YAŞAR UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
PHD IN BUSINESS ADMINISTRATION

PHD THESIS

OPTIMIZATION OF COSTS AND OPERATIONS IN EMPTY CONTAINER REPOSITIONING

HÜSEYİN GENÇER

THESIS ADVISOR: PROF. DR. M. HULUSİ DEMİR

2018 İZMİR

DOKTORA/SANATTA YETERLİK TEZİ JÜRİ ONAY SAYFASI

Bu tezi okuduğumu ve görüşüme göre doktora/sanatta yeterlik derecesi için bir tez olarak kapsam ve nitelik açısından tam olarak yeterli olduğunu onaylarım.

(09.01.2018)

(Tez Danışmanı, Prof.Dr.M.Hulusi Demir)

Bu tezi okuduğumu ve görüşüme göre doktora/sanatta yeterlik derecesi için bir tez olarak kapsam ve nitelik açısından tam olarak yeterli olduğunu onaylarım.

(09.01.2018)

(Prof.Dr.Ali Özdemir)

Bu tezi okuduğumu ve görüşüme göre doktora/sanatta yeterlik derecesi için bir tez olarak kapsam ve nitelik açısından tam olarak yeterli olduğunu onaylarım.

(09.01.2018)

(Doç.Dr.Soner Esmer)

Bu tezi okuduğumu ve görüşüme göre doktora/sanatta yeterlik derecesi için bir tez olarak kapsam ve nitelik açısından tam olarak yeterli olduğunu onaylarım.

(09.01.2018)

(Doç.Dr.Yüksel Öztürkoğlu)

Bu tezi okuduğumu ve görüşüme göre doktora/sanatta yeterlik derecesi için bir tez olarak kapsam ve nitelik açısından tam olarak yeterli olduğunu onaylarım.

(09.01.2018)

(Yrd.Doç.Dr.M.Nurol Durak)

Doç.Dr. Çağrı Bulut

SOSYAL BİLİMLER ENSTİTÜ MÜDÜRÜ

ABSTRACT

OPTIMIZATION OF COSTS AND OPERATIONS IN EMPTY CONTAINER REPOSITIONING

Hüseyin Gençer

PHD in Business Administration

Advisor: Prof. Dr. M. Hulusi DEMİR

2018

The imbalances in world trade also affect container traffic and lead to large differences in import and export rates of many locations. As a consequence of this, the surplus containers are repositioned to locations where they are required, which causes high costs. On the other hand, even if there exist an import/export balance in a location, receiving the empty containers at depot or terminal returning from import, re-transporting empty containers between depot and terminal to be filled according to customers' request, and all the handlings at depots and terminals cause extra costs as well. Allocating these activities and costs according to the type of container and location, and how these costs can be reflected in freight rates is another issue in container shipping. To this end, in the dissertation, costing models based on traditional costing techniques and activity-based costing were developed to ensure accurate calculation of the empty container repositioning unit cost for container types in the service locations in liner shipping.

Since empty container repositioning decisions involve too many parameters, constraints and variables, the plans based on real-life experiences cannot be effective and very high costs arise. For this purpose, two mathematical programming models were developed in order to make empty container repositioning plans faster, more efficient and at the lowest cost. While the resources, activities, cost drivers and costs determined for the costing models affect the parameters, variables and constraints of the mathematical programming models, the outputs of the mathematical programming models affect the unit empty container repositioning costs of each location and container type. Hence, by combining the costing models and mathematical programming models, the dissertation puts forward a decision support system which minimizes the total empty container repositioning costs and provides more accurate profit/loss analysis by obtaining unit empty repositioning cost for different container types in the locations on the transportation service routes. The models developed in the dissertation were tested with real data and provided better results than real life applications.

Keywords: Empty container repositioning, Costing in empty container repositioning, Container logistics, Empty container management,

ÖZ

BOŞ KONTEYNER POZİSYONLAMADA MALİYETLERİN VE OPERASYONLARIN OPTİMİZASYONU

Hüseyin Gençer
Doktora Tezi, İşletme Doktora Programı
Danışman: Prof. Dr. M. Hulusi Demir
2018

Dünya ticaretindeki dengesizlikler konteyner trafiğini de etkilemekte ve bir çok yerin ithalat/ihracat oranlarında büyük farklılıklara yol açmaktadır. Bunun sonucu olarak, fazlalık konteynerlerin ihtiyaç duyulan yerlere gönderilmesi ise büyük maliyetlere neden olmaktadır. Diğer taraftan, bir yerde ithalat/ihracat dengesi olsa da, ithalden boş dönen konteynerlerin ihracatta kullanılmak üzere depoda veya limanda kabul edilmesi, müşterilerin konteyner dolumunu gerçekleştirmek istedikleri yerlere bağlı olarak konteynerlerin yeniden taşınması ve buna bağlı olarak ortaya çıkan yükleme/indirme işlemlerinde de maliyetler ortaya çıkmaktadır. Boş konteyner pozisyonlamada ortaya çıkan faaliyetlerin ve maliyetlerin konteyner türlerine ve maliyetin oluştuğu yere göre nasıl yükleneceği, bu maliyetlerin navlun fiyatlarına nasıl yansıtılabileceği ayrı bir sorundur. Bu amaçla tezde, düzenli hat taşımacılığında, hizmet verilen yerlerdeki konteyner türleri için boş konteyner pozisyonlama birim maliyetinin doğru bir şekilde hesaplanmasını sağlayacak, geleneksel maliyetleme teknikleri ve faaliyet tabanlı maliyetleme tekniğine dayanan maliyetleme modelleri geliştirilmiştir.

Boş konteyner pozisyonlama kararları çok fazla değişken, kısıt ve parametre içerdiği için gerçek hayatta sezgisel tecrübelere dayanılarak yapılan planlar çok etkin olamamakta ve yüksek maliyetler ortaya çıkmaktadır. Bu amaçla tezde, boş konteyner pozisyonlama planlarının daha hızlı, etkin ve en düşük maliyette yapılmasını sağlayacak, deterministik ve stokastik iki matematiksel programlama modeli geliştirilmiştir. Maliyetleme modelleri için belirlenen kaynaklar, faaliyetler, maliyet sürücüleri ve maliyetler matematiksel programlama modellerinin parametre, değişken ve kısıtlarını etkilediği gibi, matematiksel programlama modellerinin çıktıları da her yerdeki konteyner türlerinin birim maliyetlerini etkilemektedir. Dolayısıyla tezde, maliyetleme modelleri ve matematiksel programlama modelleri birleştirilerek; hem toplam boş konteyner poziyonlama maliyetlerini minimize eden hem de taşımacılık hizmeti verilen yerlerdeki konteyner türleri için birim boş konteyner pozisyonlama maliyetleri bulunarak kar/zarar analizinin daha doğru yapılmasını sağlayacak bir karar destek sistemi ortaya konmuştur. Tezde geliştirilen modellerin gerçek hayat uygulamalarına göre daha iyi sonuçlar verdiği gerçek veriler ile test edilerek gösterilmiştir.

Anahtar sözcükler: Boş konteyner pozisyonlama, Boş konteyner pozisyonlamada maliyetleme, Konteyner lojistiği, Boş konteyner yönetimi

ACKNOWLEDGEMENTS

I would like to thank my dear supervisor Prof. Dr. M. Hulusi Demir for his assistance, kindness and close support during the whole period of my Phd study. I highly appreciate the advice and guidance of Assoc. Prof. Dr. Soner Esmer who has always been available to help me since my master studies. Special thanks to Assoc. Prof. Dr. Gürol Durak for his important feedback and valuable insights during the thesis meetings. I also appreciate Assoc. Prof. Dr. Yücel Öztürkoğlu and Prof. Dr. Ali Özdemir for their motivational advice.

I thank all my professors for helping me in understanding the mathematical modeling concepts during my PhD period. I appreciate my old manager and colleagues in my old company who provided me a suitable environment to work. I also thank all my colleagues at the Piri Reis University, my special office colleagues in particular.

Finally, I am greatly thankful to my family for their unconditional love, constant support and encouragements.

TEXT OF OATH

I declare and honestly confirm that my study, titled “Optimization of Costs and Operations in Empty Container Repositioning” and presented as a PhD Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Hüseyin Gençer

January 29, 2018

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABC	Activity-Based Costing
DSS	Decision Support System
ECR	Empty Container Respoitioning
EDI	Electronic Data Interchange
EMED	Eastern Mediterranean
ERP	Enterprise Resource Planning
EVPI	Expected Value of Perfect Information
IT	Information Technology
LP	Linear Programming
MILP	Mixed Integer Linear Programming
MIS	Management Information System
NVOCC	Non-Vessel Operating Common Carrier
OR	Operations Research
POD	Port of Destination
POL	Port of Loading
SP	Stochastic Programming
THC	Terminal Handling Cost
VSS	Value of Stochastic Solution
WMED	Western Mediterranean

1. CHAPTER
INTRODUCTION

A large part of international trade is carried out by maritime transportation. Because container ensures safe, comfortable and intermodal transportation opportunities, container transportation is one of the most preferred type of cargo transportation for long distances in international trade and maritime transportation. A very large proportion of the world container fleet is used in liner shipping which is the backbone of container shipping. The imbalances in the worldwide trade affect the container traffic directly and cause imbalances in the number of containers in many locations. In other words, export dominant locations have deficits in terms of number of containers and import dominant locations do surpluses. As a consequence, surplus containers should be repositioned as empty to the locations where they are required.

Figure 1 shows the estimated containerized cargo traffic on major trade lines in 2015. As can be seen, there are a lot of exports of containerized cargo from Asia to Europe. Conversely, the imports to Asia from Europe are not even half of this rate. In this regard, the following comment can be made: Approximately one of the two 20dv full containers going from Asia to Europe, will not be used after the containers have been unstuffed. On the other hand, containers are required in Asia to meet the demand for exports. Hence, the empty containers, which are not required in Europe, are transported back to the locations in Asia.

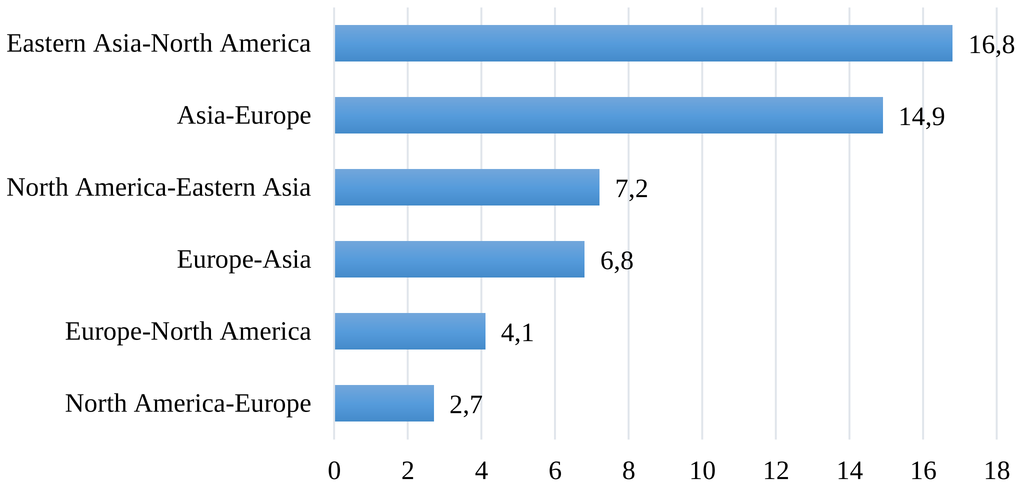

Figure 1. Containerized cargo flows on major trade routes in 2015 (in million TEUs) (Source: UNCTAD, Lloyd's List, Statista)

As can be seen in Figure 1, a similar imbalance exists in the containerized trade between Europe and North America, and Eastern Asia and North America. A similar trade imbalance on the main routes is still present today. Empty containers that are held in storage, handled and repositioned due to trade imbalances lead to extra costs for the container liner carriers. More clearly, while the liner carriers make money by carrying full containers, they spend money for the repositioning of empty containers. According to many experts, the total repositioning costs of empty containers exceed 20 billion dollars annually. Therefore, one of the main objectives of all shipping companies is to reduce the repositioning costs of empty containers.

Empty container repositioning (ECR) costs increase the total oprations costs of liner carriers and do not provide any added value to customers. No matter how the ECR costs are defined and classified, these costs have a crucial act in container shipping. With a more concrete expression; it is required to decrease and regularly monitor the ECR costs in terms of providing profitability and advantage in the global competitive environment. This can only be achieved through an effective cost management.

Since ECR causes an increase in overall traffic leading to high carbon emissions, they also affect the society and environment (Flämig, Wolff and Herz, 2011, p.49). Therefore, optimal planning of ECR would indirectly contribute to reduced congestion and environmental pollution (Hjortnaes et al., 2017).

This dissertation focuses on the management of ECR in liner shipping at the operational level. The dissertation intends to develop a decision support tool by integrating costing models and optimization models to make better decisions in the management of empty containers in liner shipping.

This chapter sets out the aim of the dissertation and explains how the models applied in the dissertation are developed and designed. The data and data collection process are also explained in this chapter. Lastly, it describes the outline of the dissertation.

1.1. Motivation

Almost all parties, especially the liner carriers in container shipping industry struggle with the high costs of ECR. Therefore, making efficient plans to reduce these costs is crucial for the container shipping companies. On the other hand, along with the efficient physical distribution and allocation plan of ECR, allocation and distribution of the costs are also vital in liner shipping to make an accurate cost analysis. There are a significant number of studies in the literature regarding the management of empty containers which mostly focus on the minimization of ECR costs. Nevertheless, no studies have examined the cost allocation or costing of ECR in liner shipping. However, in order to make a more accurate pricing and cost analysis, the operations and costs of ECR should be dynamically monitored. The main motivation of this dissertation is to show how the ECR costs can be reflected in the freight rates according to different decisions. For that purpose, the following objectives are listed:

Research Objective 1

In order to make a more accurate profit/loss analysis, shipping companies should take into account the empty container situation in the place of loading and destination that are subject to the freight rate. Besides the differences in export and import rates, transportation, storage and handling costs of empty containers can also vary from location to location. Export and import rates for various types of containers may also be different in the same location. All of these lead to different number of movements of empty containers for each location and container type. Taking into account that each movement or even storage of an empty container causes a cost, the ECR costs should be managed and controlled very carefully. The first objective of this study is developing costing models for the calculation and accurate allocation of the ECR costs in liner shipping and demonstrating the impact of these costs on freight rates.

Research Objective 2

The decision-making process for the physical allocation and distribution of empty containers is a very complex structure involving many factors which are in continuous contact with each other. Thus, decisions taken on the basis of past and intuitive experiences cannot be very efficient. The second objective of this study is developing mathematical programming models that minimize the total costs of ECR in order to make more efficient and faster plans. Besides the various objectives and constraints in the real-life applications, one of the mathematical models also takes into account the uncertainty of container demand in the locations.

Research Objective 3

The third objective is combining the costing models in a consistent manner with the mathematical programming models. In this way, the decision-maker will be able to analyze, monitor and foresee the operations and costs of ECR and to comprehend how these costs can be integrated into the freight costs. Accordingly, through the combination of the costing models and mathematical programming models, the decision-maker will be able to analyze the effects of changes in the plans of ECR in terms of unit costs for each container type in each location. In this regard, it can be used as a decision support tool by the executives of logistics and sales departments for their real-life applications.

