24%	41	971.24
33	Sinotrans	38,673	0.23%	32	1208.53
34	Seaboard Marine	36,690	0.22%	35	1048.29
35	Arkas Line / EMES	36,428	0.22%	33	1103.88
36	Matson	33,231	0.20%	23	1444.83
37	Simatech	33,122	0.20%	15	2208.13
38	Meratus	30,229	0.18%	53	570.36
39	Samudera	29,805	0.18%	37	805.54
40	Salam Pasific	28,327	0.17%	48	590.15
41	OEL / Shreyas	27,767	0.17%	22	1262.14
42	Schöller Group	27,447	0.17%	16	1715.44
43	Horizon Lines	26,264	0.16%	13	2020.31
44	Heung-A Shipping	26,166	0.16%	26	1006.38
45	Linea Messina	25,154	0.15%	13	1934.92
46	S.C. India	24,467	0.15%	7	3495.29
47	Tanto Intim Line	24,012	0.15%	40	600.30
48	Swire Shipping	23,918	0.15%	22	1087.18
49	Quanzhou An Sheng	23,078	0.14%	28	824.21

Rank	Shipping Line Operator	Slot TEU	World Share	Total Ships	Average TEU
50	Sinokor	22,599	0.14%	25	903.96
51	MACS	22,396	0.14%	14	1599.71
52	FESCO	21,147	0.13%	20	1057.35
53	Nam Sung	21,112	0.13%	24	879.67
54	Mariana Express Lines	20,020	0.12%	14	1430.00
55	Crowley Liner Services	18,718	0.11%	20	935.90
56	DAL	18,138	0.11%	8	2267.25
57	Log-In Logistica	16,402	0.10%	8	2050.25
58	Turkon Line	15,578	0.09%	9	1730.89
59	King Ocean	14,964	0.09%	17	880.24
60	Westwood	14,699	0.09%	7	2099.86
61	Grand China Logistics	14,693	0.09%	10	1469.30
62	Temas Line	14,660	0.09%	27	542.96
63	Hainan P O Shipping	13,937	0.08%	7	1991.00
64	Peel Ports (BG Freight)	13,222	0.08%	15	881.47
65	Great White Fleet	13,082	0.08%	23	568.78
66	United Feeder Services	12,887	0.08%	13	991.31
67	Emirates Shipping Line	12,630	0.08%	5	2526.00
68	Dole Ocean Liner	12,319	0.07%	18	684.39
69	Borchard Lines	12,190	0.07%	14	870.71
70	Marfret	12,089	0.07%	9	1343.22
71	Caribbean Feeder Ser-	10,382	0.06%	14	741.57
72	Interasia Line	10,230	0.06%	7	1461.43
73	Delphis NV / Team	10,030	0.06%	11	911.82
74	Containerships OY	9,480	0.06%	12	790.00
75	Independent Container	9,250	0.06%	4	2312.50
76	Goto Shipping	9,033	0.05%	6	1505.50
77	Vinalines	8,485	0.05%	14	606.07
78	SASCO (Sakhalin	8,395	0.05%	21	399.76
79	Shanghai Jin Jiang	7,794	0.05%	9	866.00
80	Chun Kyung (CK)	7,139	0.04%	14	509.93
81	Melfi C.L.	6,878	0.04%	6	1146.33
82	Lin Line	6,672	0.04%	3	2224.00
83	Eimskip	6,468	0.04%	10	646.80
84	SeaFreight	6,376	0.04%	6	1062.67
85	Tarros	6,343	0.04%	5	1268.60
86	Shin Yang Shipping	6,219	0.04%	17	365.82
87	Tropical Shg	6,178	0.04%	13	475.23
88	Kambara Kisen	6,136	0.04%	8	767.00
89	Caraka Tirta Perkasa	6,103	0.04%	9	678.11
90	Samskip	6,100	0.04%	10	610.00
91	Qatar Navigation	6,095	0.04%	8	761.88
92	HubLine Bhd	5,956	0.04%	10	595.60
93	Shanghai Hai Hua	5,919	0.04%	8	739.88
94	Maestra Navegaçao	5,674	0.03%	4	1418.50
95	OPDR	5,636	0.03%	9	626.22
96	Boluda Lines	5,427	0.03%	6	904.50
97	Merchant Shipping	5,387	0.03%	2	2693.50
98	Valfajre Eight Shg Co	5,299	0.03%	8	662.38
99	Perkapalan DZ PDZ	4,793	0.03%	7	684.71
100	TransAtlantic AB	4,770	0.03%	10	477.00
Total	Top 3	6,298,149	38.25%	1485	4241.1778
Total	Top 5	7,750,431	47.07%	1827	4242.1626
Total	Top 10	10,682,122	64.88%	2457	4347.628
Total	Top 20	14,175,174	86.10%	3294	4303.3315
Total	Top 50	15,490,032	94.08%	4257	3638.7202
Total	Top 100	16,013,562	97.26%	4810	3329.2229
Total	World	16,464,087	100.00%	4953	3324.0636

Source: Alphaliner (2013b)

Table A.2: Computer / Software benchmarking results

Algorithm	Computer	Softwarec	Score[a]	Ratio[b]
CIH	VAX 4000-500 71.4 MHz	Fortran 77	10*	0.01
ALT	Intel Pentium II 333 MHz	Fortran 77	25*	0.02
LNS	Intel Pentium IV 1.5 GHz 256 MB	C++	173	0.15
TS	AMD Athlon XP 2.0 GHz 256 MB	Pascal Deplhi 5.0	360	0.32
RTS	Sun Fire V440 1062 MHz	Fortran	100*	0.09
ILS	Intel Core 2 Duo 2.13 GHz 1024	C++ 6.0	850	0.76
ACS	Intel Xeon 2.4 GHz	C	350*	0.31
ANS	Intel Core 2 Duo T5720 2.0 GHz 2	Matlab R2009a &C#	1117	1.00

[a] Computer performance scores are according to Passmark Performance Test 7.0 software; [b]: Best solution times algorithms are scaled according to make a fair comparison. * Approximated values.

Table A.3: Best solution route sequences for CMT10Y* with service time

Route Number	Route Sequence	Route Distance	Route Duration	Starting Load	Returning Load
1	0-9-135-35-136-65-71-161-103-51-0	104.6	194.63	18.94	126.06
2	0-180-198-197-56-186-39-187-139-4-155-110-149-0	75.15	195.15	129.30	71.70
3	0-179-130-165-55-25-170-67-23-75-72-0	98.82	198.82	124.26	42.74
4	0-33-81-120-164-34-78-169-29-121-68-184-0	86.81	196.81	30.05	169.95
5	0-59-193-91-191-44-140-38-14-119-192-100-0	89.71	199.71	23.39	136.61
6	0-124-168-47-36-143-49-64-11-0	112.6	192.63	100.40	16.60
7	0-132-30-160-128-66-188-20-122--1-176-111-0	86.63	196.63	48.39	137.61
8	0-13-117-151-92-37-98-85-93-99-104-96-6-183-112-0	51.67	191.67	32.30	182.70
9	0-31-108-90-126-63-181-32-131-70-101-69-0	89.88	199.88	70.55	76.45
10	0-94-95-97-87-172-42-142-43-15-57-144-137-0	79.74	199.74	56.26	105.74
11	0-50-102-157-185-79-129-158-3-77-116-196-76-28-0	58.52	188.52	24.85	186.15
12	0-27-167-127-190-88-148-182--7-194-106-153-52-146-0	54.28	184.28	86.95	113.05
13	0-147-5-173-61-16-141-86-113-17-84-118-0	85.38	195.38	120.91	103.09
14	0-162-189-10-159-62-175-107-19-123-48-82-0	84.18	194.18	134.68	79.32
15	0-105-40-21-73-171-74-133-22-41-145-115-178-2-0	67.50	197.50	114.23	73.77
16	0-156-152-58-53-0	20.35	60.35	15.05	61.95
17	0-18-114-8-174-46-45-125-199-83-60-166-89-0	78.18	198.18	111.32	55.68
18	0-26-195-54-134-24-163-80-150-177-109-12-138-154-0	66.86	196.86	73.09	131.91
Total	-	1390.92			

*Vehicle capacity (Q): 200; Time Limit (R): 200

Table A.4: Best solution route sequences for CMT13X* without service time

Route Number	Route Sequence	Route Distance	Route Duration	Starting Load	Returning Load
1	0-95-109-37-38-39-42-41-44-47-46-49-50-51-48-43-40-68-76-77-79-80-78-72-71-70-69-67-103-104-107-106-105-120-0	266.37	266.37	190.90	197.09
2	0-102-101-99-100-116-98-110-115-97-94-96-93-92-89-84-113-83-117-112-85-87-86-111-82-119-0	89.17	89.17	120.47	159.52
3	0-52-57-54-53-55-58-56-60-63-66-64-62-61-65-59-45-29-32-28-35-36-34-31-30-33-27-24-22-25-19-16-17-20-23-26-21-0	322.80	322.80	199.17	185.82
4	0-91-90-114-18-118-108-8-12-13-14-15-11-10-9-7-6-5-4-3-1-2-81-88-0	138.53	138.53	71.56	195.43
Total	-	816.87			

*Vehicle capacity (Q): 200; Time limit (R): 720

Table A.5: Demand, supply, service time of feeder ports and distances between ports*