1.2. Research Methodology

For the second chapter, in addition to reviewing the literature, the author's practical and professional experiences in the container shipping industry has also been taken into consideration in putting forward the current situation, trends, problems and suggestions in the industry. Key words such as 'container logistics', 'container management', 'empty container movement', 'empty container repositioning', 'empty container optimization', 'costs in container shipping', 'pricing in container shipping', 'cost optimization in container shipping', 'cost management in maritime logistics', 'costing in logistics', 'costing in operations management' are searched in academic databases, journals and scholarly search engines for the literature review. As a result of these searches, articles related to the thesis topic were selected. Moreover, the references of the articles were verified to find other resources related to the dissertation topic. Sector reports and online news web-sites such as Lloyd's List, World Maritime News were also used for some topics in the literature review. Furthermore, the books that stand out in terms of maritime transportation, container shipping, logistics and cost management were referred as important resources as well.

The following sections explain the data collection process and data used in the dissertation. The costing models and the mathematical programming models developed in this dissertation are also stated in the next sections.

1.2.1. Data and Costing Models

The data used in this thesis was taken from a container shipping company which provides worldwide liner services. The company collects and combines the majority of its data and information in a business intelligence software. All the necessary data and information used in the dissertation were withdrawn from this business intelligence software. Other data sources of the company such as excel files, invoices and mails were also examinded in cases where the data was incomplete or missing. Inconsistents parts were often discussed with the logistics and commercial managers of the company. Data collection and editing process lasted from the beginning of 2016 until January 2017 by visiting the shipping company in a few times.

The costing models developed in the thesis were constructed after a detailed analysis of the operations and cost data of the container shipping company. Depots, terminals and transportation providers used by the company, and its real life applications on ECR in a specific region were investigated in detail. Data on handling, storage and transportation costs, and resources in each location were analyzed separately. Especially, the transportation costs were properly allocated according to the transportation event and where this transportation occurred. In this respect, a cost pool of ECR costs for each location and container type was formed. Besides the traditional costing methods, activity-based costing (ABC) approach was also applied for the costing models developed in the dissertation.

1.2.2. Mathematical Models

The first mathematical programming model developed in the thesis is a mixed-integer linear programming (MILP) model which minimizes the total ECR costs. It considers transportation and storage costs in ECR. The model was formulated according to the requirements of the shipping company's real-life applications to find the optimal empty container distribution combination.

The second mathematical programming model presented in the dissertation is a scenario-based stochastic programming (SP) model which also minimizes the total ECR costs. Unlike the deterministic model, this model takes into account the uncertainty in the container demand in the locations where empty containers are required to cover the weekly demand. Both models were tested with the real data and the results were compared with the applications made by the company. The scenarios created for the SP model were based on the container demands of the forecasting system used by the shipping company. The container demands in this forecasting system rely on the discrete probability distribution of the past data in the locations and are also arranged according to the experience of managers of the shipping company.

1.3. Outline of the Thesis

The second chapter of the thesis presents the literature review on ECR. It discusses the phenomenon of ECR in liner shipping, deals with the planning levels and parties involved in the operations of ECR. This chapter also investigates the mathematical models on ECR studied in the literature.

The third chapter of the thesis highlights the importance of cost management in logistics and examines the costs arising from ECR in detail. It emphasizes the importance of accurate cost allocation of ECR costs in liner shipping and shows their effect on freight costs. The costing models developed for the calculation of unit ECR cost are presented in this chapter as well.

The fourth chapter of the thesis introduces the deterministic MILP model and SP model. The numerical results of the real life data solved by these models are also presented in this chapter. Furthermore, the costing models and the mathematical programming models are combined over the numerical results in this chapter. Namely, the solutions obtained by the mathematical programming models are used as the inputs for the costing models in order to allocate the ECR costs according to the weeks, locations and container types. Finally, the results of the deterministic and stochastic models are also compared in this section.

The final chapter of the thesis contains the summary and future research directions. This chapter also emphasizes the contributions of the dissertation to the literature. The appendices, codes of the optimization software and references are presented at the end of the dissertation.

2. CHAPTER
LITERATURE OVERVIEW

The issue of container imbalances has been a point of interest in the academic world. Many researchers have addressed this issue from different aspects. Most of the studies in the literature focus on the optimization of ECR resulting from container imbalances. New strategies and methods on the management of ECR have been proposed in these studies. This chapter discusses underlying studies on ECR in the literature by putting forward the current situation, trends, problems and suggestions in the industry.

2.1. Management of Empty Container Repositioning in Liner Shipping

Other than the goods transported inside of it, a container itself is also an asset that needs to be dealt with. The phenomenon of ECR has attracted considerable attention in academic world. Jarke (1981) made the first review on container management problem and highlighted the importance of efficient container transportation logistics. Dejax et al. (1987) conducted a literature review on ECR. The author presented the trends in ECR and addressed the prominent models developed in the literature for the solution of problems on ECR.

According to the decision levels, management of empty containers are handled in three levels; strategic, tactical and operational level. Decisions such as the determination of container fleet size and long-term lease agreements are taken by the shipping lines at strategic level (Braekers et al., 2011). Vessel route planning, agreements with third-party transportation providers, terminals and depots can be considered as tactical decisions related to management of empty containers in liner shipping. Strategic and tactical decision are directly taken by the top management of the shipping companies. Operational decisions are usually carried out by local agencies and regional offices of the shipping companies and mainly involve short-term plans such as distribution of empty containers from surplus locations to deficit locations considering vessels' arrivals, departures and capacities on regular basis.

ECR are mainly treated as logistics activities in liner shipping and carried out by the logistics departments of liner carriers (Baird, 2015, p. 190). In terms of geographical planning level, ECR take place at four scales; global, interregional, intraregional and local (Theofanis and Boile, 2008). The global level includes intercontinental ECR and is directly carried out by the logistics headquarters of the container shipping companies. Sending the surplus empty containers from North America to Asia can be a good example for the ECR at global level. The interregional level includes the ECR in a large area and is usually carried out by the logistics departments at the headquarters of liner carriers as well. Nevertheless, depending on the proximity of the regions and number of containers, ECR at interregional level can also be executed by the regional offices of the liner carriers. Repositioning the surplus empty containers from North Europe to North Africa can be regarded as interregional ECR. The intraregional level involves the ECR between the locations within the same region, and the logistics departments in the regional offices are in charge of such operations. ECR between Istanbul and Odessa in the Black Sea Region can be considered as this type of planning level. ECR at local level occurs between the depots and terminals in the same location. For example, managing the movements and storage of empty containers in Istanbul are at such a level of planning. This level of operations is mainly carried out by the local agencies of the liner carriers.

The investigation of planning levels is important in terms of understanding the occurence and patterns of ECR, and therefore in terms of the designation the ECR costs. So that it can be determined in which region, location or service line the costs will be allocated.

2.2. Actors in Empty Container Repositioning in Liner Shipping

Liner carriers, which are the container shipping companies, are the most important actors in ECR in terms of expenditures and duration of container usage. Besides the liner carriers, ECR also have significant effects on other actors in container shipping industry such as other carriers, terminal and depot operators, inland carriers, leasing companies, shippers and consignees (Lun et al., 2010, p.151).

For other carriers or third-party vessel operators, transportation of empty containers means lower income as the freight rates for them are lower than the transportation rates of full containers. Similarly for inland carriers, transportation of empty containers also means little profit. Nevertheless, in case of limited weight and idle capacities on the vessels or inland transportation vehicles, transportation providers benefit from the shipment of empty containers.

Compared to full containers, terminal operators also gain lower profit from empty container handlings and storage. On the other hand, a large number of empty containers cause congestion and inefficiency at terminals. For this reason, some terminal operators do not accept empty container deliveries at terminal or charges high storage costs to customers. Accordingly, many liner carriers prefer to use off-dock depots. The depot operators are important partners of carriers as they mostly make money from empty container handling, storage and repair.

Leasing companies are also important actors in the container shipping industry. They own a share of 41 - 49 % of the total container fleet (Leeuwen, 2016). Carriers usually make long-term leasing agreements with the leasing companies. Nevertheless, depending on trade imbalances, short-term leasing agreements take place as well. In general, carriers prefer to off-hire containers in surplus locations and on-hire in deficit locations. To avoid the commercial exploitation, leasing companies put some quotas and restrictions to the carriers in many surplus locations (Theofanis and Boile, 2009). They can also lease the returned containers to another carriers in the same locations or reposition them to other locations of high demand. The relationship between the shipping companies and container leasing companies is a very broad and different issue that needs to be investigated separately.

Shippers and consignees in container shipping are usually the transportation providers such as freight forwarders or other carriers, but can also be the direct seller or buyer of the goods that are carried in the containers. In general, they are responsible for the pick up of empty containers to be filled at the port of origin, and for the returning of empty containers at the port of destination. Namely, they also take important place in ECR because of the direct connections with liner carriers.

2.3. Deterministic Approaches for Empty Container Repositioning

Researches in the literature have usually examined the problem of ECR in terms of finding the optimum empty container distribution plan (Hajeeh and Behbehani 2011). Some studies have taken into account that shipping companies use third-party vessel operators to transport their empty containers, whereas some focused on the problem through the assumptions that shipping companies have their own vessels by considering vessel capacity as the full and empty containers are carried together. Most of the studies in the literature have addressed the problem of ECR deterministically. That is, it is taken into account that the parameters in ECR decisions are strictly known.

The first study on ECR in the literature was conducted by Potts (1970). The author solved the problem of ECR using the sandard out-of-kilter algorithm. White (1972) presented an algorithm that considers the distribution of empty containers as a minimum-cost flow network problem. Ermolev et al. (1976) introduced a network model for ECR by taking into account transportation and container leasing costs. In his Phd thesis, Florez (1986) formulated a dynamic container allocation model for ECR and container leasing. The author introduced a dynamic transhipment network model which is solved by using two linear programming algorithms.

One of the first desicion support systems based on the network optimization models on empty container distribution was proposed in the paper of Shen and Khoong (1995) where a single container type and leasing decisions were assumed. Nevertheless, the technical aspects about the optimization models were not addressed in the paper. Choong et al. (2002) examined ECR at tactical level to analyze planning horizon effect on ECR and introduced an integer programming model that minimizes total ECR costs.

Wang and Wang (2007) studied the ECR problem for inland transportation. They developed an integer linear programming model to minimize ECR costs. The model in that study also considers the container shortage and leasing costs. Shintani et al. (2007) addressed the design of container liner shipping service networks by taking into account the ECR. The authors handled vessel deployment and ECR together and developed a genetic algorithm based heuristic for the solution of the problem. The numerical experiments in that study proved that the simultenous consideration of vessel deployment and ECR can provide better results than handling vessel deployment and ECR one by one.

Feng and Chang (2008) studied the ECR problem in terms of safety stock management. The authors developed a two-step approach to minimize the ECR costs. The first stage determines the empty container stock and the second stage finds the optimum distribution plan of empty containers. Bandeira et al. (2009) developed a decision support system (DSS) which considers the distributon of empty and full containers. Additional to the integrated solution of empty and full containers, the authors also provided analysis' for the customer service level in terms of transportation time and time of order completion.

Dang et al. (2012) examined repositioning of empty containers in a port area with multiple depots. The authors developed a simulation model and four heuristics to find optimal inventory policies for empty containers. Dong and Song (2012) studied the ECR problem in a shipping network with multiple service routes in detail. They introduced two solution methods to minimize the total ECR costs. The first method is a shortest-path based integer programming model and the second method is a two-stage heuristic-rule based integer programming model. Numerical results showed that both of the solution methods perform better than the real-life practices.

Furio et al. (2013) investigated ECR at local level and considered street-turn applications in the hinterland of Valencia. The authors developed a DSS based on an optimization model that minimizes total costs of ECR including storage costs at terminals and depots. The computational results based on the real data showed that the model developed in the study significantly reduces the ECR costs.

Moon et al. (2013) examined the comparison of the repositioning costs of foldable containers with standard containers. Three mathematical models were developed in the study to minimize the total costs including container purchasing cost, repositioning cost, folding/unfolding cost and storage cost. Two heuristics were also developed in the study to solve the mathematical models. Numerical results in that study showed the economic practicality of foldable containers. Myung and Moon (2014) developed a model for the repositioning of standard and foldable empty containers. The authors represented the ECR problem as a minimum cost network problem and showed that the minimum cost network flow algorithm finds the optimal solution.

Zhang and Facanha (2014) analyzed empty container operations plans of a shipping line and proposed some strategies to reduce the total ECR costs in the transpasific services. Çağlar and Esmer (2015) carried out a qualitative study on the ECR problem in Turkey. The authors conducted in-depth interviews with port authorities and agencies of liner carriers in Turkey. They discussed the issues arising from ECR and offered short and long-term solutions.

Huang et al. (2015) studied network design and cargo routing problem and proposed a mixed integer linear programming (MILP) model that minimizes total operating costs. The proposed model does not take into account different type of containers but only total number of TEUs. The numerical results based on the real data showed promising results in terms vessel capacity utilization. Akyüz and Lee (2016) considered a simultaneous service type assignment and container routing problem. Besides the vessel deployment and speed optimization, ECR were also taken into account in the study. The authors formulated a MILP model that minimizes total vessel deployment costs in liner shipping. For the solution of the problem, a column generation procedure and a branch and bound algorithm were developed. Thanks to these solution approaches, the simultaneous service type assignment and container routing problem can be solved in a reasonable time.

Xie at al. (2017) studied empty container management from a game theoritical point of view. The authors formulated two models -a centralized model and a decentralized model- for an intermodal transportation system that consists of one rail firm and one liner carrier, and obtained optimal policies for both models. Hjortnaes et al. (2017) developed a deterministic linear programming model for the minimization of ECR costs by considering container repair operations in a port area. The model was tested with the real data and provided promising results.

2.4. Stochastic Approaches for Empty Container Repositioning

Although many studies in the literature dealt with ECR in a deterministic way, there are many uncertainties in real life applications. As the parties in container shipping have different purposes, vessel arrivals, vessel space and weight capacities, customer demands can change at any time. Especially, it is crucial to meet customer demand on time in liner shipping. Studies have been carried out in the literature that take into acccount the uncertainties of real-life applications in ECR.

Lai et al. (1995) examined ECR problem and proposed a planning approach to real-life applications of a Hong-Kong based shipping company. The authors considered the uncertainty in container demand and developed a simulation model of company’s operations, and introduced a two-step heuristic in accordance with company's ECR policy to minimize total operation costs including handling, storage, short-term leasing and idling cost of empty containers. Based on the real data, the results of the study demonstrated that their approach could provide high operational cost savings to the company. Cheung and Chen (1998) formulated a two-stage stochastic network model which considers the uncertaintiy in vessel capacities and number of empty containers in the surplus and deficit locations.

Li et al. (2004) discussed the management of empty containers in a sea port from an inventory problem point of view by considering positive and negative container demands. This work was extended in a latter paper which handles the same problem for a multi-port case (Li et al., 2007). The authors also developed a heuristic algorithm to compute the feasible inventory policies. The numerical examples in the paper showed that the heuristic can provide very close results to the optimal solutions.

Song (2006) investigated the optimal policy for ECR in a periodic-review shuttle service. Random customer demand were taken into account in that study using the Markov decision process to find the optimal stationary policy of ECR. In addition to storage and transportation costs, the model proposed in the study considers the container leasing costs as well.

Some studies handled dynamic repositioning of empty containers considering the uncertainties. Crainic et al. (1993) proposed both deterministic and stochastic dynamic network models for inland repositioning of empty containers at tactical level. Lam et al. (2007) introduced a dynamic stochastic model for ECR problem in a two-ports two-voyages system. Erera et al. (2009) developed a robust optimization model for dynamic ECR. All these studies have shown promising results in reducing ECR costs.

Dong and Song (2009) introduced a simulation-based evolutionary algorithm to minimize the total ECR costs of a shipping line which has its own vessels. In their model, all type of container sizes and full containers are also considered which directly influence empty container allocation on the vessels in terms of TEU capacity. The strength of the model is to include almost all the cost items such as transportation cost, storage cost, container handling cost, penalty cost for unmet demands in ECR.

Francesco et al. (2009) handled ECR problem under uncertain parameters. They proposed a mathematical model to minimize the ECR costs by considering transportation, storage and handling costs in a shipping network. The computational results based on the historical data of a shipping company showed that the proposed mathematical model provides better repositioning plans for empty containers in comparison to the deterministic ones. Long et al. (2012) examined the ECR problem at the operational level and formulated a two-stage stochastic programming model which minimizes the ECR costs. Their study handles with the uncertainties in the demand and supply of empty containers, available space and weight capacity for empty containers on the vessels. The authors used sample average approximation method to solve the stochastic problem. Moreover, for the solution of the large-scale problems, two heuristics algorithms were applied in the same study. The numerical results demonstrated that the algorithms provide good solutions and can significantly reduce the ECR costs.

Wang and Tang (2010) studied the container transportation problem considering full and empty containers only for maritime transportation under uncertain container supply. The authors proposed a chance-constraint programming model which is transformed into an integer programming model which has an objective of maximizing the total profit. The numerical examples of that study showed promising results. Francesco et al. (2013) studied the ECR problem considering disruptions of port calls. They developed a stochastic programming model including different scenarios regarding the uncertainty in port disruptions. The computational results in the study proved the effectiveness of the model which solves even the large-scale problems in a few minutes in CPLEX optimization software.

Mittal et al. (2013) investigated the ECR problem in terms of deciding for opening new inland depots in a service network. In their study, the authors considered the uncertainty in container demand and supply, and developed a two stage stochastic programming model with recourse that minimizes ECR costs to find the optimum locations of the inland depots to be opened in a 10 year time horizon.

Wong et al. (2015) developed a yield-based container repositioning framework based on a constraint linear programming model. The model considers the uncertainty in the upsurge container demand. The results of the proposed model in the study provided satisfying container repositioning plans and can be used as a decision support tool for real life applications.

2.5. Cost Estimation in Empty Container Repositioning

Pricing in container shipping is a broad topic to be examined on its own. As Slack and Gouvernal (2011) stated, the structure of container feight rates have become much more complex. When offering a freight rate, all the costs should be taken into consideration in order to see how much profit or loss will be made. So, it is necessary to make an accurate cost analysis to offer a lucrative freight rate. In this regard, pricing and cost analysis issues are at the center of container shipping. However, this subject has received little attention in the literature. Similarly, estimation of ECR costs has been little studied in the literature as well. Along with other costs, ECR costs should also be taken into account when determining an accurate freight price. To put it more precisely, costs of ECR incurred before the shipment, and costs to be generated after the return of container from the consignee at the port of destination must also be added to the shipment price.

Slack and Gouvernal (2011) examined the effect of surcharges on container freight rates. The authors revealed the role of surcharges such as THC, BAF, CAF on a real data in detail. Although the ECR costs were mentioned as logistical imbalances surcharges in their paper, the authors did not elaborate on this issue.

One of the first studies on revenue management in container liner shipping was conducted by Wang et al. (2015). The authors developed a bi-level optimization model to maximize the expected profit of a shipping line. The analyzes in the study revealed beneficial results for pricing decisions of the managers. Liu and Yang (2015) studied slot allocation of full and empty containers on a sea-rail transport line in terms of revenue management. The authors introduced a two stage model where the first stage finds the optimal slot allocation and the second stage obtains the optimal pricing strategy. Numerical results showed that the solution approach developed in the paper can be used as an accurate tool in pricing decisions.

Xu et al. (2015) proposed a mathematical model to analyze how the pricing decisions are determined depending on the ECR costs. Their study deals with a transportation service that consists of one carrier and two freight forwarders between two ports in order to observe their pricing policies on the service.

Goh and Chan (2016) studied the impact of empty container back haul costs in the inland of USA. They proposed a solution approach to compute the shadow prices of ECR costs by using Langrangian and Kuhn-Tucker methods. The numerical results in the study demonstrated that the solution approach can help the carriers at the operational level to see the effect of ECR costs on marginal costs in terms of whether or not to accept the spot shipments.

ECR costs have also not been studied much in terms of transaction costs. Lopez (2003) examined the inland repositioning of empty containers in the USA from ocean carriers point of view. The author revealed the commercial relationships and characteristics of bargaining between ocean carriers.and inland transportation providers. According to which conditions the contracts and costs in rail and road transportation may change, was clearly analyzed in the study.

Lee and Song (2017) presented an overview and research opportunities in global container transportation where they also discussed ECR from two perspectives: quantity decision and cost estimation. Quantity decision refers to the traditional optimization methods to decide from where to where, when and how many empty containers need to be sent in a planning horizon. This perspective has been quite studied in the literature. On the other hand, cost estimation is a viewpoint of how the ECR costs would be taken into account in terms of pricing decisions. Although the authors epmhasized the importance of this, they did not provide detailed information on that issue. Likewise, they did not refer to any study in this regard as well.

2.6. Strategies to Reduce Empty Container Repositioning in Liner Shipping

One of the ways to reduce ECR is container sharing or exchange. It can also be regarded as a sub-lease in practice. Depending on the commercial imbalances, some shipping companies may have surplus containers in a location whereas some others have deficit for the same type of container in the same location, or vice versa. A shipping company which has surplus containers in a location, instead of sending these surplus containers to other locations, can give them to other shipping companies which are short of containers within the same location. A shipping company receving and using the containers will return these containers in a predetermined location where they are required by the shipping company that released these containers in the initial location. In this way, both of the shipping companies will reduce ECR and save on ECR costs.

The topic of container sharing among the shipping companies has been rarely studied in the literature. In a report on empty container logistics, Le (2003) addressed the importance of container sharing and coordination among shipping companies. Song (2007) showed that a collaborative strategy of container management can provide high cost savings especially for the shipping companies with smaller container fleet size.

Song and Carter (2009) studied the options of reducing ECR costs in liner shipping from two aspects; through an effective management of container fleet and sharing containers with other shipping companies. The authors demonstrated that worldwide coordination and sharing containers with other companies can significantly reduce the ECR costs. Zheng et al. (2015) examined the ECR problem taking into account container sharing among shipping companies. The authors introduced a two stage optimization approach to reduce ECR. As expected, the numerical results in the paper showed that the shipping companies can benefit from container sharing with each other.

Real-life applications and literature studies show that container sharing reduces ECR and provide cost savings. However, there are some difficulties to implement the sharing process of the containers with other shipping compnies. Actually, most of the shipping companies would always prefer to share the containers if there were no bureaucratic, complex documentation and operation processes. Since all the national laws and international law consider an empty container itself as an asset, shipping companies must deal with the documentation process and make official agreements with each other to share the containers. The type of the agreement is another issue that should be considered. For example, some shipping companies allow to share their container for free for 30 days and after 30 days charge 2 usd per day for each container, whereas some shipping companies charge costs already from the beginning. Namely, while sharing of containers decrease the ECR costs, it may lead to high sub-lease costs for the shipping companies. Eventually, taking into consideration the potential challenges in terms of communication and coordination for the delivery of containers in the predetermined location and depot, management and control of the shared containers cause the shipping companies to exert extra effords. Nevertheless, in parallel with the coordination and cooperation such as vessel sharing agreements in the industry, container sharing between the shipping companies will also increase in the near future.

A similar method to container sharing is the container cabotage. In case of container cabotage, the cabotage company, which is a third party carrier or an intermediary company, borrows the container from the shipping company to return in a location where the shipping company demands it. The cabotage company usually uses the container for a single one way trip. This procedure can also be regarded as a sub-lease, and the lending time of the container may vary depending on the agreement between the cabotage company and shipping company.

One of the ways that shipping companies want to implement to reduce their ECR and costs is the street turn approach which is also called triangulation. The benefits of the street turn application were also revealed by Jula et al. (2003) and Le (2003). Figure 2 shows the normal container flow and street turn approach in a location. In situation a, a local consignee, who is the importer of the full container, receives the full container from the terminal and returns it to the shipping company at the terminal as empty. A local shipper pick ups the empty container from the terminal to fill it. After the container is filled with the cargo, the local shipper brings it to terminal to be loaded on the vessel. Namely, the local shipper becomes the exporter of the full container. As can be seen, transporting the empty container to the terminal, accepting and storing at the terminal, then moving it from the terminal to the local shipper’s place caused costs in this cycle. The costs, which are incurred when the containers are under control of the shipping company, are covered by the shipping company. Other operation costs are covered by the consignee and the shipper. Namely, in liner shipping applications, the cost of accepting and storing the container at the terminal is generally borne by the shipping company.

In the situation b, after the unstuffing process of the container, the local consignee delivers the empty container directly to the local shipper instead of returning it to the shipping company at the terminal. Thus, both the consignee and shipper save on empty container transportation costs. Moreover, the shipper also avoids empty container pick up costs at the terminal. The shipping company that provides the liner services prevents empty container acceptance and storage costs at the terminal. It reduces its documentation work as well. More importantly, the shipping company provides added value to its customers, who are the local consignee and shipper, by reducing their ECR and costs.

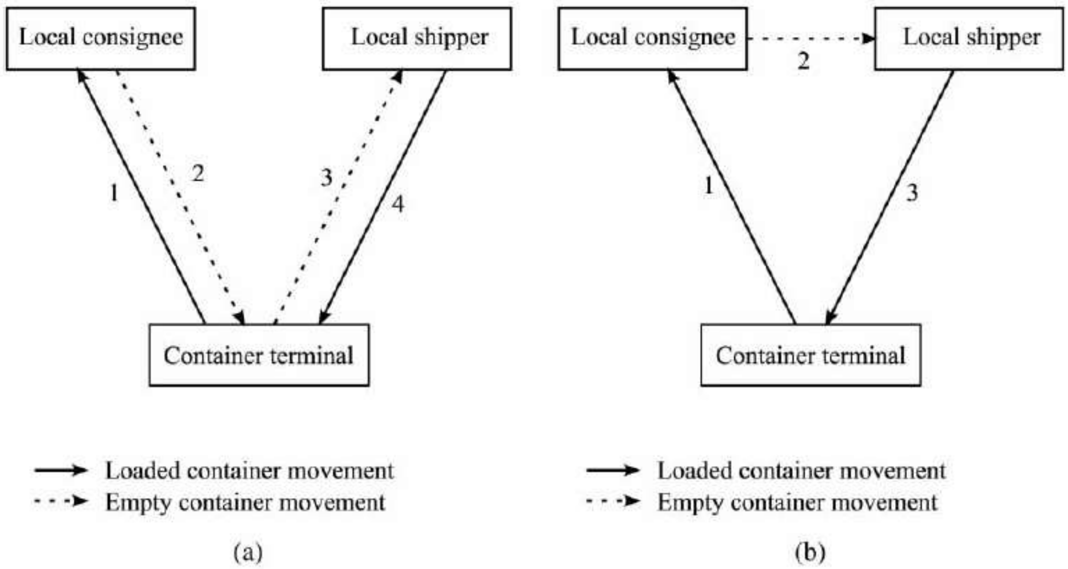

Figure 2. Street turn application of containers (Jula et al., 2003)

Although the street turn approach provides cost savings, it is quite difficult to implement it in practice. First of all, there must be a systematic and rapid communication network between the shipping company and its customers. Secondly, problems can arise on determining the parties responsible for container damage and inspection. From this point of view, it may be a good strategy for the shipping companies using the same depots with their customers or to work with the depots that are located close to their customers and provide high quality services for container cleaning and damage.

The emergence of foldable containers can be considered as an innovation in the container shipping industry. Foldable containers have been developed for the purpose of eliminating congestion at terminals, saving space at depots and terminals, and avoiding high movement costs caused by the standart empty containers (Konings and Thijs, 2001). Likewise, researches in the literature demonstrated that using foldable containers provides more savings in terms of repositioning costs than using standard containers. However, foldable containers have not attracted much attention in the container shipping industry.

Substitution between the container types can also be a a good application to reduce the ECR and costs in liner shipping. Shipping companies can handle this kind of application in their own way without needing the coordination of other companies. Nevertheless, shipping companies should perform a very detailed and accurate profit/loss analysis in case of container substitution. Studies in the literature on that topic are also scarce. In a study, Chang et al. (2008) developed a heuristic method for the solution of container substitution problem. Numerical results in that study showed that the proposed method can be effectively used by the shipping companies.

2.7. Importance of Information Technologies in Empty Container Repositioning

Information Technology (IT) is a function that has gained more importance in business. There is no technology that has succeeded in rapidly influencing shipping industry as much as IT, as it is in other sectors. Bensghir (1996) describes IT as a technology that enables faster and more efficient operations and transactions such as recording, storing and generating information through the processing of data; accessing, storing and transmitting this information in line with the purpose of the company. In other words, IT allows the collection, processing, storage, submission and transfering of the information in a more accurate way. Information and data for large companies are the two most valuable corporate assets today. To demonstrate the significance of this in the shipping industry, Detlef Trefzger, CEO of Kuehne and Nagel, stated: "*Data is the raw material for our new currency, which is information, based on real time data to enable our customers, partners and ourselves to take the right decisions*". Namely, IT has made a great contribution to the establishment of new opportunities and new business relationships.

In order to improve their service quality and increase the profitability and competitiveness, shipping companies should closely follow the developments in IT and use management information systems (MIS) such DSSs, enterprise resource planning (ERP) and business intelligence softwares. When logistical activities are supported by such advanced softwares, shipping companies can achieve success in data collection and use of these data in planning, control and decision making functions. The use of IT is also essential for the management of ECR. Like for many logistics functions, storage and processing of data, real-time communication capabilities, report generation, complex analytical tools, but simple usage are also required for the management of ECR. Many shipping companies already use advanced business intelligence softwares. These softwares are very useful in terms of tracking of containers, tracking and controlling of operations, job orders and invoices and for their reporting.

Although the problem of ECR has been studied extensively in the literature, the mathematical models developed in the literature studies are not applied much in real life. One of the reason for this is the difficulty in the adaptation of the models and external optimization softwares to the shipping companys' systems. Another reason is the high purchasing and using cost of the softwares. The former Chilean shipping company Compañía Sud Americana de Vapores (CSAV) developed a system called Empty Container Optimization (ECO) that optimizes ECR by integrating operational and commercial decisions at its all regional offices (Epstein et al., 2012). However, there is no clear information about the availability, effectivity and sustainability of this system. IBM has a software product for the optimization of ECR which works with CPLEX Optimization Solver base. Although the price of this product seems high, its use can provide much more cost savings to the shipping companies. There are also various softwares on the market for solving many other problems related to operations and logistics management. The approaches in those softwares can also be adapted to container shipping industry, particularly to ECR. Nowadays, many shipping companies are already more concerned with analytics and have begun to develop their own business intelligences and optimization softwares by spending large amounts of money.

In addition to all of the above, Industry 4.0 will also have a significant impact on the management of ECR (UNCTAD, 2016c). For example, thanks to the cloud technology, ECR will be tracked more accurately and more robust container inventory information will be obtained. Moreover, better empty container distribution plans will be made by using new developed softwares based on mathematical models and algorithms. The costs of the operations related to ECR will be better and faster analyzed, and more accurate pricing will be ensured. Consequently, better decisions will be made through the instant and constant updated data and information.

2.8. Chapter Summary

Container shipping industry struggle with the problem of trade imbalances which cause too much ECR and costs. This issue in container imbalances have been interested in the academic world as well. Many researchers developed new strategies and offered new methods to solve this problem. This chapter discussed prominent studies on ECR in the literature.

Management of ECR has been studied at many levels in the literature. Most of the studies have addressed methods for optimal empty container distribution planning and considered single container type. Likewise, operations research (OR) and other optimization methods are extensively used in the researches. The objective function in the vast majority of studies is to minimize the total ECR costs. The problems were usually solved by mixed integer linear programming (MILP) models. In some studies, advanced optimization methods such as column generation, cutting plane algorithms and heuristics have been developed to solve large-scale problems. In the majority of studies, ECR have been handled from a deterministic perspective. But there are many uncertainties in real-life applications of ECR. Thus, there is a tendency in the literature for the solution approaches that take uncertainties into consideration. Despite the sufficient number of academic studies where new approaches and models developed on the management of ECR, there are not many practical applications of these approaches and models used by the shipping companies in real life.