Name	Demand	Supply	Servive	Pireaus	Rethimno	Iraklion	Kithira	Milos	Kea	Thira	Paros	Naxos	Syros	Mykonos	Tinos	Andros	Chios	Ikaria	Samos	Astypalea	karpathos	Rhodes	Kos	Kalimnos	Skyros	Mytilini	Limnos	Amorgos	Sifnos
No	-	-	-	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	-	-	-	-	158	174	124	97	50	146	96	103	83	94	86	80	153	143	190	193	287	298	238	219	144	215	221	148	90
1	12	7	1,8	158	-	38	108	100	165	95	130	136	152	157	162	182	237	194	226	139	177	233	200	186	251	300	330	133	118
2	70	57	6,1	174	38	-	142	109	174	69	126	129	152	152	159	184	227	179	206	115	141	199	171	161	258	289	328	117	122
3	5	1	1,3	124	108	142	-	88	122	138	135	154	138	160	153	151	233	211	251	194	251	302	251	234	216	294	306	169	107
4	10	43	3,1	97	100	109	88	-	67	80	49	61	63	73	71	84	153	130	164	113	185	221	166	148	152	216	235	84	17
5	7	0	1,3	50	165	174	122	67	-	106	71	83	51	61	49	30	119	133	153	152	229	254	178	160	94	165	166	105	58
6	33	2	2,4	146	95	69	138	80	106	-	60	50	74	71	81	119	144	99	131	57	128	166	116	100	178	225	247	39	55
7	15	19	2,4	96	130	126	135	49	71	60	-	19	26	28	33	59	109	60	115	79	164	183	124	106	131	172	202	51	30
8	16	2	1,7	103	136	129	154	61	83	50	19	-	35	25	34	67	101	63	104	66	157	171	111	93	135	164	201	40	42
9	12	8	1,8	83	152	152	138	63	51	74	26	35	-	17	14	34	96	78	120	119	192	203	142	123	104	152	177	73	36
10	37	1	2,5	94	157	152	160	73	61	71	28	25	17	-	10	52	82	56	97	87	180	182	120	102	111	142	178	54	51
11	9	1	1,4	86	162	159	153	71	49	81	33	34	14	10	-	35	81	63	105	100	185	194	132	113	100	138	169	65	49
12	3	1	1,2	80	182	184	151	84	30	119	59	67	34	52	35	-	87	103	129	152	223	243	164	146	70	135	145	101	65
13	22	9	2,2	153	237	227	233	153	119	144	109	101	96	82	81	87	-	54	57	133	216	207	126	114	107	55	124	113	130
14	5	1	1,2	143	194	179	211	130	133	99	60	63	78	56	63	103	54	-	22	77	161	162	78	63	133	135	177	62	103
15	21	35	3,2	190	226	206	251	164	153	131	115	104	120	97	105	129	57	22	-	95	163	158	66	58	159	146	185	93	144
16	9	1	1,4	193	139	115	194	113	152	57	79	66	119	87	100	152	133	77	95	-	90	109	60	44	195	223	260	54	103
17	8	1	1,4	287	177	141	251	185	229	128	164	157	192	180	185	223	216	161	163	90	-	94	100	106	286	310	350	124	183
18	58	15	3,9	298	233	199	302	221	254	166	183	171	203	182	194	243	207	162	158	109	94	-	64	89	288	317	360	139	212
19	23	3	2,0	238	200	171	251	166	178	116	124	111	142	120	132	164	126	78	66	60	100	64	-	16	217	225	284	82	152
20	11	0	1,4	219	186	161	234	148	160	100	106	93	123	102	113	146	114	63	58	44	106	89	16	-	201	211	271	65	133
21	2	0	1,1	144	251	258	216	152	94	178	131	135	104	111	100	70	107	133	159	195	286	288	217	201	-	115	80	164	134
22	46	21	3,7	215	300	289	294	216	165	225	172	164	152	142	138	135	55	135	146	223	310	317	225	211	115	-	102	197	199
23	21	6	2,1	221	330	328	306	235	166	247	202	201	177	178	169	145	124	177	185	260	350	360	284	271	80	102	-	230	213
24	5	1	1,2	148	133	117	169	84	105	39	51	40	73	54	65	101	113	62	93	54	124	139	82	65	164	197	230	-	71
25	4	0	1,2	90	118	122	107	17	58	55	30	42	36	51	49	65	130	103	144	103	183	212	152	133	134	199	213	71	-

*Demand & supply (small container), service (hours), distances (nautical miles) (Karlaftis et al. 2009)

Table A.6: Route details of best solution for soft time deadline

Route number	Route sequence	Starting load	Returning load	Last approaching time	Total route delay	Route duration	Fitness value
1	0-11-18-17-16-8-0	100	20	52.27	12.27	62.55	63.16
2	0-5-9-10-7-25-4-0	85	71	25.28	0	36.47	36.47
3	0-12-21-23-22-13-0	94	37	40.35	0.35	55.30	55.32
4	0-6-24-20-19-15-14-0	98	42	39.70	0	52.82	52.82
5	0-3-1-2-0	87	65	25.60	0	46.20	46.20
Total		464	235	-	12.62	253.34	253.96

Table A.7: Route details of best solution for hard time deadline

Route number	Route sequence	Starting load	Returning load	Last Approaching Time	Total Route Delay	Route duration	Fitness value
1	0-8-16-17-18-0	91	19	33.92	0	62.65	62.65
2	0-5-12-9-11-10-7-25-4-0	97	73	29.50	0	40.73	40.73
3	0-3-2-1-0	98	42	39.70	0	52.82	52.82
4	0-6-24-20-19-15-14-0	87	65	25.60	0	46.20	46.20
5	0-21-23-22-13-0	91	36	38.65	0	53.60	53.60
Total		464	235	-	0	256.00	256.00

Table A.8: Demand parameters for related container terminals*

No.	Terminal	Port[1]	Region	Supply[2]	Demand[3]	Handling[2]
A	Port Said	A	Black Sea	-	-	50
B	Candarli (Izmir)	B	Black Sea	-	-	50
1	Burgas	1	Black Sea	8	9	16.7
2	Varna	2	Black Sea	30	35	25
3	Constanta 1	3	Black Sea	34	82	50
4	Constanta 2	3	Black Sea	100	105	16.7
5	Illiychevsk	4	Black Sea	63	90	33.3
6	Odessa	5	Black Sea	120	160	16.7
7	Novorossiysk 1	6	Black Sea	166	110	25
8	Novorossiysk 2	6	Black Sea	108	65	12.5
9	Poti	7	Black Sea	26	112	11.1
10	Batumi	8	Black Sea	8	8	25
11	Trabzon	9	Black Sea	14	29	11.1
12	Haydarpasa (Istanbul)	10	Sea of Marmara	26	58	33.3
13	Ambarli 1 (Istanbul)	11	Sea of Marmara	179	234	33.3
14	Ambarli 2 (Istanbul)	11	Sea of Marmara	120	166	33.3
15	Ambarli 3 (Istanbul)	11	Sea of Marmara	67	105	25
16	Gebze 1 (Izmit)	12	Sea of Marmara	36	63	33.3
17	Gebze 2 (Izmit)	12	Sea of Marmara	35	77	25
18	Gemlik 1 (Bursa)	13	Sea of Marmara	31	57	33.3
19	Gemlik 2 (Bursa)	13	Sea of Marmara	58	65	25
20	Gemlik 3 (Bursa)	13	Sea of Marmara	17	22	33.3
21	Aliaga 1 (Izmir)	14	Aegean Sea	34	59	50
22	Aliaga 2 (Izmir)	14	Aegean Sea	20	33	33.3
23	İzmir	15	Aegean Sea	86	165	25
24	Thessaloniki	16	Aegean Sea	37	56	33.3
25	Piraeus 1	17	Aegean Sea	51	111	33.3
26	Piraeus 2	17	Aegean Sea	102	189	25
27	Antalya	18	East Med. sea	22	50	50
28	Mersin	19	East Med. sea	90	187	25
29	Limassol	20	East Med. sea	13	78	50
30	Lattakia	21	East Med. sea	40	75	33.3
31	Beirut	22	East Med. sea	56	85	25

No.	Terminal	Port[1]	Region	Supply[2]	Demand[3]	Handling[2]
32	Haifa	23	East Med. sea	107	142	25
33	Ashdod	24	East Med. sea	123	125	25
34	Alexandria 1	25	East Med. sea	38	130	33.3
35	Alexandria 2	25	East Med. sea	26	52	33.3
36	Damietta	26	East Med. sea	60	132	25

* Distances between ports calculated by use of the Netpas Distance software; [1] Port code of terminal as shown in Figure 5; [2] Terminal's daily container supply in TEU; [3] Terminal's daily container demand in TEU;[4] Terminal container handling efficiency in TEU per hour.

Table A.9: Best solution for the feeder network design of the Candarli port

Route no.	Port sequence	Total costs	Total demand	Total supply	Ship type (TEU)	Required ships	Service no.	Voyage duration	On sea duration	On port duration
1	0-25-26-24-0	2.27E+0	1330	2492	2600	2	52	253.29	34.62	218.67
2	0-27-33-35-34-0	2.86E+0	1463	2499	2600	2	52	299.62	80.20	219.42
3	0-14-0	8.38E+0	840	1162	1200	1	52	130.69	27.59	103.10
4	0-21-13-17-0	2.23E+0	1736	2590	2600	2	52	254.53	29.70	224.83
5	0-31-30-28-0	2.64E+0	1302	2429	2600	2	52	295.67	72.66	223.01
6	0-23-0	7.32E+0	602	1155	1200	1	52	114.86	6.44	108.42
7	0-22-19-18-0	1.08E+0	763	1085	1200	1	52	137.3	30.29	107.01
8	0-12-6-4-2-1-0	3.59E+0	1988	2569	2600	3	52	417.82	69.20	348.62
9	0-7-8-5-3-0	3.65E+0	2597	2429	2600	3	52	425.32	93.27	332.05
10	0-11-10-9-20-0	2.02E+0	455	1197	1200	2	52	271.09	103.85	167.24
11	0-15-16-0	9.83E+0	721	1176	1200	1	52	144.55	33.16	111.39
12	0-29-32-36-0	2.63E+0	1260	2464	2600	2	52	290.61	72.71	217.90
Total	-	2.55E+0	15057	23247	24200	22	624	3035.34	0.16	0.58

Route no.	Feeder port duration	Hub port duration	Lay-up duration	Idle duration	Total costs	Operation cost ratio	Charter cost ratio	Administrative cost ratio	On sea cost ratio	On port cost ratio	Port cost ratio
1	140.43	78.24	24.00	58.71	2.27E+0	18.28%	24.27%	10.18%	14.46%	6.28%	26.53%
2	138.38	81.04	24.00	12.38	2.86E+0	14.54%	19.31%	8.10%	26.65%	5.01%	26.39%
3	61.56	41.54	16.80	20.51	8.38E+0	20.17%	25.48%	6.00%	16.74%	4.30%	27.31%
4	136.51	88.32	24.00	57.47	2.23E+0	18.63%	24.74%	10.38%	12.64%	6.58%	27.04%
5	146.59	76.42	24.00	16.33	2.64E+0	15.75%	20.92%	8.78%	26.16%	5.52%	22.87%
6	71.78	36.64	16.80	36.34	7.32E+0	23.08%	29.16%	6.86%	4.47%	5.17%	31.25%
7	68.55	38.46	16.80	13.90	1.08E+0	15.62%	19.74%	4.64%	14.24%	3.46%	42.30%
8	255.68	92.94	24.00	62.18	3.59E+0	17.37%	23.07%	9.68%	18.31%	6.34%	25.22%
9	229.73	102.32	24.00	54.68	3.65E+0	17.05%	22.65%	9.50%	24.23%	5.93%	20.63%
10	132.70	34.54	16.80	48.11	2.02E+0	16.70%	21.10%	4.96%	26.09%	2.89%	28.26%
11	71.95	39.44	16.80	6.65	9.83E+0	17.18%	21.71%	5.11%	17.14%	3.96%	34.90%
12	141.62	76.28	24.00	21.39	2.63E+0	15.77%	20.94%	8.79%	26.21%	5.40%	22.90%
Total	0.39	0.19	0.06	0.10	2.55E+0	16.99%	22.30%	8.43%	20.83%	5.38%	26.07%