One of the ways to reduce the ECR is the street turn application. Its implementation is quite difficult because it requires immediate and instant coordination and cooperation between the shipping companies and customers. However, the application of the street turn approach will be definitely easier in the future thanks to the advanced IT systems. Using foldable containers is another way to reduce the ECR and costs. Indeed, researches in the literature have revealed this fact.

The topic of container sharing has been studied quite less in the literature. Nevertheless, these small number of studies revealed evidences that having an efficient coordination and cooperation with other shipping companies in terms of sharing the containers can significantly reduce the ECR and provide cost savings. Another less studied topic in the literature is container substitution. Although container substitution can be a good application in terms of reducing ECR in liner shipping, studies on container substitution are also very limited in the literature.

Eventhough the models and strategies developed in the studies reduce the costs of ECR, shipping companies do not escape from these costs altogether. These costs have a direct influence on the location choices of cargo and freight prices. Although this is known by the shipping companies and researchers, there is no single study in the literature on how to accurately evaluate and allocate the ECR costs. In fact, there are also few studies on pricing and revenue management in container shipping. The analysis of ECR costs has never been addressed in these studies as well.

One of the other subjects that have not been studied in the literature on ECR is multi-objective decision making which is actually a very popular and highly studied topic in logistics and operations management. Many objectives in real-life applications of ECR can conflict with each other. On the other hand, as ECR constitute a small part of container shipping, the development of models that take into account other operations and different objectives will lead to more accurate decisions not only in ECR, but also in the whole container transportation system.

The use of sophisticated IT systems is essential for the management of ECR. Advanced IT systems have enabled more accurate and faster follow-up of ECR, as well as provided rapid information flow and electronic data interchange (EDI). Nevertheless, IT is not used with the full potential in the container shipping industry. Just as it is in many other sectors, container shipping industry will also be more digital in the future. Advanced MIS based on robust mathematical models and algorithms will be used more often and effectively within the companies. Consequently, continuous improvement in the field of digitalization and IT systems will lead to smoother processing in all aspects of container shipping.

3. CHAPTER
COSTING MODELS FOR EMPTY CONTAINER REPOSITIONING COSTS IN LINER SHIPPING

Nowadays, in parallel with the increasing competition and pace of development in all sectors, economic globalization and rapid change in technology have forced companies to have the ability to respond to increasing customer demand and to keep up with the competitive environment. As logistics provide competitive advantage through service differentiaton, increasing profitability and reducing costs to companies, management of logistics costs for companies has begun to have a big influence on service profitability, pricing decisions, customers' and company's profitability. Regardless of how the logistics costs are identified and classified, cost management is a vital part of the logistics.

Logistics costs can be defined as the monetary value of the sacrifices that companies make for their logistics activities. These are the costs associated with all the activities carried out from the beginning of procurement process until the delivery of the product to the customer. Namely, logistics costs consist of all service costs related to storage, packaging, delivery, transportation, assembly and process of invoice preparation, transaction, accounting and revenue collection costs (Rushton et al., 2014).

Container logistics is the prevailing type of logistics in container liner shipping (Frémont, 2009). On the other hand, ECR can be considered as the core logistics activity in liner shipping and cause high costs to shipping companies. As ECR do not provide any added value to the customers, the operations related to ECR must be solved within the shipping company itself. In particular, due to very low freight rates nowadays, shipping companies need to focus more comprehensively on the costs of ECR. In order to make a more accurate profit/loss analysis, shipping companies should take into account the empty container situation in the place of loading and destination that are subject to the freight rate. Besides the differences in export and import rates, transportation, storage and handling costs of containers can also vary from location to location. Export and import rates for various types of containers may also be different in the same location. All this leads to different number of movements of empty containers for each location and container type.

Considering that each movement of an empty container causes a cost, the costs incurred due to ECR should be managed and controlled very carefully.

This chapter highlights the importance of cost management for ECR in liner shipping. It briefly discusses the costing methods and addresses some prominent studies on the costing of logistics costs. This chapter also introduces and analyzes the ECR costs of the company studied in the dissertation. The costs arising from ECR and the costing models are explained accordingly.

3.1. Costing in Logistics Management

One of the strategies required for the success in today's competitive conditions is the cost leadership. In order to be advantageous against the competitors, companies should apply an effective cost control system. In this control system, the position of the company against its competitors is measured by the accumulation of costs in the value chain (Seuring and Goldbach, 2002). In this respect, costs and cost data take an important place for the companies because of their operational, strategic and financial contents. Many factors have changed the cost structure of the companies and led to the need for more advanced costing techniques.

The accurate analysis of logistics costs and their contribution to customers, products or supply chain is crucial for the companies. The recording and evaluation of logistics costs have been extremely difficult due to the complexity of logistics services and lack of a logistics-specific cost accounting system. For this reason, logistics costs have previously been considered to be a percentage of the total sales or costs. However, companies require more precise and detailed logistics information from their cost accounting systems. Likewise, logistics managers also require detailed information from the cost accounting systems as they may need different products, customers and supply channels to provide logistics services. In that respect, the prominence of logistics function in the cost accounting systems of companies has increased.

Logistics costs may vary according to the industry, supply structure and business models of the companies. According to Weiyi and Luming (2009), logistics costs can be distinguished as explicit and inexplicit logistics costs. Procurement, transportation, distribution, ordering, communication, packaging and inventory costs can be expressed as explicit logistics costs, whereas stock holding costs such as interest, opportunity and damage costs, and extra logistics costs such as coordination and human resources cost can be regarded as inexplicit logistics costs. Companies pay more attention to explicit logistics costs which are more pronounced since these costs are traceable and controllable. On the other hand, sufficient effort is often not shown in determining inexplicit logistics costs, since they are difficult to measure and distinguish from other costs. This is why the decision makers make the wrong decisions because they do not know exactly the relationship with other cost items and which cost elements increase the logistics costs. Although there is such a distinction, the situation can change according to the industry, structure of the company, and the operations carried out. For example, some transport and storage costs, which are explicit logistics costs, can be taken into consideration carelessly because it might be very difficult to measure them due to very complex operations in certain industries. Conversely, opportunity and damage costs in some specific industries or companies, which are normally regarded as inexplicit costs, can be calculated very accurately because they can be measured very easily.

The costs of ECR in liner shipping can be considered as explicit logistics costs. However, despite a clear physical traceability of ECR, it can be quite difficult to analyze these costs in detail. The most important reason for this is the operations carried out with various transportation modes at different locations at different times. As container shipping service takes a long time, especially in intercontinental transportation, it might be complicated to reflect the costs arising from these operations at the freight prices. The costs of ECR that occur before and after the transportation service of full container can be considered as part of the opportunity cost. In this respect, costs of ECR can be regarded as implicit logistics costs as well. Nevertheless, no matter how they are called, costs of the operations such as transportation, handling and storage of empty containers must be properly calculated and allocated. The purpose of this dissertation is essentially to analyze the costs of these operations and demonstrate the assignment of these costs to the freight prices accurately.

On the other hand, the costs of ECR can be considered as relevant costs because these costs vary according to the operation plans of ECR. Relevant costs are the costs affected by the choice of various options. Namely, these costs vary according to future options. A relevant cost has two main attributes: (1) Being related to the future and (2) Showing options between the decision options. In terms of management decisions, the relevant costs are not past costs, but future costs that will be caused by the decision (Horngren et al., 2009, p. 1023). When planning the ECR, the total costs will vary depending on where, when, with which third-party carrier and how many empty containers to be shipped. Furthermore, the unit cost of each location will also vary according to all of these decisions. Therefore, ECR costs in liner shipping can be regarded as relevant costs as well.

3.1.1 Traditional Costing Approach

Decision making is the basis of management and crucial for business. The attention of cost information for management decision making have been attracting much interest in cost accounting for years. In fact, the most important objective of cost accounting and costing is to support the management in decision making (Boyd and Cox, 2002). Costing is a calculation process of total costs and unit cost from the data compiled through the financial accounting. It is often called a "technique" because it uses different approaches to determine the costs of products, processes and services (Demir, 2007: 54-55). On the other hand, it is also referred to as "transaction" because it is routinely assigned to day-to-day costs and to cost-allocation metrics. With the simplest expression; costing is the allocation, classification and recording of expenditures in different operations of a firm or at various stages of production (Mortaji et al., 2013).

The system to be applied for the calculation of unit cost in an organization depends strictly on the size of the organization as well as on the nature of the products, on the structure of the general organization and on the production technique. Therefore, every organization has to establish a system that best suits the characteristics and needs of its own organization, and continually develop and adapt it to the changing conditions. The cost of products and services is measured in accordance with this cost system. It should be noted that it is never possible to calculate the cost of production with a single system. A cost system consists of a combination of costing methods related to the characteristics of costs and the way they are calculated.

The most well-known cost system is the traditional costing system in which the static and single cost ratio is used to allocate indirect costs of different processes to cost objects such as goods and services. Traditional costing may lead to wrong cost estimation in complex environments such as where a large number of products or services designed and a large amount of resources used in different forms, a large number of suppliers required and numerous operational data dealt with.

According to the type of the production activities, the costs are basically divided into two as the job-order and process costing system. In job-order costing system, the production cost elements for each order are tracked separately as far as possible from the start to the completion of the production. Production costs are allocated to the orders by using some appropriate metrics. Then, the unit cost is calculated by dividing the total cost of each order by the amount of that production. Process costing is a cost system that is generally related to the batch production of the same type of products. In this system, the average unit cost of each stage is found by dividing the total costs of each production stage to the total production volume in question. The average unit cost of each stage is transferred to the following stage according to its ratio in that stage (Horngren et al., 2009). In short, an important feature of the process costing is the accumulation of costs during the stages of production. Beacuse costs are periodically processed in that costing system, the products, that are not completed at the end of a costing period, are considered to be the products of the beginning of the next costing period. This complicates the calculation of unit cost. There are three basic approaches for calculating the unit costs in the current period:

- First in, first out (FIFO) method
- Last in, first out (LIFO) method
- Weighted average method

FIFO method is based on the assumption that the goods to be processed or sold must be from the stock that first enter the stock. The order of use of the goods in the stock starts from the first-entering goods and continues in order. In other words, the goods entering the stocks are taken out of stock in the order of entry. LIFO method is based on the assumption that the goods to be given for production or to be sold must be from the goods that have last entered into stock. The order of use of the goods in the stock starts from the last receipt goods and continues backwards. In other words, the goods entering the stocks are out of the stock according to the reverse order of entry. The unit cost of the goods in the LIFO and FIFO methods is known directly. However, very strict follow-up of the goods and extra efforts are required to implement these methods. In the weighted average method, the unit cost is determined by dividing the total costs of the goods purchased during the period and the goods at the beginning of the period into the total amount of the goods. Although the weighted average method is an appropriate method to calculate the unit cost, it requires extra effort for the accounting department or company.

In container logistics, implementation of the FIFO method is quite difficult because empty containers are not easy to store and handle. There is a need for extra handling in order to remove the first incoming containers as the containers are stacked on top of each other. This will lead to extra time for the terminal and depot operators, and costs for the shipping companies. This is why some depot operators in the sector apply LIFO method. In an ideal world, a specific container desired by the shipping company is taken from stocks and filled. This would prevent containers from being left idled. Nevertheless, its implementation is also very troublesome. In fact, terminal and depot operators do not pay much attention to the container stacking applications in terms of inventory costing methods. Therefore, it would be more appropriate for the shipping companies to apply the weighted average method for their empty container stocks.

3.1.2. Activity-Based Costing and Problems in Traditional Costing Approach

The traditional costing approach assumes that the production volume is the only factor that affects the resources used (the more units are produced, the more cost of production). It also makes no distinction between the product and service, market and customer. The same issues happen both in the production and service sector (Griful-Miquela, 2001). The traditional costing approach also has other weaknesses. The companies do not know whether the goods or services they produce are profitable and can not determine profitable and non-profitable customers. Moreover, companies focus on short-term and neglect long-term commitments to fulfill planning, control and decision-making functions (Demir, 2007, p. 55).

According to ABC system, activities are carried out for the production of products, and activities consume company resources. There is a causal relationship between the activities and the costs. Accordingly, activities are the causes; costs are the result. ABC uses this causal relationship to allocate the costs to the products. The allocation of the costs on products based on the activities ensures that each product receives a share according to its consumption of the resources. ABC is an instrument of business strategy as much as it is an accounting system. Therefore, besides a product costing system, ABC system forms a data source for the activities and provides important information on the other functions of the company (Kaplan and Cooper, 1987).

The basic concepts used in the ABC system are the resources, activities and cost drivers. Resources are the economic elements that are managed or referred in order to conduct the activities. Activities are the actions taken by the company during the production of goods and services. A cost driver is a factor that determines the effort or workload required to perform an activity, and creates a cost when it arises. For an accurate costing model, the resources, activities and cost drivers, and the relations between them must be determined correctly.

ABC is a measurement process for the activities within the production cycle. It does not improve costs or processes in itself (Shapiro, 1999). Costs and processes can only be improved through the conscious management of specific activities. Although ABC provides a better understanding of production conditions, more precise product and service cost, and more accurate decisions, it is burdensome and difficult to set up and work with. Indeed, it is quite difficult to describe the output of logistics activities. Since the combined capacity is a large part of the total cost, it is challenging and difficult to establish links between the output and related activities. However, once a costing model is established on a basis, it can be used continuously and effectively with simple changes in the future.

Although ABC can be applied to logistics operations in many different industries, the number of studies in that area is rather low. One of the first studies, where the ABC was applied in logistics, was conducted by Pirttilä and Hautaniemi (1995). The case study in that research showed that ABC ensures better cost information for logistics operations. Dekker and Goor (2000) addressed the role of management accounting in supply chain management and applied ABC to a Dutch wholesaler in the pharmaceutical industry. Gupta and Galloway (2003) discussed the managerial applications of ABC for various operations management decisions. Baykasoğlu and Kaplanoğlu (2008) presented an application of ABC method to a land transportation company and showed that ABC provides more accurate cost measurement for the company than traditional costing approach. Schulze et al. (2012) developed an ABC model for supply chain management. The study revealed that the combination of standard costing and ABC can greatly support supply chain management decisions. All of these studies showed that ABC can be used as an important tool to contribute to process optimization.

Although the ABC method provides accurate cost information, a robust costing system requires a combination of multiple costing methods. Indeed, there are some studies addressing the combination of costing methods and focusing on model-based approaches with costing methods on distribution logistics dealing with process optimization by considering costs of various activities in manufacturing industry (Becker et al. 2016). There is still no single study in the literature on the applications of ABC or other costing methods in maritime transportation. However, maritime transportation, especially container transportation, is a very suitable field for costing applications. Because container transportation is a cellular type of transportation and a large number of customers are serviced on the same vessel, it is an extremely attractive issue not only for the costing approaches, but also for the pricing researches.

3.2. Empty Container Repositioning Costs in Liner Shipping

It is crucial to monitor, analyze and calculate all the costs that arise in container liner shipping. Due to complexity of the operations, shipping companies are suffering difficulties in estimating the ECR cost. Most of the researches on ECR have focused on the optimization process of empty container usage once the containers unstuffed or emptied. Customers' demand, capacity of the vessels, environmental, economic and political situation change every moment. Accordingly, everything needs to be reviewed again and again. That is why many optimization models developed in academic world can not be applied in reality completely and on time. In fact, the question needs to be asked; how and when the costs of ECR can be estimated? As all liner shipping companies have their own statistics for each trade route or location they are already aware of the imbalances in each location. Hence, they should be able to estimate the costs of ECR to some extent. For example, if shipping companies are transporting full containers from China to USA, they are already aware of that most of these containers will not be used in the USA once they returned from the customers, and they will be returned to China or sent other locations or regions where they needed. This means that, depending on the profit margin, shipping lines are ready to pay the costs of ECR to evacuate them out of

USA before they transport the full containers from China to USA. At this point, the next destination of the empty containers is important due to changing costs of transportation, handlings and storage at each destination. Thus, according to the container imbalances and empty container operations in each location, there is a need for a costing model that accurately computes the costs of ECR for each container type in each location in liner shipping. The following sections introduce the container shipping company investigated in the dissertation, and present the costing models and types of ECR costs incurred in the company.