Table A.10: Figures of contracted container terminals*

	Terminal	Country	M.share**	2005***	2006	2007	2008	2009	2010	2011
1	Burgas	Bulgaria	31.00%	25000	26400	30600	45900	23800	23500	25000
2	Varna	Bulgaria	21.00%	84000	94000	99700	155300	112600	118700	122844
3	Constanta 1	Romania	19.00%	476600	737100	1111400	1080900	294300	256500	350000
4	Constanta 2	Romania	24.00%	300000	300000	300000	300000	300000	300000	300000
5	Illiychevsk	Ukraine	20.00%	291100	312100	532800	670600	256800	301500	280000
6	Odessa	Ukraine	22.00%	288400	395600	523500	572100	255500	354500	453700
7	Novorossiysk 1	Russia	29.00%	-	60000	90100	182000	84000	188652	335847
8	Novorossiysk 2	Russia	29.00%	-	99100	141400	124500	111000	124626	200153
9	Poti	Georgia	20.00%	105900	126900	184800	209600	172800	209800	254022
10	Batumi	Georgia	20.00%	-	-	-	44200	8800	16300	45439
11	Trabzon	Turkey	35.00%	300	5400	22300	22100	21100	34072	40251
12	Haydarpasa	Turkey	15.00%	340600	400100	369600	356300	191400	176500	206082
13	Ambarli 1	Turkey	10.00%	790300	962900	1296800	1541200	1263600	1663600	1548485
14	Ambarli 2	Turkey	15.00%	439000	531000	666000	649000	476000	621000	844000

	Terminal	Country	M.share**	2005***	2006	2007	2008	2009	2010	2011
15	Ambarli 3	Turkey	15.00%	161500	198500	276300	359700	200200	376400	449400
16	Gebze 1	Turkey	15.00%	33800	35800	68800	135500	133400	184500	230884
17	Gebze 2	Turkey	15.00%	14000	33000	78000	118000	156300	248200	283903
18	Gemlik 1	Turkey	15.00%	90500	94800	114500	141000	152300	200500	195021
19	Gemlik 2	Turkey	15.00%	240500	274600	341300	336300	214100	269300	462987
20	Gemlik 3	Turkey	15.00%	-	-	-	21800	84700	108100	107322
21	Aliaga 1	Turkey	15.00%	-	-	-	-	-	139918	256598
22	Aliaga 2	Turkey	15.00%	-	-	-	-	-	99414	127961
23	İzmir	Turkey	14.00%	784400	847900	898200	884900	826600	726700	672486
24	Thessaloniki	Greece	13.00%	366000	344000	447000	239000	270200	273300	295870
25	Piraeus 1	Greece	13.00%	1394500	1403400	1373100	433600	498838	178919	490904
26	Piraeus 2	Greece	12.00%	-	-	-	-	166062	684881	1188100
27	Antalya	Turkey	15.00%	11800	40200	63400	67100	59500	125700	165474
28	Mersin	Turkey	9.00%	594243	632905	799532	869596	845117	1015567	1126866
29	Limassol	Cyprus	10.00%	320100	358100	377000	417000	353700	348400	345614
30	Lattakia	Syria	9.00%	390800	472000	546600	568200	621377	586283	524614
31	Beirut	Lebanon	8.00%	463700	594200	947200	945134	994601	949155	1034249
32	Haifa	Israel	9.00%	1123000	1070000	1170000	1396000	1140000	1263552	1235000
33	Ashdod	Israel	11.00%	587000	693000	809000	828000	893000	1015000	1176000
34	Alexandria 1	Egypt	7.00%	733900	762000	977000	632250	638700	666500	757572
35	Alexandria 2	Egypt	5.00%	-	-	-	632250	638700	666500	700000
36	Damietta	Egypt	8.00%	1129600	830100	894200	1125000	1139000	1060100	800000

*Source: Dyamar (2009), Ocean Shipping Consultants (2011) and web pages of related container terminals. ** Market share of interested feeder shipping line in related container terminal *** Total throughput of related container terminal in TEU

Table A.11: Monthly export and import rates of countries in 2005-2011

Georgia	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	1.57%	1.45%	2.04%	2.26%	1.72%	2.06%	2.15%	2.34%	2.20%	2.27%	3.25%	2.47%
Import	2005	3.97%	4.16%	5.41%	5.27%	5.23%	5.21%	6.89%	6.67%	6.94%	7.29%	9.03%	8.14%
Export	2006	1.47%	1.31%	1.87%	1.90%	1.61%	1.47%	1.63%	1.67%	1.75%	1.46%	1.92%	2.23%
Import	2006	4.14%	4.85%	5.80%	6.19%	6.38%	6.66%	6.70%	7.88%	7.59%	7.41%	7.23%	8.88%
Export	2007	1.08%	1.05%	1.34%	1.54%	1.75%	1.67%	1.78%	1.72%	1.51%	2.02%	1.72%	1.93%
Import	2007	5.09%	5.19%	5.92%	5.66%	6.80%	5.83%	6.67%	7.19%	6.58%	8.10%	6.91%	10.93%
Export	2008	1.23%	1.30%	1.68%	1.74%	1.85%	2.40%	2.06%	1.44%	2.19%	1.43%	0.91%	0.95%
Import	2008	5.17%	6.08%	6.77%	7.43%	7.83%	7.70%	8.07%	5.62%	6.97%	7.10%	5.68%	6.41%
Export	2009	1.12%	1.35%	1.49%	1.65%	1.78%	1.94%	1.85%	2.04%	1.68%	1.89%	1.77%	2.04%
Import	2009	5.56%	5.52%	6.42%	5.77%	5.75%	6.98%	7.01%	6.65%	6.84%	7.63%	6.93%	8.35%
Export	2010	1.53%	1.58%	1.80%	1.83%	2.08%	1.77%	2.16%	1.75%	2.26%	2.33%	2.37%	2.72%
Import	2010	4.24%	4.78%	6.32%	5.65%	6.40%	6.00%	6.09%	6.55%	6.59%	7.26%	7.13%	8.82%
Export	2011	1.61%	1.59%	1.83%	2.08%	2.16%	1.95%	1.61%	1.99%	1.96%	2.02%	2.14%	2.73%
Import	2011	4.88%	4.58%	6.31%	5.75%	6.07%	6.14%	6.21%	7.38%	6.66%	7.20%	7.22%	7.91%

Romani	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	2.89%	3.15%	3.69%	3.42%	3.39%	3.56%	3.81%	3.55%	3.95%	3.69%	3.90%	3.55%
Import	2005	3.33%	3.80%	4.58%	4.50%	4.72%	5.01%	4.87%	4.75%	5.02%	5.41%	5.84%	5.64%
Export	2006	2.67%	3.16%	3.51%	2.81%	3.46%	3.42%	3.34%	3.10%	3.32%	3.39%	3.70%	2.94%
Import	2006	3.62%	4.30%	4.94%	4.42%	5.30%	5.23%	5.18%	5.05%	5.08%	5.83%	6.12%	6.10%
Export	2007	2.58%	2.88%	3.27%	2.72%	3.07%	3.12%	3.28%	2.79%	3.10%	3.51%	3.44%	2.81%
Import	2007	4.30%	4.62%	5.28%	4.77%	5.40%	5.34%	5.53%	5.04%	5.21%	6.26%	6.24%	5.45%
Export	2008	2.81%	3.19%	3.06%	3.08%	3.37%	3.42%	3.61%	2.95%	3.29%	3.61%	2.84%	2.15%
Import	2008	4.42%	4.93%	5.37%	5.50%	5.41%	5.74%	5.80%	4.92%	6.03%	5.94%	4.74%	3.82%
Export	2009	2.83%	3.07%	3.81%	3.18%	3.40%	3.77%	4.13%	3.25%	3.84%	4.04%	4.06%	3.44%
Import	2009	3.85%	4.34%	4.79%	4.53%	4.55%	4.89%	4.94%	4.35%	5.52%	5.39%	5.30%	4.75%
Export	2010	2.75%	3.05%	3.60%	3.45%	3.58%	4.00%	4.04%	3.32%	4.19%	4.19%	4.30%	3.89%
Import	2010	3.32%	3.83%	4.71%	4.50%	4.77%	5.13%	4.82%	4.07%	5.18%	5.08%	5.41%	4.82%
Export	2011	3.42%	3.53%	4.11%	3.41%	3.86%	3.78%	3.80%	3.47%	4.21%	4.12%	4.13%	3.28%
Import	2011	3.64%	3.94%	5.00%	4.40%	5.06%	4.69%	4.49%	4.36%	5.03%	4.91%	5.06%	4.30%

Lubnan	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	1.24%	1.44%	1.77%	1.98%	2.45%	2.32%	0.89%	0.74%	1.60%	1.53%	1.90%	1.77%
Import	2005	5.49%	6.56%	8.03%	7.26%	8.38%	7.50%	5.14%	2.30%	6.26%	7.28%	8.41%	7.73%
Export	2006	1.24%	1.43%	1.76%	1.97%	2.44%	2.31%	0.89%	0.74%	1.60%	1.52%	1.89%	1.76%
Import	2006	5.50%	6.57%	8.05%	7.27%	8.39%	7.51%	5.14%	2.30%	6.27%	7.29%	8.42%	7.74%

Export	2007	1.29%	1.50%	1.46%	1.58%	1.59%	1.55%	1.48%	1.52%	1.87%	1.76%	2.00%	1.65%
Import	2007	6.06%	5.68%	6.72%	6.46%	6.35%	6.09%	7.18%	7.12%	6.44%	8.15%	7.21%	7.27%
Export	2008	1.53%	1.82%	1.83%	1.68%	1.61%	1.95%	1.86%	1.87%	1.91%	1.59%	1.88%	1.48%
Import	2008	5.31%	5.68%	6.13%	6.53%	6.10%	5.93%	8.30%	7.03%	6.99%	7.33%	7.98%	5.70%
Export	2009	1.66%	2.12%	1.49%	1.37%	1.67%	1.50%	1.39%	1.46%	1.72%	1.84%	1.87%	2.08%
Import	2009	5.60%	5.19%	5.67%	8.72%	6.08%	7.46%	7.08%	6.84%	6.31%	6.29%	8.01%	6.60%
Export	2010	1.56%	1.72%	1.85%	1.68%	1.79%	1.89%	1.56%	1.61%	1.49%	2.12%	1.67%	2.42%
Import	2010	5.63%	5.43%	8.36%	5.88%	5.93%	6.27%	7.86%	6.51%	5.69%	6.48%	7.90%	6.67%
Export	2011	1.50%	1.41%	1.63%	1.72%	2.61%	2.09%	1.91%	1.76%	1.66%	1.77%	1.61%	1.77%
Import	2011	6.87%	4.73%	6.44%	5.87%	6.23%	5.98%	6.17%	7.10%	7.01%	9.47%	6.23%	6.45%

Cyprus	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	1.24%	1.29%	1.75%	1.44%	1.56%	1.57%	1.56%	1.45%	1.78%	1.86%	1.91%	1.48%
Import	2005	5.35%	5.88%	7.15%	6.32%	6.66%	6.55%	6.59%	6.00%	7.33%	7.60%	8.04%	7.65%
Export	2006	1.31%	1.29%	1.50%	1.38%	1.34%	1.35%	1.37%	1.14%	1.39%	1.16%	1.66%	1.34%
Import	2006	6.39%	6.38%	6.87%	6.63%	7.34%	8.73%	6.51%	6.83%	6.83%	7.21%	7.26%	6.78%
Export	2007	1.54%	1.09%	1.25%	1.23%	1.44%	1.44%	1.18%	1.07%	1.15%	1.36%	1.24%	1.09%
Import	2007	5.86%	5.72%	6.82%	7.26%	7.17%	7.57%	7.45%	7.05%	7.03%	8.03%	7.83%	7.13%
Export	2008	1.09%	1.05%	1.11%	1.13%	0.93%	0.92%	0.88%	1.05%	0.94%	1.11%	1.35%	1.16%
Import	2008	6.91%	5.67%	7.57%	6.69%	7.39%	7.35%	8.76%	7.12%	8.08%	7.77%	7.69%	6.28%
Export	2009	1.01%	1.18%	1.05%	1.37%	1.44%	1.31%	1.30%	0.99%	1.15%	1.35%	1.13%	1.31%
Import	2009	6.60%	6.60%	6.55%	7.11%	7.64%	7.38%	7.11%	6.94%	7.68%	7.55%	7.05%	7.22%
Export	2010	1.00%	1.04%	1.43%	1.10%	1.28%	1.24%	1.36%	1.07%	1.56%	1.42%	1.48%	1.48%
Import	2010	6.00%	5.63%	7.60%	6.57%	6.96%	7.43%	6.80%	6.97%	7.27%	6.99%	8.96%	7.38%
Export	2011	1.25%	1.42%	1.65%	1.38%	1.61%	1.63%	1.58%	1.38%	1.48%	1.54%	1.68%	1.50%
Import	2011	6.16%	6.95%	7.46%	6.96%	6.85%	7.07%	6.71%	7.70%	6.04%	6.39%	6.77%	6.82%

Syria	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	3.01%	3.36%	3.88%	3.65%	3.99%	3.63%	3.91%	4.10%	4.76%	3.98%	3.26%	4.26%
Import	2005	3.62%	3.47%	3.62%	4.33%	4.77%	4.84%	4.56%	5.70%	3.95%	5.52%	3.84%	6.01%
Export	2006	2.85%	3.01%	3.85%	4.31%	5.25%	4.22%	3.88%	4.30%	3.76%	3.07%	3.51%	6.73%
Import	2006	2.62%	3.32%	4.39%	3.84%	4.85%	4.67%	3.99%	3.91%	4.20%	4.76%	4.89%	5.83%
Export	2007	1.91%	2.93%	3.37%	3.99%	4.05%	3.08%	3.17%	3.81%	3.95%	3.55%	5.23%	6.79%
Import	2007	3.99%	4.34%	3.85%	4.08%	5.17%	3.85%	4.53%	6.64%	4.77%	4.15%	4.40%	4.40%
Export	2008	3.36%	3.88%	4.14%	3.49%	4.22%	4.01%	3.80%	3.77%	4.24%	3.40%	2.81%	4.62%
Import	2008	4.69%	4.22%	5.24%	4.87%	5.22%	4.59%	4.69%	4.96%	3.69%	4.29%	4.41%	3.39%
Export	2009	1.56%	1.93%	2.32%	2.33%	2.98%	3.06%	3.32%	3.38%	3.11%	4.86%	4.47%	7.27%
Import	2009	4.10%	3.83%	4.35%	4.41%	4.29%	4.94%	4.97%	5.77%	4.81%	5.67%	5.67%	6.57%
Export	2010	2.46%	2.20%	2.95%	3.21%	3.22%	3.66%	2.85%	3.37%	3.31%	4.47%	3.40%	6.11%
Import	2010	4.73%	4.33%	5.04%	4.90%	4.51%	4.60%	4.92%	5.09%	4.65%	5.31%	5.29%	5.43%
Export	2011	2.46%	2.20%	2.95%	3.21%	3.22%	3.66%	2.85%	3.37%	3.31%	4.47%	3.40%	6.11%
Import	2011	4.73%	4.33%	5.04%	4.90%	4.51%	4.60%	4.92%	5.09%	4.65%	5.31%	5.29%	5.43%

Egypt	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	2.22%	2.24%	2.71%	2.43%	2.71%	2.48%	2.74%	2.82%	3.11%	4.07%	3.53%	3.90%
Import	2005	4.79%	4.52%	5.60%	5.27%	5.99%	5.53%	5.65%	5.49%	5.70%	5.05%	5.53%	5.93%
Export	2006	2.85%	3.54%	3.56%	3.61%	3.56%	3.08%	3.40%	3.02%	3.06%	3.07%	3.66%	3.56%
Import	2006	4.70%	4.48%	4.87%	4.40%	4.93%	4.82%	5.60%	6.23%	4.19%	5.24%	4.86%	5.71%
Export	2007	2.59%	3.26%	3.32%	3.18%	3.25%	2.84%	3.08%	2.64%	2.65%	2.98%	3.88%	3.75%
Import	2007	4.88%	4.42%	5.01%	5.36%	5.10%	4.92%	4.63%	5.53%	4.86%	5.45%	6.23%	6.18%
Export	2008	2.87%	2.79%	3.18%	3.17%	3.07%	3.71%	3.30%	2.40%	2.43%	2.36%	2.12%	1.80%
Import	2008	4.90%	4.65%	5.41%	5.45%	6.03%	5.52%	6.04%	6.79%	5.72%	6.14%	5.55%	4.59%
Export	2009	2.26%	2.63%	2.67%	2.78%	2.83%	3.15%	2.62%	2.82%	2.65%	2.76%	2.86%	3.93%
Import	2009	5.25%	5.24%	5.11%	5.06%	5.05%	5.13%	6.16%	6.43%	4.96%	6.00%	5.15%	6.53%
Export	2010	2.49%	2.54%	2.96%	2.81%	3.11%	2.98%	2.78%	2.68%	2.73%	2.86%	2.75%	3.33%
Import	2010	4.96%	4.39%	5.45%	4.97%	5.17%	5.05%	6.22%	5.95%	5.14%	6.64%	5.66%	6.39%
Export	2011	2.29%	2.56%	3.10%	3.08%	3.22%	3.30%	2.98%	2.49%	2.63%	2.74%	2.75%	3.02%
Import	2011	5.20%	3.67%	5.21%	5.03%	6.38%	5.43%	5.51%	5.89%	6.11%	6.34%	5.07%	5.98%

Ukraine	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	3.53%	3.75%	4.58%	4.31%	3.96%	3.92%	3.87%	3.94%	4.02%	4.16%	4.17%	4.47%
Import	2005	2.56%	3.42%	4.66%	4.39%	3.96%	4.51%	4.25%	4.64%	4.55%	4.55%	4.62%	5.20%
Export	2006	2.80%	3.02%	3.75%	3.54%	3.72%	3.98%	4.01%	4.21%	4.41%	4.12%	4.01%	4.43%
Import	2006	3.25%	3.80%	4.64%	3.94%	4.36%	4.33%	4.42%	4.60%	4.97%	4.82%	4.70%	6.16%
Export	2007	2.92%	3.10%	3.74%	3.70%	3.71%	3.85%	3.87%	3.79%	3.74%	3.95%	4.05%	4.37%
Import	2007	3.37%	3.91%	4.51%	4.39%	4.41%	4.26%	4.84%	4.43%	4.41%	5.34%	5.30%	6.03%

Export	2008	2.40%	3.07%	3.57%	3.65%	4.12%	4.52%	4.99%	4.41%	4.38%	3.84%	2.38%	2.56%
Import	2008	3.03%	4.24%	5.06%	5.20%	5.06%	5.20%	5.79%	5.35%	5.56%	5.01%	3.45%	3.13%
Export	2009	2.87%	3.16%	3.76%	3.63%	3.44%	3.49%	3.77%	3.77%	4.38%	4.90%	4.64%	4.82%
Import	2009	2.40%	4.46%	4.63%	4.22%	3.76%	3.76%	4.58%	4.50%	4.77%	5.09%	5.30%	5.89%
Export	2010	2.68%	3.01%	3.52%	3.75%	3.74%	3.86%	3.78%	3.79%	4.19%	4.23%	4.57%	4.72%
Import	2010	2.91%	3.31%	4.21%	4.10%	3.93%	4.21%	4.60%	4.84%	5.06%	5.51%	5.56%	5.93%
Export	2011	3.06%	3.56%	3.56%	3.71%	3.95%	3.90%	3.55%	3.82%	3.96%	3.79%	4.16%	4.28%
Import	2011	3.34%	4.28%	4.65%	4.17%	4.48%	4.48%	4.32%	4.77%	4.91%	5.00%	5.08%	5.23%

Bulgaria	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	2.65%	2.69%	3.28%	3.10%	3.05%	3.40%	3.56%	3.24%	3.20%	3.79%	3.69%	3.56%
Import	2005	3.76%	3.86%	4.65%	4.61%	5.08%	5.35%	5.26%	5.28%	5.20%	5.91%	6.05%	5.78%
Export	2006	2.69%	2.88%	3.20%	3.26%	3.23%	3.52%	3.52%	3.52%	3.45%	3.48%	3.44%	3.20%
Import	2006	4.05%	4.01%	4.85%	4.63%	5.00%	4.90%	5.29%	5.51%	5.06%	5.71%	5.58%	6.03%
Export	2007	2.46%	2.56%	3.18%	2.94%	3.15%	3.36%	3.51%	3.24%	3.39%	3.69%	3.58%	3.14%
Import	2007	4.31%	4.07%	4.87%	4.58%	5.01%	5.14%	5.48%	5.16%	5.36%	5.98%	6.15%	5.71%
Export	2008	2.76%	3.01%	3.29%	3.41%	3.28%	3.47%	3.78%	3.27%	3.26%	3.21%	2.66%	2.32%
Import	2008	4.52%	4.73%	4.95%	5.59%	5.56%	6.04%	5.95%	4.92%	5.26%	5.88%	4.75%	4.11%
Export	2009	2.85%	3.15%	3.30%	2.91%	3.17%	3.50%	3.60%	3.44%	3.66%	4.20%	3.80%	3.37%
Import	2009	4.30%	4.64%	5.27%	4.85%	5.01%	5.01%	5.02%	4.62%	4.92%	5.48%	4.98%	4.98%
Export	2010	2.62%	2.87%	3.22%	3.37%	3.48%	4.06%	4.39%	4.17%	4.12%	4.20%	4.18%	4.01%
Import	2010	3.34%	3.38%	4.37%	4.60%	4.72%	4.79%	4.82%	4.42%	4.69%	5.06%	5.76%	5.34%
Export	2011	3.58%	3.56%	3.87%	3.58%	3.94%	3.92%	4.39%	4.28%	4.28%	4.46%	4.36%	3.56%
Import	2011	3.78%	3.65%	4.40%	4.25%	4.46%	3.93%	4.90%	3.91%	4.33%	4.78%	5.16%	4.66%