3.2.1. Information About the Shipping Company

The company, whose operations and data were investigated in this dissertation, provides container liner shipping services all over the world and has a significant market share in liner shipping. For the development of the costing model, the commercial data from 2012 in the Eastern Mediterranean (EMED) Region including the Black Sea Region of the company was reached. The shipping company offers weekly liner services in this region. It works with third-party service providers for its all operations within the region. Namely, its inland transportation, feeder services, container handlings and storage operations are carried out by the third-party logistics providers. The company does not have its own mainliner vessels serving within the region as well. For example, the company's EMED-Far East service is carried out by MSC's mother vessels. The mother vessels for the EMED-South America service are up to Italy and the connection between EMED and Italy is carried out by the third-party feeder connections. All the operations related to ECR are also conducted in the same way.

The operations related to ECR of the company are carried out by the logistics departments in each region. That is, each regional logistics department makes its own decisions within the region. The operations related to ECR are carried out by the company's agencies under the supervision of the regional logistics department. Interregional decisions are made at the request of headquarters.

The shipping company operates a large container fleet that consists of various type of containers. The vast majority of this fleet is the company's own containers. At the same time, the company has long-term container leasing agreements with some leasing companies. These long-term leasing containers are also operated like the company's own containers. The company do not prefer to make short-term leasing agreements unless it is urgently necessary.

The costs occurred in each region are covered by the regional headquarters of the shipping company. Hence, the costs of ECR associated with a region are under the responsibility of this regional logistics department. Nevertheless, there may be some confusion due to complexitiy of the empty container operations. For example, empty containers transported from one region to another are transhipped through a third region and these empty containers are stored at the terminal in the third region for 5 days. Other than the tranportation costs of these empty containers, handling and storage costs occur in the third region although they are not related to this region. On the other hand, some of these empty containers may be required and used in the third region. This type of operations further complicate the costing process of the transhipped containers. Such events make analysis of the costs even more important for the company.

As mentioned in the first chapter, the shipping company uses a special business intelligence software where the data and information from all the local agencies and regional offices are gathered and constantly updated. It is crucial for the company in order to see the most recent version of the big picture and to be able to make most accurate decisions.

3.2.2. Empty Container Repositioning Costs in the Shipping Company

Understanding and defining the activities and their costs is the first major step in the development of a costing model in ECR. Essentially a well-designed costing model begins by analyzing the processes. Process analysis is the systematic analysis of the activities required to produce a product or service. It identifies the activities that consume resources related to the production of product or service (Horngren et al., 2009). Every movement, even holding an empty container causes a cost to shipping companies. Once the container unstuffed, consignees deliver the empty container to the place that was stated in advance according to the agreement. This delivery place is usually the location where the container had been picked up by the consignee as full. So it can be said that the costs of ECR start to emerge once the full container is unstuffed on the consignee`s side. The major cost items of the shipping company in the regional ECR are explained in the following sections.

3.2.2.1. Transportation Costs

Transportation costs usually have the highest percentage in total costs of ECR. The transportation of empty containers can be carried out by various types of modes including maritime, road, railway and river transportation. The cost types incurring by transporting empty containers according to the movement places are described below.

<u>Transportation costs between the locations</u>

This title describes the costs that occur through the transportation of empty containers from a surplus location to a deficit location. The locations may be in the same region, but also in two different regions that are far from each other. This type of cost usually constitutes the major part of the ECR costs. If the shipping company transports the empty containers on its own vessel, it should consider many cost items such as vessel running cost, terminal costs, agency and documenation fees etc., when determining the costs for a specific transportation leg. On the other hand, if the shipping company transports their empty containers by third party vessels, they are charged transportation cost by third party companies. In that case the prices are determined according to agreement made between the shipping company and third party transporation companies.

<u>Transportation costs within the location</u>

The costs for empty container transportation carried out by the shipping companies in a location can be regarded under this title. Transportation costs between the terminal and depot, transportation costs between the depots are the examples of this type of costs. These costs are also determined according to the agreements made between the shipping company and inland transport providers.

Some terminals do not allow the delivery of the empty containers into terminals due to limited space unless the shipping line specifies the vessel name on which the container will be loaded. As a result of this, empty containers are inevitably accepted at the shipping companys' off-dock depots. In some cases, shipping companies might have a demand for containers from the depots and tend to accept the empty containers at the depots eventhough they are allowed to accept the empty containers at terminal directly. The empty containers which are not needed at the depots are transported to the terminals to be sent to other locations on vessels.

Transportation between the terminal and the depot can also be in the other direction. For example, empty containers that come into a deficit location can be transported from the terminal to the depot to cover the demand. Although the depots are usually close to the terminals, transportation of the empty containers between the terminal and depot leads to a considerable cost.

Other transportation costs

As already mentioned, empty containers are delivered to shipping companys' depots or to terminals by the customers (consignees). Transportation for the delivery of empty containers also causes a cost. Depending on the type of agreement with the customer, these costs should be taken into account as well. Nevertheless, this type of costs are usually borne by the customers in liner shipping.

3.2.2.2. Handling Costs

Handling costs are the costs resulting from the lifting of containers with various types of vehicles or cranes. These costs vary according to the operations agreements. They are explained below according to the place of generation.

Handling costs at terminal

Either by the direct delivery of the consignee or transportation from the depot to terminal, the acceptance of an empty container at terminal causes a handling costs (unloading costs from truck or rail). Moreover, if an empty container is sent to a deficit location by vessel, it will be loaded on the vessel that leads to another handling costs (loading costs on the vessel). Once an empty container is loaded on the vessel to another location, it will definitely be discharged in the location where it is needed, which means another handling costs at the discharged terminal. Furthermore, once an empty container discharged from a vessel, it may be moved to a depot, meaning that loading this empty container on a truck or rail at terminal also leads to handling costs. Transhipment costs at terminal which also includes shifting of empty containers can also be considered under this title. Container handlings for vessels are generally more expensive than the handlings on yards. Terminal handling cost (THC) is usually determined with the agreement done on annual basis between the shipping company and terminal management, and varies from terminal to terminal.

Handling costs at depot

Many shipping companies accept the delivery of empty containers at their depots because they would be filled (reused or stuffed) at these depots or sent to terminals to be loaded on the vessels. Acceptance of an empty container at the depot leads to a cost that emerges by unloading this empty container from truck or rail which is called lift off. Depending on the agreement, this cost is usually borne by the shipping company. Releasing an empty container to a customer (shipper) to be loaded on truck or rail, which is called lift on, also cause a handing costs at the depot. Such type of handlings costs are generally beared by the customer. Handling costs are usually determined with the agreement done on a certain time period basis between the shipping company and depot owner.

Other handling costs

Once the customer (consignee) empties the full container, it will deliver the empty container to the place specified by the shipping company. To load the empty container on the truck or rail, a handling (lift on) cost emerges accordingly. In some cases, the customer wants to stuff the container at his depot. In this manner, unloading cost of the empty container from truck occurs accordingly. In such a case, the costs are beared by the customer as the container is not under the control of the shipping company.

3.2.2.3. Storage Costs

Altthough storage cost consists a small proportion of total costs, it directly affects the decision making in ECR. These are the costs arise at terminals and depots.

Storage costs at terminal

Holding the empty containers at terminals causes a cost to shipping companies. Many terminals provide free storage for empty containers for a certain period of time, for example 5 days. After this period, storage costs usually increase as the number of storage days increases. Because of their limited space capacity, terminals usually do not prefer to store many empty containers at the yard area. Too many empty containers cause congestion at the terminal and this may lead to a decrease in the total terminal productivity. Similar to the handling costs, storage costs are also determined with the agreement done on a certain time period basis between the shipping company and terminal management. Some terminals charge the storage fees according to the container type or size, while others charge total costs in terms of total TEU number by forming a storage pool of empty containers.

Storage costs at depot

As mentioned before, shipping companies use off-dock depots to store their empty containers. The first reason for this is to meet the demand of customers who want to fill the containers at these depots or pick up the containers from these depots. The second reasons is that the terminals accept only a limited number of containers to avoid the congestion. The third reason is the high storage fees at terminals. The storage fees at the depots are generally lower than those at the terminals. Some depots does not even charge any storage fees and earn money from services such as container handling, cleaning, maintenance and repair and some other value-added services. The storage fees are determined by agreements between the shipping companies and depots.

3.2.2.4. Other Costs

There are other costs associated with ECR in liner shipping. Each container is inspected and cleaned before it is filled. Containers may be damaged during transportation. In that case, containers are repaired before they are filled. The costs incurred for all these operations are considered as maintenance and repair costs. Taking into consideration the commercial situation in the locations, the maintenance and repair operations are usually performed where the costs are the lowest.

Container leasing also causes a cost to shipping companies. Especially short-term container leasing can affect ECR depending on the quota in the locations where these containers can be returned. Since long-term container leasing is more of a decision taken at tactical level, it does not affect the ECR at operational level.

Demurrage and detention costs can be taken into account as another costs related to the empty containers. Demurrage occurs due to holding of full containers at terminal longer than the agreed time. Detention is the fee that is charged to the customers by the shipping companies due to retaining the empty containers longer than the agreed amount of free time. In other words, the demurrage can be associated with the full container and the detention with the empty container. The main concern here is that the shipping companies earn money through the demurrage and detention charges. Similarly, they also earn money trough the drop-off charges. Drop-off charge is a penalty cost that arises from the returning the empty container by customer in a different location other than the agreed location. Other costs such as documentation and customs fees are mostly included in the above mentioned costs and do not vary much with operational decisions.

3.3. Costing Model for Empty Container Repositioning in a Surplus Location

Figure 3 shows the commercial statistics for 20dv containers in an import dominant location of the shipping company in a 12 weeks of period. As can bee seen, this location has much more full imports of 20dv containers than full exports, and there will be a lot of accumulation for such type of empty containers every week if they are not evacuated regularly from this locaiton. These excess empty containers cause high storage costs in this location, while other locations may need such type of containers. Therefore, they should be sent to the locations where they are required.

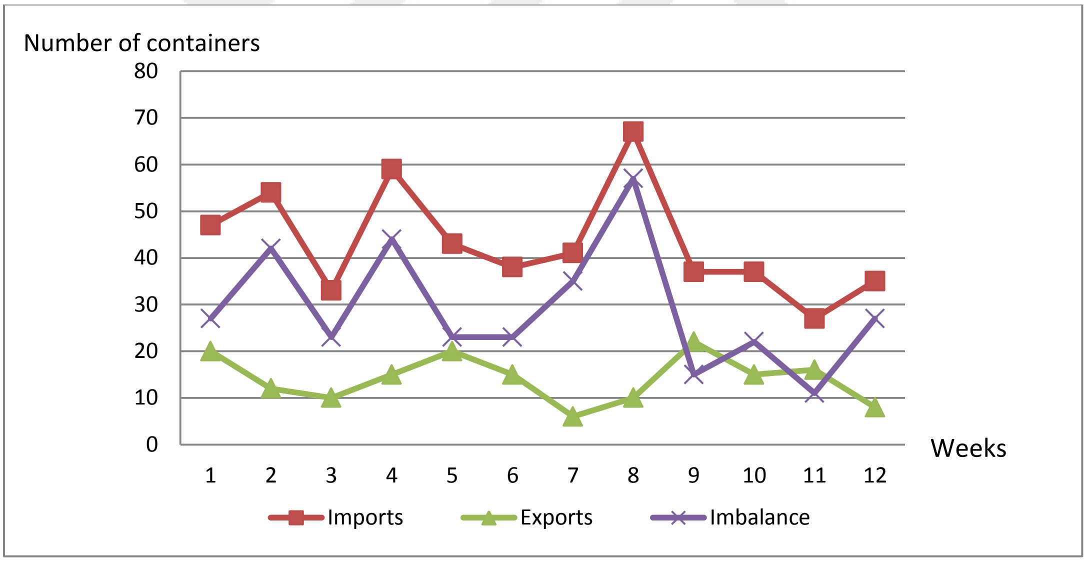

Figure 3. Commercial figures for 20dv containers in an import dominant location

Decisions on the evacuation of excess containers strictly depend on the weekly vessel connections and capacities, and transportation prices. Figure 4 shows an illustrative example of the ECR for 20dv type of containers in the same location in week 8. Due to limited storage capacity, only 20 emtpy containers were accepted at the terminal. Other 20dv type of empty containers returned by the customers were received at the company's depot. Accepting these empty containers incurred handling (lift off the empty containers from the truck) costs at the depot and terminal. Holding the empty containers at the depot and terminal also caused storage costs to the shipping company. 5 empty containers both from depot and terminal were released to the customers for full exports. As the pick-up costs of empty containers are beared by the customers, there is no costs for the shipping company. The excess 42 containers at the depot were carried by truck to the terminal to be sent to other locations. Lifting these containers off the trucks at the terminal also caused costs to the shipping company. The total number of 67 empty containers accumulated at the terminal were loaded into the vessels to be sent to other locations. Accordingly, this loading caused handling costs at the terminal. The empty containers were sent by third-party vessels to other locations depending on the connection options and capacities of the vessels, transportation prices and the container requirements in the locations. 15 containers were sent to the deficit location D_1, 15 containers to D_2 and 27 containers to D_3 where they are required for full exports. Certainly, these transports by vessels caused a cost.

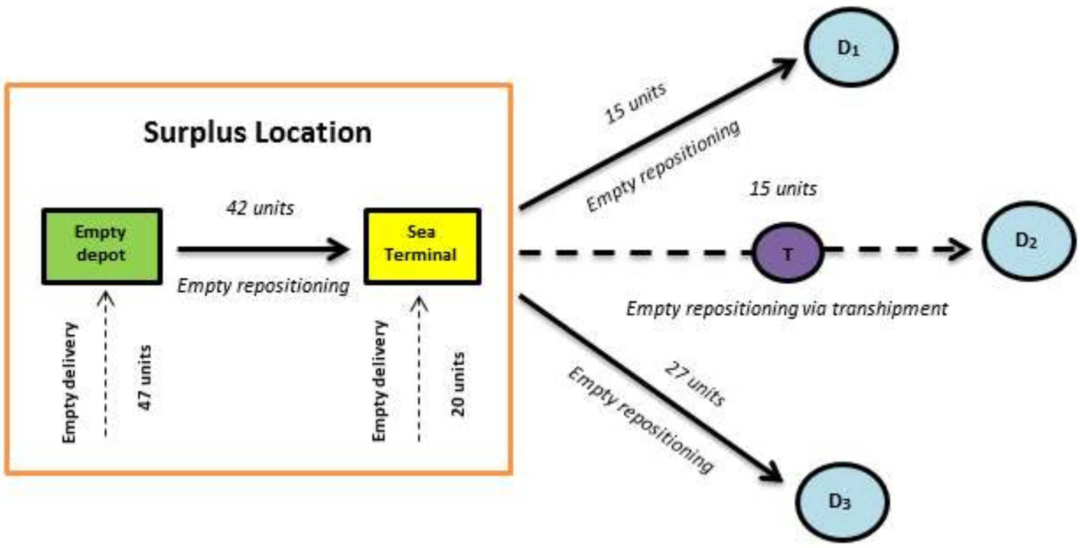

Figure 4. ECR in the import dominant location in week 8

All the costs of ECR, other than the maritime transportation costs, can be allocated to this location as they occured in this location. However, the maritime trasnportation occurs between two locations and the associated costs should be allocated equally to both locations. That is, half of these costs should be allocated to the location where the empty containers are loaded and the other half should be allocated to the location where the empty containers are discharged. In other words, with this cost sharing, the port of loading (POL) takes on the evacuation costs of the empty containers, while the port of discharge (POD) assumes the supply costs of the empty containers. Another important point here is that 15 containers were transhipped in the location *T*, and handling costs occurred accordingly. These handling costs should be allocated to the surplus location and the deficit location D_2 as well, though the handlings occurred in the transhipment location *T*. Hence, the total costs for this connection - which is the sum of the transportation cost between the surplus location and transhipment location *T*, the transportation cost between transhipment location *T* and deficit location D_2, and the handling costs in transhipment location *T* - should be divided into two and allocated to the surplus location and deficit location D_2 equally. Table 1 shows the cost items and costs arising from ECR in the surplus location in week 8.