Greece	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	1.79%	2.10%	2.05%	2.06%	1.90%	1.90%	2.00%	2.05%	2.11%	1.95%	2.07%	2.15%
Import	2005	6.36%	6.50%	6.76%	6.58%	5.92%	5.76%	5.92%	6.39%	6.61%	6.24%	6.33%	6.48%
Export	2006	1.96%	1.83%	1.93%	1.76%	2.26%	2.14%	1.96%	2.23%	2.32%	1.98%	2.23%	2.09%
Import	2006	5.78%	5.59%	5.79%	5.95%	6.56%	6.41%	6.22%	6.58%	6.60%	6.47%	6.60%	6.77%
Export	2007	1.89%	1.79%	2.01%	1.81%	1.70%	1.81%	1.85%	2.00%	2.14%	2.07%	2.24%	1.88%
Import	2007	5.76%	5.95%	5.90%	5.92%	6.25%	6.05%	6.50%	6.48%	6.62%	6.82%	7.25%	7.28%
Export	2008	1.74%	1.90%	1.77%	1.95%	2.06%	2.04%	2.13%	1.88%	2.02%	1.89%	1.48%	1.45%
Import	2008	6.34%	6.42%	6.85%	7.25%	7.06%	7.41%	7.23%	6.62%	6.29%	5.94%	5.05%	5.21%
Export	2009	1.63%	1.86%	1.65%	1.78%	1.98%	2.00%	1.95%	1.86%	2.04%	2.06%	1.90%	1.99%
Import	2009	6.32%	6.15%	6.03%	5.91%	6.16%	6.66%	6.67%	6.49%	6.80%	6.43%	6.99%	6.69%
Export	2010	1.93%	1.83%	2.10%	2.02%	1.88%	1.90%	1.86%	2.16%	1.74%	2.60%	2.68%	2.76%
Import	2010	6.97%	6.51%	7.05%	6.15%	5.86%	5.66%	5.80%	5.72%	6.02%	6.51%	6.22%	6.06%
Export	2011	2.50%	2.43%	2.69%	3.12%	3.28%	3.01%	3.06%	3.28%	3.00%	2.78%	2.58%	2.78%
Import	2011	5.96%	5.89%	5.86%	6.19%	6.01%	5.95%	5.89%	5.99%	5.34%	3.98%	4.20%	4.23%

Israel	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	3.91%	3.59%	4.23%	3.30%	4.16%	3.80%	3.65%	3.68%	4.25%	2.88%	4.04%	3.67%
Import	2005	4.31%	4.21%	4.92%	3.84%	5.34%	4.51%	4.66%	4.82%	5.06%	4.03%	4.48%	4.66%
Export	2006	3.45%	3.46%	4.13%	3.14%	4.60%	3.99%	3.48%	3.56%	3.91%	3.80%	4.17%	3.93%
Import	2006	4.49%	4.20%	4.33%	4.07%	4.92%	4.53%	4.31%	4.78%	4.15%	5.15%	4.52%	4.92%
Export	2007	3.61%	3.25%	3.99%	3.05%	4.32%	3.62%	3.84%	3.41%	3.45%	3.92%	4.44%	4.12%
Import	2007	3.94%	3.98%	4.17%	4.02%	4.55%	4.48%	5.21%	4.99%	4.09%	5.05%	4.88%	5.63%
Export	2008	3.74%	3.71%	4.18%	3.50%	4.29%	4.24%	4.35%	3.44%	3.91%	2.79%	3.25%	2.92%
Import	2008	4.46%	4.40%	5.19%	4.72%	4.99%	5.10%	5.48%	4.94%	4.62%	4.18%	4.02%	3.59%
Export	2009	3.41%	3.17%	4.00%	2.91%	3.99%	3.93%	4.05%	3.66%	4.19%	4.60%	4.42%	4.94%
Import	2009	3.83%	3.72%	4.24%	3.64%	3.86%	4.40%	4.72%	4.97%	4.33%	4.52%	5.17%	5.34%
Export	2010	3.76%	3.38%	4.47%	3.73%	3.85%	4.33%	3.99%	3.55%	3.45%	3.79%	3.98%	4.14%
Import	2010	4.10%	3.85%	4.68%	4.15%	4.38%	4.48%	4.42%	4.79%	3.82%	5.26%	4.47%	5.16%
Export	2011	3.36%	3.47%	4.47%	3.25%	4.23%	4.06%	3.81%	3.60%	3.74%	3.03%	3.75%	3.64%
Import	2011	4.21%	4.13%	5.16%	4.42%	5.19%	4.70%	5.07%	4.83%	4.27%	4.45%	4.78%	4.40%

Turkey	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	3.10%	3.38%	3.25%	3.24%	3.13%	3.12%	3.01%	3.15%	3.40%	3.36%	3.07%	3.39%
Import	2005	4.68%	5.27%	5.11%	5.07%	4.98%	4.87%	4.86%	5.33%	5.25%	5.37%	5.12%	5.49%
Export	2006	2.75%	3.00%	3.11%	2.98%	3.01%	3.32%	3.15%	3.24%	3.25%	2.96%	3.69%	3.56%
Import	2006	4.52%	5.13%	5.02%	5.23%	5.28%	5.04%	5.03%	5.18%	5.31%	5.11%	5.69%	5.44%
Export	2007	2.82%	3.02%	2.95%	3.14%	3.14%	3.12%	3.21%	3.39%	3.30%	3.44%	3.82%	3.25%
Import	2007	4.75%	4.79%	4.53%	4.83%	4.95%	4.77%	5.22%	5.07%	5.24%	5.78%	5.99%	5.49%
Export	2008	3.70%	3.46%	3.25%	3.47%	3.50%	3.57%	3.63%	3.62%	3.84%	2.79%	2.76%	2.12%
Import	2008	5.79%	5.39%	4.89%	5.39%	5.38%	5.57%	5.60%	5.66%	5.34%	4.32%	3.72%	3.23%

Export	2009	3.62%	3.76%	3.22%	3.15%	3.01%	3.35%	3.61%	3.53%	3.64%	3.84%	3.67%	3.73%
Import	2009	4.45%	4.29%	4.20%	4.13%	4.38%	4.80%	4.93%	5.21%	5.17%	5.14%	5.56%	5.62%
Export	2010	3.02%	2.98%	3.10%	3.11%	3.27%	3.18%	2.98%	3.13%	3.11%	3.54%	3.06%	3.58%
Import	2010	4.76%	4.52%	4.80%	4.95%	4.81%	4.75%	4.87%	5.11%	5.15%	5.87%	6.02%	6.32%
Export	2011	2.90%	2.87%	2.88%	3.15%	2.93%	2.96%	3.20%	3.22%	2.95%	3.03%	2.95%	2.92%
Import	2011	5.47%	5.34%	5.26%	5.62%	5.52%	5.23%	5.45%	5.14%	5.50%	5.40%	5.19%	4.94%

Russia	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Export	2005	4.52%	4.93%	5.21%	5.49%	5.34%	5.36%	5.84%	5.53%	5.71%	5.86%	6.06%	6.28%
Import	2005	2.55%	2.63%	2.69%	2.72%	2.70%	2.75%	2.88%	2.81%	2.91%	2.98%	3.11%	3.15%
Export	2006	5.05%	5.31%	5.18%	5.40%	5.60%	5.43%	5.48%	5.63%	5.55%	4.93%	5.44%	6.11%
Import	2006	2.43%	2.51%	2.59%	2.61%	2.81%	3.09%	2.85%	2.98%	3.09%	3.11%	3.22%	3.59%
Export	2007	4.28%	4.73%	4.78%	4.80%	4.94%	4.89%	4.86%	4.96%	4.97%	5.61%	6.10%	6.54%
Import	2007	2.81%	2.90%	3.04%	3.01%	3.16%	3.26%	3.20%	3.28%	3.24%	3.39%	3.61%	3.67%
Export	2008	5.18%	5.22%	5.60%	5.53%	5.52%	5.71%	5.77%	5.66%	5.23%	4.68%	4.14%	3.53%
Import	2008	2.97%	3.17%	3.25%	3.45%	3.41%	3.26%	3.59%	3.47%	3.30%	3.06%	2.73%	2.57%
Export	2009	4.32%	4.47%	4.35%	4.49%	4.69%	4.80%	4.98%	5.19%	5.43%	5.75%	6.13%	6.56%
Import	2009	3.22%	3.33%	3.12%	3.11%	3.02%	3.03%	3.01%	3.02%	3.26%	3.44%	3.60%	3.69%
Export	2010	5.22%	5.59%	5.48%	5.31%	5.02%	4.94%	4.65%	4.36%	4.87%	5.08%	5.26%	6.19%
Import	2010	2.70%	2.94%	3.06%	3.07%	3.19%	2.96%	3.13%	3.43%	3.28%	3.35%	3.45%	3.48%
Export	2011	4.36%	5.47%	5.37%	5.89%	5.01%	5.09%	4.86%	4.67%	4.61%	5.10%	5.49%	5.82%
Import	2011	2.94%	3.17%	3.43%	3.40%	3.45%	3.19%	3.15%	3.25%	2.91%	3.01%	3.27%	3.10%

Table A.12: Forecasted weekly total throughputs of regional container terminals*

	Burgas		Varna		Constanta 1		Constanta 2		Illiychevsk		Odessa	
Weeks	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
1	187	203	1002	1150	1271	3011	2913	3068	2195	3151	3824	5079
2	213	179	1003	1203	1411	2786	2784	2982	2017	2911	3991	3903
3	218	190	1162	1359	1402	2792	2418	2894	2287	2616	4352	5499
4	260	200	1031	1291	1165	2861	2680	2567	2415	2662	4069	4975
5	219	217	885	1642	1642	2827	2426	3555	2669	3095	3880	4963
6	215	243	877	1736	1820	3389	2683	3027	3053	3304	4771	6326
7	199	237	830	1908	1662	2988	2874	3612	2901	3406	5012	5590
8	225	208	820	1683	1829	2921	2795	3204	2892	3267	5155	6578
9	211	248	828	1310	1447	3173	2416	3297	2775	3339	4969	6365
10	248	270	784	1342	1425	2823	2688	3497	2311	3061	4657	6455
11	257	268	875	1331	1298	2890	2977	3598	2351	2861	4156	5804
12	277	283	890	1369	1508	2794	3078	3699	2182	3164	4824	5841
13	261	233	777	1543	1694	2838	2964	3262	2660	3173	4304	7082
14	314	251	722	997	2254	3058	2841	3407	3177	3602	5498	6590
15	294	231	843	1036	2253	3317	3177	3410	3066	3430	5119	6840
16	259	242	661	1012	1825	3145	3150	2937	3006	3051	5208	6557
17	318	242	782	963	2354	3443	2866	3665	2937	3135	5641	7004
18	304	244	663	936	1957	2930	2885	3412	3053	3254	5578	6353
19	280	222	809	1105	2321	3091	2814	3349	2833	3513	5221	6002
20	261	245	785	1038	2087	3328	3091	3296	3084	2736	5660	7084
21	285	214	717	898	1904	3013	2893	3300	3073	3467	4516	6658
22	327	231	823	939	1918	3087	2465	2881	2584	3100	5364	6611
23	460	244	1081	865	1458	2985	2403	4330	2744	3524	5432	6988
24	405	240	1071	1007	1634	3232	2149	3469	2943	3469	5353	6774
25	406	241	1056	974	1370	3142	2417	3351	2470	3447	6091	7063
26	394	300	1212	916	1662	3041	2717	3439	2538	3419	5513	8134
27	405	421	1397	1235	3935	2987	3264	3414	2540	3660	5205	8092
28	462	418	1405	1534	3700	3089	3372	3414	2403	3374	5530	7854
29	455	395	1323	1358	3278	2937	3257	2894	2526	3552	5653	7432
30	473	351	1432	1595	3193	2848	2594	3174	2734	3493	4795	7343
31	464	246	1357	1415	2281	3206	2371	3264	2979	4257	4580	7081
32	460	205	1559	1368	1439	2869	2285	2943	3591	4003	5398	7966
33	437	194	1452	1216	1595	3106	2618	3670	3390	3943	5619	8387
34	464	177	1651	1370	1636	3156	2774	3191	3503	3577	5901	8359
35	390	216	1469	1411	2006	3177	2872	3100	3115	3337	5826	7993
36	536	257	1499	1238	2270	2906	3116	3511	2826	4574	7506	9296

37	448	231	1621	1156	2539	3580	3352	4223	3200	4690	6322	8839
38	454	261	1600	1299	2110	2909	3328	4965	2648	4491	5319	8439
39	482	246	1739	1281	2366	3704	3345	3755	2690	4491	6290	8093
40	410	226	1096	1041	6390	3737	2674	3961	3039	4900	5761	7817
41	374	224	1104	1237	7444	3238	3171	3560	3120	5075	5834	8422
42	382	260	1234	1029	7468	3208	2810	4262	2740	4972	5839	8889
43	366	248	1198	1172	6737	3177	2613	4109	2974	4744	5712	7441
44	431	336	1346	1315	8217	3352	2691	4558	3275	5483	6312	9106
45	437	468	1376	1484	10710	3138	3344	4246	4077	6131	6114	7152
46	495	428	1536	1436	9979	3568	3202	4056	3771	4926	5583	8224
47	420	422	1583	1689	9530	3553	3646	4331	3587	6148	5163	7485
48	398	340	1297	1378	7954	3520	2971	3823	3155	6043	5718	6313
49	358	195	1369	1028	4100	3136	2606	3800	2561	6698	4760	7349
50	335	187	1357	1006	4211	3210	2375	2906	2328	5952	5197	6703
51	336	196	1389	1005	4296	2869	2391	3232	2388	6756	5297	6676
52	382	213	1414	909	3877	2921	2330	3296	2131	6099	5060	6272

	Novorossiysk 1		Novorossiysk 2		Poti		Batumi		Trabzon		Haydarpasa	
Weeks	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
1	3998	2658	2595	1569	905	3911	275	297	286	571	1221	2708
2	3472	2788	2700	1562	889	4275	303	328	286	484	1403	2660
3	3949	2707	2350	1361	933	4715	278	289	238	521	1399	2899
4	4106	2664	2982	1366	931	4662	294	305	258	460	1268	2163
5	3918	2951	2729	1438	1296	5057	333	346	289	482	1620	2483
6	3566	2969	3095	1607	1339	4693	304	355	320	583	1505	2470
7	4375	3229	2832	1815	1396	4379	332	329	320	544	1636	2913
8	4028	3024	2636	1822	1566	4329	308	346	329	486	1546	2694
9	4218	2688	2620	1577	1334	5070	347	337	307	535	1400	2398
10	4584	2836	2703	1577	1422	4494	298	306	289	524	1287	1965
11	4920	2929	2582	1519	1375	4472	288	304	280	511	1496	2178
12	5028	2974	2330	1504	1682	5069	301	328	287	469	1243	2403
13	4189	2678	2551	1426	1529	4934	312	321	239	490	1402	2439
14	5102	2961	3477	1415	1883	5941	337	359	325	475	1497	2511
15	5228	3131	2751	1768	1708	4760	298	332	318	478	1485	2307
16	5008	3227	2538	1659	1710	4982	281	339	284	497	1338	2092
17	4884	2699	2568	1789	1806	5071	340	334	268	529	1440	2478
18	4455	3124	2685	1587	1800	5794	329	340	275	439	1334	2212
19	4674	2493	2668	1731	1686	4951	304	315	271	490	1433	2059
20	5243	3037	2741	1410	1789	4865	280	361	266	484	1407	2641
21	5247	3238	2968	1363	1781	4654	300	302	307	499	1308	2420
22	5450	2864	2794	1664	1641	4930	331	323	293	487	1465	1995
23	4766	2803	2311	1588	1834	5455	318	296	285	642	1369	2236
24	4669	2906	2406	1555	1590	5112	328	316	290	558	1332	2112
25	5021	3117	2504	1405	1681	5043	360	314	344	516	1470	2423
26	5201	3274	2542	1546	1887	5062	281	309	260	541	1623	2238
27	4912	2712	3093	1475	1529	5198	313	368	277	514	1289	1896
28	4814	3074	2702	1387	1465	5226	278	340	285	580	1419	2574
29	4483	2938	2845	1306	1256	5073	393	336	272	583	1303	2344
30	4382	3081	2610	1565	1555	5397	324	342	281	524	1423	2031
31	5447	2924	3065	1787	1590	4981	297	347	298	557	1310	2072
32	4987	2917	2892	1784	1743	5501	321	353	286	526	1407	2304
33	4770	3252	2906	1846	1869	4801	321	364	278	497	1593	2129
34	5130	3247	2865	1592	2012	5343	332	341	298	502	1575	2270
35	5613	3129	2869	1461	1697	5751	350	360	301	486	1436	1987
36	5479	3352	3007	1538	1620	4836	358	363	330	544	1553	2269
37	5367	3051	2867	1840	1716	5884	325	419	323	527	1563	2112
38	5214	3197	3168	1724	1569	5902	358	375	348	508	1652	2182
39	5743	3138	3201	1826	1367	5856	357	360	315	543	1626	2239
40	5614	3397	3621	1677	1711	5405	317	390	331	572	1615	1984
41	5245	3014	2880	1499	1961	5136	381	440	308	624	1626	2442
42	5244	3017	3164	1765	1845	6098	378	398	264	600	1709	2243
43	5318	3454	2957	1496	1940	5749	332	386	313	609	1549	2461

44	5008	2645	3033	1803	2105	5829	342	336	334	567	1449	2248
45	5251	3189	2985	1564	1784	5221	357	318	267	495	1621	2309
46	4909	3163	2675	1620	1775	4996	357	337	299	515	1446	2359
47	5386	3308	3175	1759	1966	5664	310	337	285	544	1724	2037
48	5261	3118	3081	1905	1889	5468	295	344	321	508	1510	2084
49	4669	2883	2902	1448	1826	4665	301	293	258	519	1554	1837
50	4861	2835	2923	1502	1733	5404	335	292	303	591	1626	2226
51	5159	2811	2488	1549	1653	5189	282	334	279	541	1388	1928
52	4922	2905	2571	1683	1671	4779	331	292	304	531	1294	2032

	Ambarli 1		Ambarli 2		Ambarli 3		Gebze 1		Gebze 2		Gemlik 1	
Weeks	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
1	12558	16359	5605	7766	3107	4921	1688	2939	1624	3594	1443	2658
2	11777	15446	5341	9240	3464	5750	1616	2923	1750	3629	1705	2436
3	11780	15432	5730	8871	3143	5219	1476	2856	2157	3696	1455	2486
4	13682	15345	5585	8142	3290	6027	1644	3169	1755	3410	1373	2306
5	12185	17018	4926	9164	3239	5453	1725	3346	2265	3831	1343	2664
6	11742	15372	6243	9409	2899	6392	1714	3130	2181	3900	1539	3032
7	13348	15687	6687	11747	2702	5557	1967	3003	2322	4050	1510	2887
8	12096	19454	6534	9274	3466	5643	1802	3040	2140	3345	1439	3077
9	11707	14980	5281	10179	3787	5872	1518	2967	2203	3471	1559	2441
10	13492	14190	6148	10034	3851	5429	1335	3331	2083	3475	1591	2728
11	13866	16121	5844	10627	4859	5158	1509	2587	1824	3822	1710	2822
12	13233	15001	5105	10073	5181	5234	1513	2830	2077	3587	1742	2456
13	15910	15577	6176	10343	4109	5854	1546	2881	1853	3301	1791	2807
14	16092	13239	5674	9746	4182	5744	1632	3069	2160	3243	1848	2635
15	13853	12774	5309	9653	3930	5401	1571	3528	2028	3926	1729	3167
16	14822	13282	6015	9706	4036	5588	1429	3130	1999	3323	1713	2908
17	14619	10066	6669	10431	3645	5021	1771	2937	2194	3174	1643	2662
18	15201	10931	6004	9673	3507	5114	1652	2949	1938	3250	1805	2812
19	14212	12351	5838	9982	3452	5336	1493	2905	2165	3118	1553	3039
20	15488	11736	6788	9639	3684	5566	1586	3092	2243	3640	1655	2625
21	14689	12406	5077	9662	4299	4846	1644	2896	2008	3220	1887	2709
22	14508	10119	6474	8466	3890	5697	1604	3149	2026	3746	1719	2290
23	15284	8711	6187	9814	4353	5425	1571	3519	2173	4483	1876	3104
24	13662	8382	5521	9381	3692	5700	1678	3500	2265	3627	1819	2947
25	14749	9229	6613	9361	4345	5858	1789	2717	2060	3601	2044	3308
26	14977	9018	5844	9591	3736	6176	1830	3277	2302	3989	1730	2953
27	12360	8587	6448	9431	4608	6129	1799	3408	2183	3836	1711	2362
28	14369	8878	6076	9860	4168	5552	1669	3295	2051	4174	1775	2835
29	13569	9747	5646	8824	4299	5911	1514	3115	1875	3735	1785	2290
30	14460	8668	6051	9148	4302	5905	1864	3216	2052	3997	1620	2503
31	9620	13404	6119	9752	4040	5563	1554	3063	2218	3639	1479	2591
32	7980	13071	5800	9432	4494	5795	1825	2547	2403	3700	1518	2656
33	9257	14049	5993	10575	4405	5956	1894	2523	2053	3556	1448	2623
34	8068	13872	6276	11071	4330	5871	1787	2584	2211	3969	1539	2963
35	9785	16045	7289	9363	4568	6016	1651	2500	2040	4138	1324	2876
36	17157	30450	6241	10683	4228	6192	1724	3679	2366	3575	1244	3124
37	15553	28010	5639	9656	3818	4818	1549	3369	2548	3755	1262	2970
38	17054	27267	7031	8699	4213	6879	1506	3458	2045	3982	1324	3095
39	16443	26597	7501	9347	3956	5750	1561	3123	2181	3448	1135	3045
40	9976	17972	6175	10723	4871	6410	1659	3476	2297	4044	1443	3311
41	10011	17162	7025	10495	5355	6696	1546	3967	2080	4745	1410	2862
42	10025	14726	6776	11169	5315	5723	1710	2999	2489	4080	1196	3175
43	10789	18919	6826	10236	5133	6100	1542	3499	2456	4522	1513	3108
44	13969	11589	6420	10518	4773	5871	1768	3405	2154	3770	1746	2582
45	14039	10982	5805	10617	3868	5992	1799	2855	2007	3350	1939	2583
46	13680	9482	6919	9892	4254	6338	1902	3766	1967	3633	2067	2902
47	16770	10115	6694	10152	3784	5056	1767	3681	2410	3568	1738	2788
48	12524	12133	5720	10531	4662	6726	1751	3254	1995	3667	1906	2904
49	5577	12040	6062	8942	5135	5658	1876	2466	2065	3867	1811	2218
50	6238	14473	5827	9034	4914	5405	1822	2671	1981	3904	1774	2233