Table 1. Costs of ECR occured for 20dv containers in the surplus location in week 8

Maritime transportation costs	*15 containers x 60 USD*	900 USD
	15 containers x 135 USD	2025 USD
	27 containers x 50 USD	1350 USD
Loading costs at terminal	*57 containers x 50 USD*	2850 USD
Transportation costs between depot and terminal	*42 containers x 20 USD*	840 USD
Lift on/off costs at terminal	*62 containers x 15 USD*	930 USD
Lift on/off costs at depot	*89 containers x 12 USD*	1068 USD
Storage costs at terminal	*62 containers*	100 USD
Storage costs at depot	*47 containers*	310 USD
TOTAL COST		**10373 USD**
UNIT COST		**155 USD**

As explained before, only half of the maritime transportation costs are considered in the Table 1. Other half of these maritime transportation costs are reflected as the costs to the deficit locations where the empty containers are sent. For example, the cost of transportation a 20dv empty container from the surplus location to the deficit location D_1 is 120 USD. This cost is equally allocated to both locations as 60 USD. Transportation costs can vary depending on the third-party transportation companies, distance and capacity on the vessels. Except for the storage costs, other costs are easily calculated according to the number of ECR. Storage costs have not been shown in detail in the table because the entry time of each container into the depot or terminal are different, and different costs incur for each container. For this reason, only the total storage costs that occurred in this surplus location during the week 8 were shown in the Table 1.

The total ECR costs for 20dv containers in the 8. week is 10373 USD. When the total cost is divided by the total number of empty containers moved (67 units) in this week, the unit ECR cost of a 20dv container in this surplus location in the week 8 will be about 155 USD. This cost represents the cost of the shipping company paying for a full import of a 20dv that arrived in this location in the week 8, resulting from the ECR during this week. So the shipping company should add this cost to the freight cost of a full import container that arrived in this location in the 8. week.

Another cost that needs to be determined here is the ECR costs resulting from the trade imbalance. These are the costs arising only from the evacuation of excess empty containers in the surplus location. If expressed more clearly; even if all of the empty containers in the location were used for full exports, handling costs and storage costs would arise from the acceptance of containers to the terminal and depot, and from holding them at the terminal and depot. However, the costs would not have arisen from the evacuation of empty containers to other locations. This means cost savings for the shipping company. In other words, the shipping company can avoid empty container evacuation costs by exporting full containers from this location. Table 2 shows the costs that occured due to the evacuation of excess empty containers from the surplus location in week 8.

The total imbalance costs of the considered surplus location for 20dv containers in the 8. week is 9099 USD. As can be seen in the Table 2, the storage costs and handling costs occurred due to delivery of empty containers from the customers are not included in the total imbalance costs. When the total imbalance cost is divided by the total number of empty containers (67 units) accumulated in this location, the unit imbalance cost for a 20dv container in this surplus location in that week will be about 136 USD. This is the cost of evacuating an empty 20dv container from this location in week 8. Instead of sending an empty 20dv container from this location to the deficit locaitons, the shipping company may save 136 USD by keeping the empty container in this location and exporting it full from this location.

So this cost can be interpreted as a bonus in full exports for 20dv containers from this location. Namely, this cost should be deducted from the total freight costs when offering a freight rate for a full export of 20dv container from this location.

Table 2. Imbalance costs for 20dv containers in the surplus location in week 8

Maritime transportation costs	*15 containers x 60 USD*	900 USD
	15 containers x 135 USD	2025 USD
	27 containers x 50 USD	1350 USD
Loading costs at terminal	*57 containers x 50 USD*	2850 USD
Transportation costs between depot and terminal	*42 containers x 20 USD*	840 USD
Lift on/off costs at terminal	*42 containers x 15 USD*	630 USD
Lift on/off costs at depot	*42 containers x 12 USD*	504 USD
Storage costs at terminal	*62 containers*	100 USD
Storage costs at depot	*47 containers*	310 USD
TOTAL COST		**9099 USD**
UNIT COST		**136 USD**

The above example of cost analysis was only for one type of container. The shipping company provides transportation services for various types of containers. Transportation, handling and storage costs in ECR vary according to container type. Moreover, these costs can also vary from location to location. The transportation costs can change according to the contracts made with the transportation providers, as well as the number of containers or TEUs transported. The transportation costs may vary according to the contracts made with the transport companies, as well as the amount transported. Similarly, handling and depot fees also vary according to the contract made with the terminals and depots, and the number of containers handled and stored. Although all these costs are generally calculated per container and movement, sometimes different applications can be seen. In this respect, it is necessary to pay attention to how the empty container operations consume the resources and to analyze the cost relationships of these resources and operations.

Resources

The resources used by the shipping company to carry out the ECR can be listed as follows:

- Transportation providers

- Transportation connections
- Transportation capacities
- Terminals
- Depots
- Stock capacities

Since the shipping company works with third-party carriers in the region, it transports its empty containers in accordance with the agreements that has made with these third-party carriers. Therefore, the third-party carriers that the shipping company works with can be considered as the intangible resources of the company. The transportation routes and frequency of the empty containers are determined according to these agreements and vessel calls of the third-party carriers. Namely, transportations of the empty containers strictly depend on the vessel schedule of the third-party carriers. Accordingly, transportation connections can be interpreted as the resources of the company as well. Depending on all these, the capacities on the vessels of the third-party carriers are one of the concrete resources of the shipping company. The company usually buys capacity for one connection on the vessel, while sometimes purchases round trips depending on the commercial circumstances. The inland transportation of the shipping company are carried out in the similar way. So the inland transportation providers and the carrying capacities they offered can also be considered as the resources of the shipping company.

As the storage and handling operations are carried out at the depots and terminals which are the service providers of the shipping company, they can be regarded as another resources of the shipping company. In particular, the space capacity at the depots and terminals constitutes a significant source of the company in each location.

Activities

The main activities for the realization of ECR of the shipping company are as follows:

- Maritime transportation
- Railway transportation
- Road transportation
- Handlings at depots and terminals

- Storage at depots and terminals

Transportation activities of various empty container types consume the transportation capacity resources of the shipping company. Maritime transportation is the activity that generally leads to the highest costs in ECR.

Cost drivers

The cost drivers which are the unit of measure used to obtain the cost of the activities in ECR are as follows:

- Number of containers
- Number of TEUs
- Number of days
- Number of weeks

As the containers are carried on the cellular type of vessels, the transportation costs are measured per TEU or number of units. It is quite similar for the inland transportation as well. Container handling is an activity that can be easily measured as it is generally based on each number of movements. On the other hand, although empty container storage costs vary according to the container size or TEU, the main cost factor is the storage period of the containers. Many depot and terminal operators, increase the storage costs according to the increase in holding time of empty containers to avoid congestion at their yard areas.

Table 3 summarizes the resources, activities and cost drivers, and their relationships to each other.

Table 3. Resources, Activities and Cost Drivers in Empty Container Repositioning

Resources	**Activities**	**Cost Drivers**
Third-party transportation providers Transportation connections Transportation capacities	Maritime transportation Railway transportation Road transportation	Number of containers Number of TEUs
Terminals Depots Stock capacities	Handling at terminal Handling at depot Storage at terminal Storage at depot	Number of containers Number of TEUs Number of days Number of weeks

After the explanation of the illustrative example for the calculation of ECR costs, and in addition to the determination of resources, activities and cost drivers, the costing model for the calculation of weekly unit cost of ECR for each location and container will be as follows:

$$\sum_{d}\sum_{p}\sum_{i} O_{epditw} * \left(THC_{ept} + \frac{SC_{epdit}}{2}\right) + \sum_{p}\sum_{a}(NL_{eptaw} + NET_{eptw}) * TLS_{ept} + \sum_{p} NTD_{eptw} * TDC_{ept} \qquad (a)$$

$$\sum_{p}\sum_{a}(NL_{eptaw} * (LC_{epta} + LO_{eta}) + NED_{etaw} * LO_{eta}) + \sum_{a} AC_{etaw} * DC_{eta} \qquad (b)$$

$$DE_{etw} + DOFF_{etw} \qquad (c)$$

$$C_{etw} = \frac{a + b - c}{NI_{etw}}$$

where;

e is the set of locations which has exceed empty containers

t is the set of container types

d is the set of deficit locations where the empty containers required

p is the set of seaports or terminals

a is the set of the depots

i is the set of connection types

w is the set of weeks

C_{etw} is the unit ECR cost for container type of *t* in surplus location *e* in week *w*

NI_{etw} shows the total number empty containers accumulated in location *e* for container type *t* in week *w*

O_{epditw} represents the number of empty containers' type of *t* sent from terminal *p* in location *e* to *d* via connection *i* in week *w*

THC_{ept} represents the handling cost of an empty container type of *t* at terminal *p* in the location *e*

SC_{epdit} is the transportation cost of an empty container type of *t* from terminal *p* in location *e* to location *d* via connection *i*

NL_{eptaw} shows the number of empty containers' type of *t* transported from depot *a* to the terminal *p* in location *e* in week *w*

NET_{eptw} shows the number of empty containers' type of *t* accepted at terminal *p* in location *e* in week *w*

TLS_{ept} shows the lift on/off costs for empty container type of *t* at terminal *p* in location *e*

NTD_{eptw} shows the number of empty containers' type of *t* stored at terminal *p* in location *e* in week *w*

TDC_{ept} shows the storage cost of empty containers' type of *t* at terminal *p* in location *e*

NED_{etaw} shows the number of empty containers' type of *t* accepted at depot *a* in location *e* in week *w*

LC_{epta} represents the transportation costs for empty container type of *t* from depot *a* to the terminal *p* in location *e*

LO_{eta} represents the lift on/off costs for empty container type of *t* at depot *a* in location *e*

AC_{etaw} represents the number of empty containers' type of *t* stored at depot *a* in location *e* in week *w*

DC_{eta} represents the storage cost for empty container type of *t* at depot *a* in location *e*

DE_{etw} is the total demmurage and detention costs charged to the customers for the containers' type of *t* in location *e* in week *w*

$DOFF_{etw}$ is the drop-off costs charged to the customers for the containers' type of *t* at in location *e* in week *w*

The unit imbalance cost that occurs due to the evacuation of empty containers from the surplus location *e*, will be as follows:

$$IMBC_{etw} = \frac{\sum_p \sum_d \sum_i O_{epditw} * \left(THC_{ept} + \frac{SC_{epdit}}{2} \right) + \sum_p \sum_a NL_{eptaw} * (TLS_{ept} + LC_{epta} + LO_{eta})}{NI_{etw}}$$

This model considers the transportation and handling costs that arise because of the evacuation of empty containers out of the location. In other words, other transportation and handling costs that may occur for full exports in that location are not taken into account.

3.4. Costing Model for Empty Container Repositioning in a Deficit Location

Figure 5 shows the commercial situation for 20dv containers in an export dominant location in a 12 weeks of period. As can bee seen, this location has much more full exports than full imports, and empty containers should be regularly supplied to this location from the surplus locations to meet the 20dv container demand.

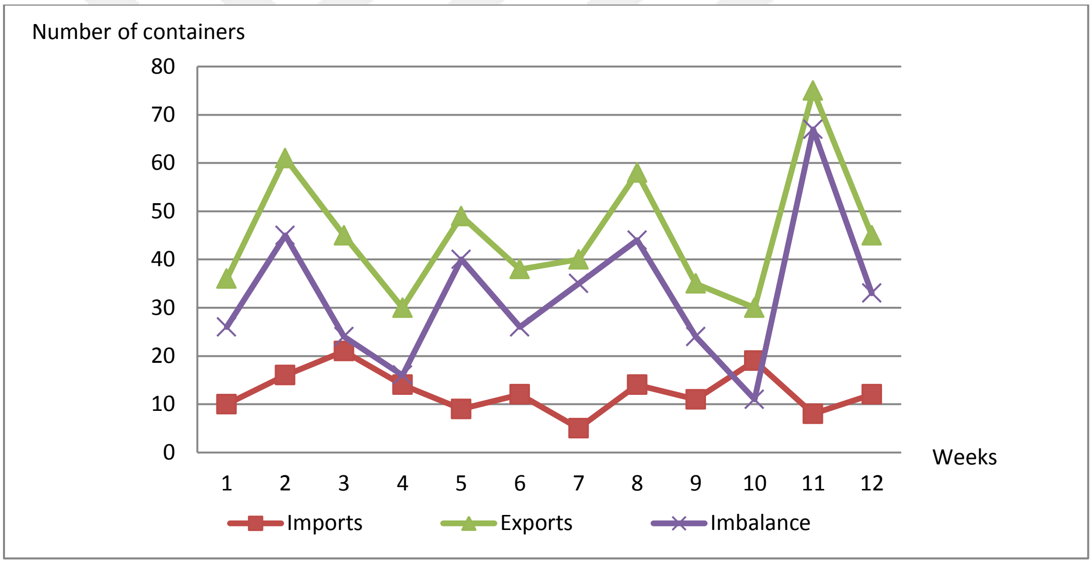

Figure 5. Commercial figures for 20dv containers in an export dominant location

Decisions on the container supply depend on the vessel connections and capacities, and transportation costs. Figure 6 shows an illustrative example of the ECR for 20dv type of containers in the same location in the 11. week. 10 empty containers returned by the customers were received at the depot 1 and 5 of them at the depot 3. Accepting these empty containers caused handling (lift off the empty containers from the truck) costs at the depots. 20 empty containers coming from surplus location S_1 were discharged at terminal 1 and 10 of them were trucked to the depot 1 to cover the demand at this depot. All these movements caused handling and transportation costs accordingly. The other 10 containers were released for full exports to the customers directly from the terminal 1. As can be seen in the Figure 6, 50 empty containers were arrived at the terminal 2 from the surplus location S_2. 20 of these containers were transhipped at the terminal 2 to be sent to the deficit location D_1 to cover the demand there. 10 empty containers were trucked to the depot 1, 5 empty containers to the depot 2 and 15 empty containers to the depot 3. All of these operations also caused costs. Finally, 10 empty containers were procured from the surplus location S_3. These 10 units were transported by train and accepted directly at the depot 2. Likewise, all these movements incurred costs for this deficit location. Furthermore, holding the empty containers at the depots and terminals caused storage costs to the shipping company as well. Table 4 shows the cost items and costs arising from ECR in this deficit location in week 11.