51	6200	13941	5659	9312	5067	5935	1868	2452	2210	4179	1783	2592
52	6140	12539	6856	9303	4597	5623	1462	2562	2150	3866	1699	2562

	Gemlik 2		Gemlik 3		Aliaga 1		Aliaga 2		Izmir		Thessaloniki	
Weeks	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
1	2697	3038	793	1029	1595	2775	933	1522	4285	8256	1994	3038
2	2724	3379	747	1161	1879	2668	773	1370	4381	8645	2210	2706
3	2928	3711	696	1253	1830	3020	848	1650	4194	8422	2292	2611
4	2694	3069	707	1288	1689	2804	781	1621	3896	8650	1764	2893
5	2854	2872	818	1365	1698	3407	885	1505	4864	7511	2287	3094
6	3055	2492	885	1438	2064	3229	1006	1718	4940	9922	1882	3335
7	2858	2580	1009	1516	1835	3033	906	1643	4991	10303	2089	2709
8	3215	2212	888	1429	1953	3119	978	1560	5178	9482	1949	3199
9	3336	3195	764	1352	2067	2891	880	1490	4833	8301	1313	3169
10	2511	4306	875	1313	1545	3020	899	1568	4441	8648	868	2362
11	2966	3977	829	1370	2039	2815	859	1686	5051	9922	872	2592
12	2843	4247	786	1451	1694	2872	871	1519	4693	9769	723	2559
13	2634	4080	776	1256	1582	2987	799	1564	4565	8992	888	2638
14	3478	5048	970	1461	1724	2960	884	1447	4259	10555	1785	2598
15	3219	4278	997	1272	1881	3281	930	1612	4719	10536	1917	2918
16	3395	5047	988	1382	2089	3333	874	1640	4821	9731	1764	2590
17	2845	4392	1071	1407	1875	3058	970	1637	4866	11152	2113	2470
18	3250	4378	913	1309	1876	3313	799	1411	4506	9558	1828	2636
19	3043	4830	974	1441	1840	3026	960	1582	4797	9418	1899	2624
20	2793	4856	984	1328	1975	3006	816	1652	4877	11118	1685	2661
21	3381	4534	907	1299	1777	3175	897	1609	4550	11069	1894	2668
22	3333	4733	1012	1391	1706	2894	972	1591	4429	9025	1813	2782
23	3328	6208	639	1520	1893	3436	889	1575	4562	8644	1742	4048
24	3783	6554	720	1454	2003	2763	889	1678	5259	8558	1593	3379
25	2831	6484	709	1398	1894	3336	1016	1606	5227	9104	1789	3583
26	3730	6699	760	1367	1871	3306	922	1631	4575	10001	1748	4079
27	2813	5048	1049	1390	1928	3158	870	1562	5106	13190	811	3788
28	2634	4960	940	1398	2025	3275	820	1852	4854	11770	875	3636
29	2991	4813	997	1412	1873	2999	989	1713	4413	10837	732	4179
30	2766	5067	1050	1407	1816	3175	939	1704	4829	10502	814	3945
31	3049	2770	806	1564	1941	3016	920	1441	4981	12610	1790	3928
32	3566	2030	724	1607	1860	3040	984	1640	4855	11869	2397	4099
33	2792	2226	755	1277	2011	3275	958	1271	5116	12042	2428	4243
34	3064	2207	863	1611	1853	3632	1006	1479	4789	11813	2113	4886
35	2801	3135	842	1759	1949	3003	901	1577	4438	12467	2039	4145
36	2530	4368	1108	1516	2099	3223	995	1627	5142	10814	1544	3690
37	2455	3814	1011	1532	2181	3074	965	1755	5119	9760	1493	3271
38	2531	4363	1157	1553	1892	3542	1066	1803	5686	10445	1510	3936
39	2202	4149	1060	1535	2081	3815	965	1748	5034	10217	1485	4065
40	1486	1875	967	1307	2068	3143	866	1499	5264	7177	970	3181
41	1552	2215	981	1568	1871	3619	1028	1755	4482	8158	894	3168
42	1711	2144	912	1446	1967	3488	1138	1645	5463	9053	847	3970
43	1840	2062	927	1597	2130	3431	949	1834	5489	8616	873	3946
44	1782	2070	812	1484	1973	3622	1041	1828	4915	8303	1698	3680
45	1987	2150	746	1565	1946	3183	986	1888	4866	10715	2826	3284
46	1921	2010	707	1377	2004	3409	897	1975	5234	10994	2615	3459
47	2422	2082	695	1216	2019	2937	944	1675	5147	9570	2797	3906
48	1975	2034	725	1260	2060	3556	1003	1548	4809	9860	2127	4027
49	1629	2151	877	1391	1732	3164	961	1317	4918	6901	907	3939
50	1374	1731	855	1303	1829	3160	805	1361	4824	8978	1220	4363
51	1488	2076	1024	1194	2008	3095	958	1564	4296	7606	988	4511
52	1513	2017	1154	1481	1732	2864	900	1534	4427	7953	958	3955

	Piraeus 1		Piraeus 2		Antalya		Mersin		Limassol		Lattakia	
Weeks	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
1	2767	5976	5932	11021	1028	2335	6986	14574	938	5437	3130	5832
2	2501	6110	5885	14383	1105	2007	7985	15149	942	5007	3536	5148
3	2668	5874	6011	12887	1078	2150	8154	14749	848	4715	3015	6178

4	2818	5174	6246	12988	1185	1869	8169	12677	924	4165	2967	6063
5	2731	7449	6653	13927	1101	2016	9016	12586	973	6120	3036	6144
6	3244	9906	6857	14439	1249	1846	8857	15808	1046	7136	2717	5295
7	2725	8805	6662	14183	1258	2274	9039	14814	949	7332	3408	5965
8	3041	9494	6673	14821	1158	2058	9928	14837	1048	6109	3167	6147
9	2857	8725	5893	13799	1193	2339	8394	13745	1071	7035	3487	5657
10	2380	8331	6783	14768	1168	2000	8413	14580	1114	5693	5281	5427
11	2852	9451	6310	13221	992	2243	9015	14152	1312	6012	5125	5996
12	2656	7480	6327	12435	1098	1971	7400	14473	1081	6535	4614	4881
13	2792	8256	6073	14696	1100	2078	9188	17021	1383	5456	5103	5248
14	3104	10647	6563	14396	1125	2073	9143	13573	1454	7713	4632	6660
15	3002	8624	6706	16293	1116	2409	9125	15130	1484	7382	4515	6584
16	2483	11674	7150	14673	1231	2381	9177	13335	1347	6755	4255	6508
17	2577	9499	6351	13285	1266	2210	8976	15666	1297	7551	4411	6381
18	2706	9943	6614	11941	1099	2189	7686	14045	1339	7040	4547	6528
19	2863	8911	6263	15515	997	2387	9061	15194	1506	6544	4183	5821
20	2680	10950	6349	14852	1179	2365	8731	14813	1251	7789	4276	6221
21	3019	10389	7264	13479	1157	1998	8712	12655	1303	6634	4420	6194
22	2838	9643	6627	16830	1245	2148	10234	14376	1152	7576	4005	6388
23	2802	10565	6665	13730	1225	2052	9136	14710	1038	6250	5067	7074
24	2960	9342	6668	17287	1111	2109	8919	15569	831	6715	4900	6717
25	2896	9246	7008	16091	1155	2007	9350	14633	942	6270	4053	6874
26	3011	8934	6749	16380	1220	2071	7900	14493	942	6810	4925	8144
27	3175	11992	7440	17080	1095	2594	9433	16312	1077	8681	5976	5811
28	3192	11578	7021	16976	1201	2119	8336	16444	940	8339	5214	5223
29	3403	12670	7999	17932	1218	2188	9936	14364	1022	7007	5038	6301
30	3362	11830	8051	15457	1152	2427	8896	15415	990	7551	5478	6425
31	2782	9517	6957	16264	1252	1758	8360	14403	1133	7974	4905	6556
32	3056	8925	7801	18211	1275	1457	9415	13021	1333	7186	4950	6803
33	3386	9521	7062	15292	1043	1725	8495	12689	1297	8737	4765	6362
34	2818	8576	6920	17774	1154	1727	9743	14550	1190	8323	4804	6048
35	3139	7644	7089	16749	1382	1785	9445	12906	1284	7961	4730	6868
36	3102	3158	7631	18197	1373	2347	9815	16423	1625	9234	4459	5988
37	3072	3037	9458	17625	1242	2677	9849	17708	1589	8590	4414	6484
38	3057	3141	8696	18468	1330	2671	9862	15558	1463	9610	5480	6942
39	3217	3234	8305	18280	1086	2771	10025	17562	1881	9600	4898	5906
40	3110	6103	8577	19743	1154	1905	9549	15429	1063	8484	5868	7362
41	3472	7228	8267	14591	1157	2130	10033	13170	1099	9478	6273	7866
42	2992	6693	8641	15108	1293	1775	9480	16260	1330	8929	5532	7784
43	3144	6896	7368	16567	1375	1978	9693	16247	1389	8274	5815	6875
44	3522	6666	8600	15553	1408	2181	8082	14042	1154	9893	5881	7694
45	3102	5164	8276	15446	1075	2608	8606	15861	938	9130	5815	7004
46	2799	5218	8473	15680	1201	2534	9050	17879	1054	8374	5022	6679
47	2953	6164	8704	15852	1274	2339	10095	16973	934	7893	5761	8334
48	3158	4086	8710	14897	1257	2114	9557	15083	994	7946	5708	6089
49	3159	2459	7074	14333	1016	1234	8588	16294	927	8248	6769	5208
50	2989	2324	8297	14711	1271	1144	9063	12749	1158	8956	6154	5447
51	2600	2580	6675	15639	1151	1075	8685	13892	1216	9487	7243	5346
52	2573	2540	7903	13050	1154	1287	9648	14894	1144	8675	6724	5317