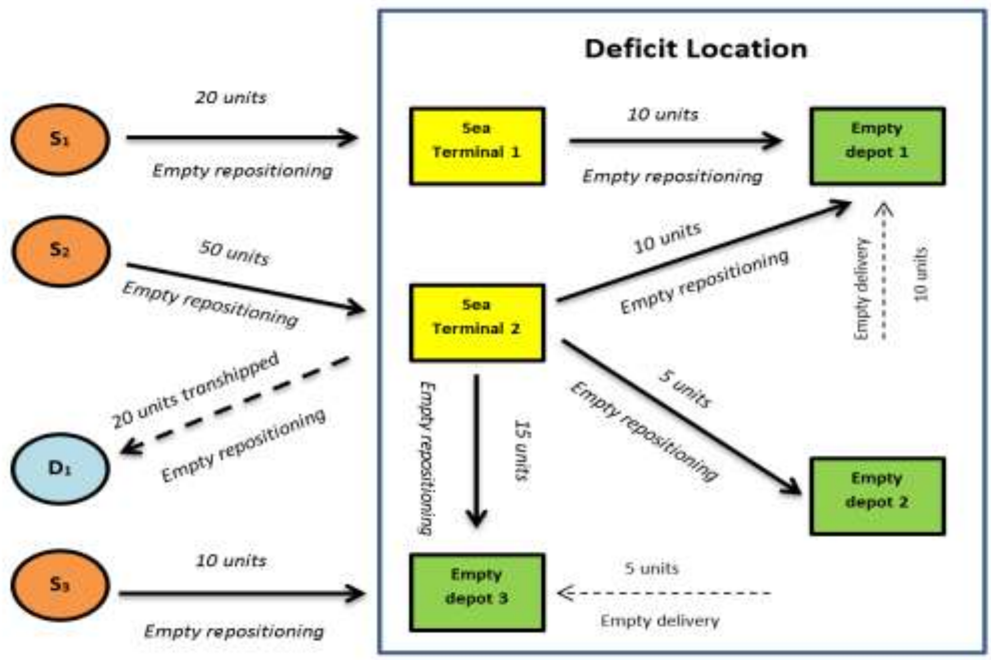

Figure 6. ECR in the export dominant location in week 11

As explained in the surplus location example, only half of the maritime transportation costs are considered in the Table 4. Other half of these maritime transportation costs will be allocated to the surplus locations where the empty containers came from. Here, in addition, the cost of transportation by train is also divided into two as 10 empty containers came from the surplus location S_3. Namely, the cost of this transportatin is equally allocated to both locations. Another important point here is the transhipment costs which includes container unloading, loading and shifting costs incurred at the terminal 2. Since these 20 containers are associated with the surplus location S_2 and the deficit location D_1, the transhipment costs should be allocated to these two locations. On the other hand, the transportation costs of 30 containers coming from S_2 and remaining at the deficit loaciton should be equally allocated between the two locations, and the discharging costs at the terminal 2 should be allocated to the deficit location. Empty containers in this deficit location also caused storage costs depending on the waiting days at the terminals and depots.

The total ECR costs for 20dv containers in this deficit location in the 11. week is 10385 USD. When the total cost is divided by the total number of empty containers (75 units) moved in this week, the unit ECR cost of a 20dv container in this deficit location will be about 138 USD. This cost represents the cost of the shipping company paying for a full export of a 20dv container from this location, resulting from the ECR during the week 11. So the shipping company should add this cost to the freight cost of an export a 20dv container from this location in the 11. week.

Table 4. ECR costs occured for 20dv containers in the deficit location in week 11

Maritime transportation costs	*20 containers x 70 USD*	1400 USD
	30 containers x 50 USD	1500 USD
Railway transportation costs	*10 containers x 200 USD*	600 USD
Discharging costs at terminal 1	*20 containers x 50 USD*	1000 USD
Discharging costs at terminal 2	*30 containers x 60 USD*	1800 USD
Transportation costs between terminal 1 and depot 1	*10 containers x 30 USD*	300 USD
Transportation costs between terminal 2 and depot 1	*10 containers x 20 USD*	200 USD
Transportation costs between terminal 2 and depot 2	*5 containers x 40 USD*	200 USD
Transportation costs between terminal 2 and depot 3	*15 containers x 20 USD*	300 USD
Lift on/off costs at terminal 1	*10 containers x 15 USD*	150 USD
Lift on/off costs at terminal 2	*30 containers x 12 USD*	360 USD
Lift on/off costs at depot 1	*30 containers x 10 USD*	300 USD
Lift on/off costs at depot 2	*5 containers x 15 USD*	75 USD
Lift on/off costs at depot 3	*30 containers x 15 USD*	450 USD
Storage costs at terminal 1	*10 containers*	110 USD
Storage costs at terminal 2	*30 containers*	0 USD
Storage costs at depot 1	*30 containers*	100 USD
Storage costs at depot 2	*5 containers*	20 USD
Storage costs at depot 3	*30 containers*	120 USD
TOTAL COST		**10385 USD**
UNIT COST		**138 USD**

As can bee seen in the Table 4, handling and storage costs vary among the terminals and depots. Also, the transportation costs between the terminals and depots may also vary in this location. These are important in terms of making an accurate imbalance cost analysis. The imbalance costs are the costs resulting from the operations of empty containers supplied from other locations. If there were sufficient number of empty containers in this location, handling costs and storage costs would arise anyhow from the delivery of containers from the customers to the terminals and depots, and from holding them at the terminals and depots, but there would be no costs incurred due to empty container supply from other locations. The shipping company can avoid empty container supply costs by importing full containers into this location as these import containers would be used once they returned by the customers. Table 5 shows the costs that incurred due to the supply of empty containers from the surplus locations in week 11.

Table 5. Imbalance costs for 20dv in the deficit location in week 11

Maritime transportation costs	*20 containers x 70 USD*	1400 USD
	30 containers x 50 USD	1500 USD
Railway transportation costs	*10 containers x 200 USD*	2000 USD
Discharging costs at terminal 1	*20 containers x 50 USD*	1000 USD
Discharging costs at terminal 2	*30 containers x 60 USD*	1800 USD
Transportation costs between terminal 1 and depot 1	*10 containers x 30 USD*	300 USD
Transportation costs between terminal 2 and depot 1	*10 containers x 20 USD*	200 USD
Transportation costs between terminal 2 and depot 2	*5 containers x 40 USD*	200 USD
Transportation costs between terminal 2 and depot 3	*15 containers x 20 USD*	300 USD
Lift on/off costs at terminal 1	*10 containers x 15 USD*	150 USD
Lift on/off costs at terminal 2	*30 containers x 12 USD*	360 USD
Lift on/off costs at terminal 1 *	*10 containers x 15 USD*	-150 USD
TOTAL COST		**9060 USD**
UNIT COST		**121 USD**

An important point here is the interpretation of the lift on/off costs occurred at the terminal 1. As explained above, 20 empty containers arrived at the terminal 1 from the surplus location $S_{1.}$ 10 of them were trucked to the depot 1 and 10 of them were released to the customers from this terminal. If there were 10 more full imports in this location and they were accepted at the terminal 1 when returning from the customer in that week, these delivery (lift of from the truck) costs at the terminal 1 would not be considered as imbalance costs. Consequently, these costs should be deducted from the container discharging costs at the terminal 1. This is why these costs are shown as negative in the last row of the Table 5.

The total imbalance costs of the deficit location for 20dv containers in the 11. week is 9060 USD. As can be seen in the Table 5, the storage costs and handling costs occurred due to delivery of empty containers from the customers are not included in the total imbalance costs. When the total imbalance costs is divided by the total number of empty containers (75 units) moved in this location in week 11, the unit imbalance cost for a 20dv container in this deficit location in that week will be about 121 USD. This is the cost of supplying an empty 20dv container into this location in week 11. Instead of sending an empty 20dv container to this deficit location, the shipping company can save 121 USD by importing a full 20dv container there as it would be definitely used after their delivery from the customers. So this cost can be interpreted as a bonus in full imports for 20dv containers coming to this location. In other words, this cost should be deducted from the total freight costs when offering a freight rate for a full import of a 20dv container in this location.

Unlike the surplus locations, the important point to highlight for the deficit locations is that the incoming containers may remain in the next weeks. The reason for this is the mixing of empty containers , which arrive from other locations, with empty containers returning returning from the customers in that location. Since most terminals and depots do not operate with FIFO method, it is best to use the weighted average method to calculate the weekly unit cost of ECR. Therefore, it is necessary to show the ECR costs of the empty containers in the following weeks that are received from other locations and are not used within the current week. For this purpose, the variable *NPW* is added to the formula which shows the number of empty containers' type of *t* remaining from last week. This is the typical application of the process costing technique. The costing model for the unit cost of ECR for a deficit (export dominant) location is as follows:

$$\sum_{e}\sum_{p}\sum_{i} O_{epditw} * \left(THC_{dpt} + \frac{SC_{epdit}}{2}\right) + \sum_{p}\sum_{a}(NL_{dptaw} + NET_{dptw}) * TLS_{dpt} + \sum_{p} NTD_{dptw} * TDC_{dpt} \qquad (d)$$

$$\sum_{p}\sum_{a}(NL_{dptaw} * (LC_{dpta} + LO_{dta}) + NED_{dtaw} * LO_{dta}) + \sum_{a} AC_{dtaw} * DC_{dta} \qquad (e)$$

$DE_{dtw} + DOFF_{dtw} \quad (f)$

$$C_{dtw} = \frac{d + e - f + (IMBC_{dtw-1} * NPW_{dtw-1})}{NE_{dtw}}$$

where;

e is the set of locations which has exceed empty containers

t is the set of container types

d is the set of deficit locations where the empty containers required

p is the set of seaports or terminals

a is the set of the depots

i is the set of connection types

w is the set of weeks

C_{dtw} is the unit ECR cost for container type of *t* in deficit location *d* in week *w*

NE_{dtw} shows the total number empty containers accumulated in location *d* for container type *t* in week *w*

O_{epditw} represents the number of empty containers' type of *t* sent from location *e* to *d* via connection *i* in week *w*

THC_{dpt} represents the handling cost of an empty container type of *t* at terminal *p* in the location *d*

SC_{epdit} is the transportation cost of an empty container type of *t* from terminal *p* in location *e* to location *d* via connection *i*

NL_{dptaw} shows the number of empty containers' type of *t* transported from depot *a* to the terminal *p* in location *d* in week *w*

NET_{dptw} shows the number of empty containers' type of *t* accepted at terminal *p* in location *d* in week *w*

TLS_{dpt} shows the lift on/off costs for empty container type of *t* at terminal *p* in location *d*

NTD_{dptw} shows the number of empty containers' type of *t* stored at terminal *p* at location *d* in week *w*

TDC_{dpt} shows the storage cost of empty containers' type of *t* at terminal *p* in location *d*

NED_{dtaw} shows the number of empty containers' type of *t* accepted at depot *a* in location *d* in week *w*

LC_{dpta} represents the transportation costs for empty container type of *t* from depot *a* to the terminal *p* in location *d*

LO_{dta} represents the lift on/off costs for empty container type of *t* at depot *a* in location *d*

AC_{dtaw} represents the number of empty containers' type of *t* stored at depot *a* in location *d* in week *w*

DC_{dta} represents the storage cost for empty container type of *t* at depot *a* in location *d*

NER_{dptw} shows the number of empty containers' type of *t* released for full export from terminal *p* in location *d* in week *w*

DE_{dtw} is the total demmurage and detention costs charged to the customers for the containers' type of *t* in location *d* in week *w*

$DOFF_{dtw}$ is the drop-off costs charged to the customers for the containers' type of *t* in location *d* in week *w*

$NPW_{dt(w-1)}$ shows the number of empty containers' type of *t* arrived in location *d* from other locations and remained from last week

The weekly unit imbalance cost that occurs due to the supply of empty containers type of *t* to location *d* is as follows:

$$IMBC_{dtw} = \frac{\sum_p \sum_d \sum_i O_{epditw} * \left(THC_{dpt} + \frac{SC_{epdit}}{2} \right) - NER_{dptw} * TLS_{dpt} + \sum_p \sum_a NL_{dptaw} * (TLS_{dpt} + LC_{dpta}) + (IMBC_{dtw-1} * NPW_{dtw-1})}{NE_{dtw}}$$

Similar to the costing model for the surplus location, this model only considers the transportation and handling costs that arise due to supply of empty containers to the deficit location. Namely, other transportation and handling costs of the empty containers that already exist in the deficit location are not taken into account.

3.5. Chapter Summary

Almost all the container shipping companies in the industry struggle with the problem of ECR. This issue will continue as long as the volume of world trade increases, trade imbalances exist and the intensive competition between the shipping companies continues. Accordingly, shipping companies do not escape from the costs of ECR. Therefore, shipping companies must analyze these costs correctly and see their impact on their shipping services. This chapter highlighted the costs of ECR in liner shipping in the case of a container shipping company, revealed the cost types and introduced costing models for the costs of its regional ECR.

Companies require accurate and timely information in order to make the right decisions and achieve their goals. With an effective costing system, timely and accurate information flow can be provided to the management so that the managers can take their future decisions more effectively. When establishing a cost system, companies should take into consideration the structure of the industry, its fields of activity, production patterns, production efficiency and procurement methods. Moreover, they should also examine their resources and opportunities in detail and develop the best costing model accordingly.

Container shipping is a sector where a wide variety of complicated operations take place. ECR, which constitute a significant part of these operations, also consists of highly complex operations which bring out mixed cost structures. Indeed, shipping companies face difficulties in calculating the costs of ECR which lead to challenges to make right decisions. For that purpose, costing models were developed in this chapter. The costing models can compute the weekly unit repositioning cost and imbalance cost of each type of empty container in each location where the shipping company provides liner services. They accurately show which operations and items the costs originate from. The models also demonstrate which location, container type and operations consume the company’s resources. Namely, thanks to the costing models it is visible why the costs of ECR in a location is high: Whether due to a great imbalance in import/export numbers; or transportation costs; or handling costs; or inland repositiponing costs; or storage costs of empty containers. This enables the company to better deal with its suppliers, taking into account the costs and size of the operations. For instance, the shipping company is able to see that it should work with new inland transportation providers which offer better prices or negotiate with the existing suppliers in a location where the inland trasportation costs are high.

The costing models developed in this chapter can be used not only for calculating the past costs, but also to estimate the future costs of ECR. They provide the availability to find the relevant costs associated with ECR. This is why the sunk costs such as depreciation and leasing cost are not considered in the models. As a consequence, the costs resulting from the trade imbalances can be monitored more clearly. Especially, thanks to the approach introduced in this chapter, of how the costs resulting from ECR are reflected in the freight price, the costing models are also useful for the customer selection and freight price proposals. Last but not least, the costing models can also be used by other shipping companies by making minor changes according to their operations, cost structures and requirements.

4. CHAPTER
OPTIMIZATION MODELS FOR EMPTY CONTAINER REPOSITIONING

As mentioned in the previous chapters, the imbalances in international trade directly affect container shipping and cause imbalances in the number of containers in many locations. In some locations, where imports are too much compared to exports, empty container accumulation take place. Repositioning of these excess empty containers from import dominant locations to export dominant locations leads to high cost for shipping companies. So the initial aim of the shipping companies is to minimize the ECR costs.

This chapter introduces two mathematical programming models to minimize the total ECR costs. The first mathematical programming model is a mixed-integer linear programming (MILP) model that deals with the ECR problem from a deterministic point of view. The second mathematical programming model is a stochastic programming model which takes into account the uncertainty in the container demand in the export dominant locations.

4.1. Mixed Integer Linear Programming Model

Linear programming (LP) is a decision-making tool and a technique for determining how limited resources can be used most effectively. An LP model arises when limited resources are allocated to specific activities and contributes to the realization of an objective. In LP problems, sharing of resources by activities is desired in a way that maximizes or minimizes the objective. LP is one of the most known and used methods in Operations Research (OR). It has been successfully applied in many fields such as production planning and scheduling, optimization of raw material mixture and usage, personnel assignment, transportation and distribution planning etc.