	Beirut		Haifa		Ashdod		Alexandria 1		Alexandria 2		Damietta	
Weeks	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export	Import
1	4865	7422	8327	11031	7815	7924	3766	12995	3628	7297	5283	11532
2	4903	8327	8193	11214	7856	7377	3856	14730	4230	7180	4873	11828
3	5802	9194	7321	11331	7259	7986	4607	13291	4087	6896	5545	13007
4	5289	9388	7971	10919	8443	7283	4203	11536	3397	6612	4767	13844
5	4075	13216	9543	12588	10684	10308	4043	12566	4346	7727	6647	11333
6	2775	13864	9749	15062	13944	12220	4813	11540	3474	7563	7225	12209
7	3292	14126	8864	15102	11662	10985	4796	10206	4318	7793	8103	11981
8	3263	15751	9581	13069	14347	11747	5596	11105	3815	8981	6479	11437
9	3015	15626	10652	15193	10953	12362	5462	13069	4749	9600	9463	13754
10	2929	18771	12631	17744	13587	13990	6671	13854	4241	10956	8895	14938

11	3200	15539	11243	16706	13068	13448	5892	14188	3855	9785	8922	13454
12	3146	20252	12691	13989	9466	16078	5620	14010	4006	10312	8201	13237
13	3748	18194	11656	15933	13021	15676	6513	13558	4039	10030	8880	12126
14	4543	14232	11549	19423	13935	11917	8052	11009	4279	10974	8008	15854
15	4025	16174	11438	16676	12448	10522	7919	10432	3879	10234	8618	18760
16	4960	13642	11611	16781	12975	11638	7850	10218	4397	9861	8543	18294
17	4456	15099	13022	16512	14117	12376	6887	11301	4601	10200	10021	16945
18	4857	15169	12142	17449	13459	11117	7023	9367	4200	9971	9098	17028
19	4391	13967	11545	15166	12767	12479	7365	10672	4140	9387	9468	17425
20	4757	14018	10348	18706	11832	10055	7873	9729	4372	9531	7849	16335
21	3838	14189	9938	16351	13083	10895	7306	10596	4085	10378	8472	15313
22	5346	13635	12326	14935	14221	13475	7267	8527	3887	8665	6711	16184
23	5516	14879	14534	13693	13074	13763	8663	6376	3990	7050	6572	14931
24	5544	16287	13864	13093	12926	18135	8848	6650	4612	7944	6671	15804
25	5618	15414	12561	12855	13035	14912	8724	6518	4631	7956	6846	13526
26	4737	17191	13008	12438	14352	15559	8870	8143	4027	8418	6775	18430
27	5682	21077	8411	15966	14240	13148	10500	13375	3474	10565	8354	14939
28	5212	21741	8410	14715	12778	13641	8541	13238	3469	11823	8425	15489
29	5399	21264	8866	16635	12903	13415	7523	12249	3595	11041	7204	15160
30	5411	19919	8497	13477	12431	14402	7562	12711	3518	10756	7749	16952
31	3779	16098	12835	11428	11068	10725	8961	7834	4106	10536	7567	17914
32	4048	13336	16294	10845	12402	11815	9213	6925	4013	12101	7382	18396
33	3588	12954	14427	11126	15386	10395	10017	7030	4344	10683	7332	16644
34	3369	13564	13625	10108	12665	9376	10059	6117	4591	10719	7872	17752
35	3722	15221	12860	12759	12342	12789	9086	7294	4521	10577	7474	17060
36	4750	21523	15112	18410	12054	16389	10495	7632	4885	8601	10979	12290
37	4493	19531	16681	20671	11287	16212	9906	7597	5157	8521	8803	12573
38	4837	17650	15520	19779	11340	17031	9740	6930	5149	8155	10864	13110
39	4665	17984	15017	18004	11588	16433	10224	7228	4558	8458	9655	13034
40	1436	19919	11437	21637	8632	11269	8729	7050	4314	11683	13342	20797
41	1268	23481	9873	19160	8943	13358	9162	7295	4463	13138	10900	19789
42	1459	19738	10417	20390	8991	12612	10133	7397	4230	11928	12039	22346
43	1502	20978	10037	20088	8599	11421	9047	7026	4087	11516	13431	21527
44	3579	20126	13204	17566	11518	13983	8858	7172	3864	9599	9906	14620
45	5143	18392	16134	19306	11168	14743	7643	6987	5369	11767	9617	10762
46	5141	16907	15436	17525	12224	16528	7255	6485	4640	10787	10613	10872
47	5795	17394	15753	17806	12844	17950	7448	7259	4510	11258	9123	11020
48	4951	15316	15335	15749	11183	14182	5459	8928	3608	8927	7875	10155
49	3752	6867	10930	11214	10546	14325	5468	13330	3424	10272	6472	10190
50	4070	6285	10972	10293	9869	12946	4726	12483	3444	11015	6011	11219
51	4144	6393	10674	9066	10223	13650	4973	12144	3299	9559	6438	10655
52	3821	6401	10188	8864	9354	12773	5052	12173	3438	9623	7123	9463

Total throughput of related container terminals, the operation amount of interested feeder shipping line could be calculated by using market share ratios in Table A.10.

Table A.13: Results of designed experimental tests

Test 1	Scenario A	Scenario B	Scenario C	Scenario D	Result
1	1	2	1	3	309855.9
2	2	2	1	3	316330.0
3	3	2	1	3	320460.0
4	4	2	1	3	323732.3
5	5	2	1	3	324134.4
6	6	2	1	3	340600.3
Test 2	**Scenario A**	**Scenario B**	**Scenario C**	**Scenario D**	**Result**
7	1	1	1	3	327220.0
8	2	1	1	3	347200.0
9	3	1	1	3	357500.0
10	4	1	1	3	363880.8
11	5	1	1	3	377676.9
12	6	1	1	3	404373.1
13	1	2	1	3	309855.9

14	2	2	1	3	316330.0
15	3	2	1	3	320460.0
16	4	2	1	3	323732.3
17	5	2	1	3	324134.4
18	6	2	1	3	340600.3
19	1	3	1	3	280241.0
20	2	3	1	3	262368.2
21	3	3	1	3	253920.7
22	4	3	1	3	246371.3
23	5	3	1	3	237288.7
24	6	3	1	3	218361.3
25	1	4	1	3	298832.7
26	2	4	1	3	292802.2
27	3	4	1	3	283924.0
28	4	4	1	3	276514.3
29	5	4	1	3	265712.6
30	6	4	1	3	258623.5
31	1	5	1	3	302509.6
32	2	5	1	3	301000.0
33	3	5	1	3	301453.8
34	4	5	1	3	301978.9
35	5	5	1	3	300421.2
36	6	5	1	3	304585.8

Test 3	Scenario A	Scenario B	Scenario C	Scenario D	Result
37	1	2	1	3	309855.94
38	1	2	2	3	316330.00
39	1	2	3	3	320460.00
40	1	2	4	3	323732.28
41	1	2	5	3	324134.35
42	1	2	6	3	340600.33
43	2	2	1	3	272609.09
44	2	2	2	3	278270.00
45	2	2	3	3	283941.90
46	2	2	4	3	286478.88
47	2	2	5	3	284813.16
48	2	2	6	3	299669.71
49	3	2	1	3	268230.00
50	3	2	2	3	277350.00
51	3	2	3	3	276907.46
52	3	2	4	3	283280.75
53	3	2	5	3	283309.51
54	3	2	6	3	299669.71
55	4	2	1	3	278951.00
56	4	2	2	3	283800.00
57	4	2	3	3	286003.42
58	4	2	4	3	289055.76
59	4	2	5	3	285777.16
60	4	2	6	3	299669.71
61	5	2	1	3	282090.00
62	5	2	2	3	284584.69
63	5	2	3	3	290578.67
64	5	2	4	3	291378.70
65	5	2	5	3	291052.98
66	5	2	6	3	299669.71
67	6	2	1	3	274360.00
68	6	2	2	3	280860.00
69	6	2	3	3	282710.00
70	6	2	4	3	287904.92
71	6	2	5	3	287291.76
72	6	2	6	3	299669.71

Test 4	Scenario A	Scenario B	Scenario C	Scenario D	Result

73	3	2	1	3	320463.00
74	3	2	2	3	283942.00
75	3	2	3	3	276907.00
76	3	2	4	3	286004.00
77	3	2	5	3	290579.00
78	3	2	6	3	282708.00
79	3	2	1	3	320463.00
80	3	2	2	3	284384.00
81	3	2	3	3	280418.00
82	3	2	4	3	286933.00
83	3	2	5	3	292077.00
84	3	2	6	3	284638.00
85	3	2	1	3	320463.00
86	3	2	2	3	285310.00
87	3	2	3	3	283817.00
88	3	2	4	3	287104.00
89	3	2	5	3	291293.00
90	3	2	6	3	284666.00
91	3	2	1	3	320463.00
92	3	2	2	3	285383.00
93	3	2	3	3	285187.00
94	3	2	4	3	287156.00
95	3	2	5	3	290332.00
96	3	2	6	3	285799.00
97	3	2	1	3	320463.00
98	3	2	2	3	286623.00
99	3	2	3	3	288002.00
100	3	2	4	3	287049.00
101	3	2	5	3	290149.00
102	3	2	6	3	286410.00
103	3	2	1	3	320463.00
104	3	2	2	3	287820.00
105	3	2	3	3	293124.00
106	3	2	4	3	286340.00
107	3	2	5	3	291569.00
108	3	2	6	3	287750.00

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