Although some operational problems can be solved with LP, an integer result must be obtained. For example, whether a depot is established or not, or a worker is assigned to a machine or not, can be determined with the decision variables that take the values 1 and 0. In other words, in some problems the LP's assumption of divisibility is invalid. Therefore, full-scale solutions can not be guaranteed with standard LP solution techniques. For this reason, the integer programming (IP) method has been developed (Tütek et al., 2012, p. 297). In some problems, some of the decision variables must be integer, while other decision variables can take any value. Such problems are called MILP problems in the literature. As the deterministic mathematical programming model developed in this section involves both binary and integer variables, it is also a MILP model.

Container shipping is a very suitable field for the applications of LP and MILP models. As a matter of fact, many models in the literature have used such models. The use of such models is also important to show how the activities consume the company's resources. In this respect, LP and its variants are also important solution methods to be applied for cost management. Considering the linearity of costing methods and the cellularity of container shipping, it is highly suitable to apply such type of mathematical programming models to real life applications in container shipping. In particular, it can be said that LP models are superior to non-linear models in terms of combining mathematical programming models and costing methods.

The description, assumptions and deterministic solution model of the ECR problem are described below.

Problem Description:

As mentioned in the third chapter, the shipping company serves its customers by using third party transportation providers. Other than carrying full containers, the shipping company also repositions its empty containers via third party vessels, trucks and trains in order to meet the demand of export dominant locations. In particular, the shipping company is strictly dependent on the schedule and capacity allocation of other shipping companies' vessels. Therefore, it needs to make detailed plans a few weeks in advance to cover the demand and minimize the total ECR costs.

The shipping company provides weekly container shipping services to its customers and has some imbalances in some locations in a specific region. Accordingly, the excess empty containers in the import dominant locations must be sent to the export dominant locations to cover the container demand. Because the vessel transportation service in the region lasts four weeks at most, a four-week ECR plan is needed. For this purpose, a MILP model was developed which considers the transportation, handling and storage costs of empty containers.

Although there are more locations within the service region of the shipping company, it is not necessary to include these locations in the data set of the problems, as there are only one transportation option for repositioning excess empty containers to the outside of the region. Therefore, these locations are not considered in the weekly data sets to reduce the number of parameters and decision variables in the problems, depending on the requirement for empty containers in the export dominant locations. Only three types of containers are taken into consideration since the container types that the shipping company carries the most in this region are 20dv, 40dv and 40HC. In the MILP model, ECR costs do not include the THC in the locations, but the transportation costs between the locations. Since the excess containers from import dominant locations have to be repositioned to any export dominant locations at any time and these export dominant locations will receive empty containers at any time, the THC in the locations would occur at all events. Therefore, these costs will be considered in the costing models. If the THC was also taken into account within the ECR costs in the MILP model, it would cause containers to be accumulated in the surplus locations, preventing the empty containers from being sent from these locations due to high THC. All other assumptions are the same as mentioned in the third section in line with the information on the shipping company's operations. The transportation and storage costs are determined according to the price quotations given by the third party service providers and according to the resource, activity and cost driver analysis for the costing model introduced in Chapter 3. Other assumptions, sets, parameters and decision variables for the MILP model are as follows:

Assumptions:

- A four-week period is considered.

- Import and export numbers of container types in each location are known for the four-week period.

- In each location, the number of container types returning from the customers per week is known.

- Transportation of empty containers that return from hinterland is carried out by the customers meaning that they do not cause any costs to the shipping company.

- All the surplus containers are available in the locations and ready to be repositioned.

- The weekly demand of each export dominant location must be covered.

- All the empty containers are transported via third party transportation providers.

- Vessel arrival times and capacities are known for each week.

- Empty containers arrive in the deficit locations at the beginning of the week and free storage times at terminals are taken into account.

-Apart from the empty containers remaining for the next week, other empty containers will be used within that week and no storage costs will incur for those empty containers.

- No short-term leasing is allowed.

<u>Sets:</u>

E= {1…|E|} set of the surplus locations- indexed by e.

D= {1…|D|} set of the deficit locations – indexed by d.

I= {1…|I|} set of the transportation connections between the locations – indexed by i.

T= {1…|T|} set of the container types – indexed by t.

W= {1…|W|} set of the weeks – indexed by w.

C= {1…|C|} set of the stock levels – indexed by c.

<u>Parameters:</u>

C_{edit}: $transportation\ cost\ of\ an\ empty\ container\ type\ of\ t\ from\ location\ e\ to\ d\ via\ i,$
$e \in E, d \in D, i \in I, t \in T$

EC_{etc}: $weekly\ storage\ cost\ of\ an\ empty\ container\ type\ of\ t\ at\ location\ e\ for\ stock\ level\ c,$
$e \in E, t \in T, c \in C$

DC_{dtc}: $weekly\ storage\ cost\ of\ an\ empty\ container\ type\ of\ t\ at\ location\ e\ for\ stock\ level\ c,$
$d \in D, t \in T, c \in C$

F_{etw}: $number\ of containers\ of\ type\ t\ that\ can\ be\ sent\ out\ of\ location\ e\ in\ week\ w,$
$e \in E, t \in T, w \in W$

Y_{dtw}: $number\ of containers\ of\ type\ t\ that\ are\ needed\ at\ location\ d\ in\ week\ w,$
$d \in D, t \in T, w \in W$

Kap_{edi}: $total\ capacity\ of\ the\ connection\ i\ from\ location\ e\ to\ d,\ \ e \in E, d \in D, i \in I$

B_t: $Size\ of\ the\ container\ type\ t\ in\ terms\ of\ TEU,\ \ t \in T$

Z_{ediw}: $transportation\ time\ from\ location\ e\ to\ d\ via\ i\ in\ week\ w,\ \ e \in E, d \in D, i \in I, w \in W$

SQE_{ewc}: $total\ stock\ quantity\ in\ terms\ of\ TEU\ at\ location\ e\ for\ stock\ level\ c\ in\ week\ w,$
$e \in E, w \in W, c \in C$

SQD_{dwc}: $total\ stock\ quantity\ in\ terms\ of\ TEU\ at\ location\ d\ for\ stock\ level\ c\ in\ week\ w,$
$d \in D, w \in W, c \in C$

M: $a\ very\ large\ integer\ number$

Decision variables:

O_{editw}: $number\ of\ containers\ of\ type\ t\ sent\ from\ location\ e\ to\ d\ via\ i\ in\ week\ w,$
$e \in E, d \in D, i \in I, t \in T, w \in W$

G_{editw}: $number\ of\ containers\ of\ type\ t\ coming\ from\ location\ e\ to\ d\ via\ i\ in\ week\ w,$
$e \in E, d \in D, i \in I, t \in T, w \in W$

R_{etw}: $number\ of\ containers\ of\ type\ t\ remaining\ at\ location\ e\ in\ week\ w,\ \ e \in E, t \in T, w \in W$

K_{dtw}: $number\ of\ containers\ of\ type\ t\ remaining\ at\ location\ d\ in\ week\ w,\ \ e \in E, t \in T, w \in W$

$$TC_{ewc}: \begin{cases} 1, if\ location\ e\ has\ the\ stock\ level\ c\ in\ week\ w, & e \in E, w \in W, c \in C \\ 0, otherwise \end{cases}$$

$$IC_{dwc}: \begin{cases} 1, if\ location\ d\ has\ the\ stock\ level\ c\ in\ week\ w, & d \in D, w \in W, c \in C \\ 0, otherwise \end{cases}$$

Objective function:

$$\sum_t \sum_w [\sum_c [\sum_e R_{etw} * EC_{etc} * TC_{ewc} + \sum_d K_{dtw} * DC_{dtc} * IC_{dwc}] + \sum_e \sum_d \sum_i G_{editw} * C_{edit}]$$

Constraints:

$$O_{editw} = G_{edit(w+Z_{ediw})} \qquad \forall\ e, d, i, t, w \qquad (1)$$

$$\textstyle\sum_e \sum_i G_{edit1} \geq Y_{dt1} \qquad \forall\ d, t \qquad (2)$$

$$\textstyle\sum_e \sum_i G_{editw} + K_{dt(w-1)} \geq Y_{dtw} \qquad \forall\ d, t, w \in \{2 \ldots |W|\} \qquad (3)$$

$$K_{dt1} = \textstyle\sum_e \sum_i G_{edit1} - Y_{dt1} \qquad \forall\ d, t \qquad (4)$$

$$K_{dtw} = \sum_e \sum_i G_{editw} - Y_{dtw} + K_{dt(w-1)} \qquad \forall\, d, t, w \in \{2 \ldots |W|\} \qquad (5)$$

$$\sum_t G_{editw} * B_t \leq Kap_{edi} \qquad \forall\, e, d, i, w \qquad (6)$$

$$\sum_d \sum_i O_{edit1} \leq F_{et1} \qquad \forall\, e, t \qquad (7)$$

$$\sum_d \sum_i O_{editw} \leq F_{etw} + R_{et(w-1)} \qquad \forall\, e, t, w \in \{2 \ldots |W|\} \qquad (8)$$

$$R_{et1} = F_{et1} - \sum_d \sum_i O_{edit1} \qquad \forall\, e, t \qquad (9)$$

$$R_{etw} = F_{etw} - \sum_d \sum_i O_{editw} + R_{et(w-1)} \qquad \forall\, e, t, w \in \{2 \ldots |W|\} \qquad (10)$$

$$\sum_t K_{dtw} * B_t \leq \sum_c IC_{dwc} * SQD_{dwc} \qquad \forall\, d, w, c \qquad (11)$$

$$\sum_c IC_{dwc} \leq 1 \qquad \forall\, d, w \qquad (12)$$

$$\sum_t R_{etw} * B_t \leq \sum_c TC_{ewc} * SQE_{ewc} \qquad \forall\, e, w, c \qquad (13)$$

$$\sum_c TC_{ewc} \leq 1 \qquad \forall\, e, w \qquad (14)$$

$$O_{editw}, G_{editw}, R_{etw}, K_{dtw} \in Z \qquad \forall\, e, d, i, t, w \qquad (15)$$

$$TC_{ewc},\ IC_{dwc} \in \{0,1\} \qquad \forall\, e, d, w, c \qquad (16)$$

The objective function minimizes the total ECR costs in the four-week period. Constraint set (1) indicates when the empty containers' type of *t* that are sent from location *e* via connection *i* will be in location *d*. Constraints (2) and (3) ensure that all the weekly demands for each type of container *t* in each deficit location *d* must be covered. Constraint sets (4) and (5) show the number of empty containers for each type of *t* left in each deficit location in each week. Constraint (6) guarantees that the total number of TEUs of empty containers to be transported from surplus location *e* to deficit location *d* cannot excess the capacity of connection *i*. Constraints (7) and (8) ensure that each surplus location *e* cannot send more empty containers type of *t* than existing containers in this location in each week. Constraint sets (9) and (10) show the number of empty containers for each type of *t* left in each surplus location *e* in each week. Constraint (11) shows the weekly stock level in each deficit location *d* in terms of TEU. Constraint set (12) indicates that each deficit location *d* will have one stock level. Constraint (13) demonstrates the weekly stock level in each surplus location *e* in terms of TEU. Constraint (14) ensures that each surplus location *e* will have one stock level. Constraints (15) and (16) represent the range of decision variables.

4.2. Stochastic Programming Model

The ability of optimization models to adapt to real-life applications depends on the efficient modeling of the uncertainty. Stochastic programming (SP) can be applied if uncertain parameters can be defined with discrete random variables. It is one of the most effective methods to solve these types of models (Kall and Wallace, 1994). In fact, SP is an inherent and powerful extension of deterministic mathematical programming and is used effectively in the analysis of optimization problems where the parameters are not known precisely. In the case of SP, the uncertainty is represented by discrete distributions of random variables, and random variables take values from a set of discrete values. As in other optimization models, the dimensions of the SP models increase with the size of the random vector. The larger this random vector, the harder it is to solve the problem. The solution of large-scale problems depends on the computational methods and cevelopments in computer technology.

Nowadays SP is used to solve many real-life problems in many areas such as portfolio optimization, production planning, resource planning, facilitiy location, energy production, distribution and transportation planning, energy production and technology processes (Birge and Louveaux, 2011). The models that reflect real-life applications, are very complex and contains many parameters and decision variables. As the number of parameters and variables increases, the solution of the models becomes more difficult. For this purpose, advanced optimization and OR techniques, heuristic methods and algorithms have been developed for solving the SP problems.

There are two main modeling techniques in SP. These are recourse SP models and chance constraint SP models. In chance constraint models, some constraints must provide a predetermined level of confidence. The general form of chance constraint is as follows:

$$P\{f(x, \overline{\omega})\} \geq \alpha$$

α indicates the probability value that the constraint should provide. Chance constraint programming was first modeled by Charnes and Chooper (1959). For more detailed information, we refer the reader to the textbooks by Kall and Wallace (1995), Prekopa (1995), Birge and Louveaux (2011).

In recourse models some decisions have to be taken in an uncertain environment. These decisions are often referred to as first stage decisions. Later, when the uncertainty ceases to exist, auxiliary decisions (recourse action or second stage decisions) are taken based on the first stage decisions. In the literature, such models are called two stage SP with recourse action. Recourse models were originally developed by Dantzig (1955) and Beale (1955). The studies published by Stougie and van der Vlerk (1996), Haneveld and van der Vlerk (1999), Schultz (2003), Sen (2005) and Sherali and Zhu (2009) can be examined for the features and solution methods of two-stage recourse stochastic models. The recourse function is usually measured by taking the average value of all actual values of the random event. On the other hand, some alternative risk measures have also been included in the SP models by Takriti and Ahmed (2004), Riis and Schultz (2003) and Ogryczak and Ruszczynski (2002).

The goal of two-stage SP is to optimize the first stage cost and the average value of the cost based on the first stage decision. The two-stage mixed integer stochastic programming can be modeled as follows:

$$\text{Min } c^{\mathrm{T}}x + E[f(x,\varpi] \qquad (1.1a)$$

$$\text{subject to } \mathrm{A}x \geq b, \qquad (1.1b)$$

$$x \geq 0,\ x_i \text{ integer},\ i \in I, \qquad (1.1c)$$

$c \in \Re^{n_1}$ is the first stage cost vector; $E[.]$ is the overall mathematical mean operator. The constraint set (1.1b) shows the first stage constraints; $A \in \Re^{m_1 \times n_1}$ is the first stage constraint matrix and $b \in \Re^{m_1}$ is the right-hand side vector. The constraint set (1.1c) shows that some of the first-step decision variables must be integer, I denotes an integer set of indices, and includes partial or all first-step decision variables $x \in \Re^{n_1}$.

For any ω that is the actual value of the $\overline{\omega}$ scenario, the second stage problem (scenario subproblem) can be expressed as:

$$f(x, \omega) = \text{Min } q(\omega)^{\mathrm{T}} y, \qquad (1.2a)$$

$$\text{subject to } W(\omega) y \geq r(\omega) - T(\omega) x, \qquad (1.2b)$$

$$y \geq 0, \; y_j \text{ integer}, \; j \in J \qquad (1.2c)$$

In problem (1.2), $q(\omega) \in \Re^{n_2}$ specifies the second stage cost vector for each ω scenario; y denotes the auxiliary decision variable vector. $W(\omega) \in \Re^{m_2 \times n_2}$ denotes auxiliary decision matrix, $r(\omega) \in \Re^{m_2}$ the second-stage right-hand vector, and the $T(\omega) \in \Re^{m_2 \times n_1}$ the technology matrix. The constraint set (1.2c) shows that some of the second-step decision variables must be integer, J denotes an integer set of indices, and includes partial or all second-step decision variables $y \in \Re^{n_2}$. $A, W(\omega), T(\omega)$ matrices are assumed to be rational matrices for each ω scenario. If the $W(\omega)$ matrix is deterministic, then the second stage problem is said to have a fixed recourse. If the technology matrix $T(\omega)$ is not random, the second stage problem is said to have a fixed tender. Finally, the decision variable y in the second stage problem varies depending on the scenario ω. But this commitment is implicit in the second stage problem.

If any first-step decision variable vector x makes the second-stage problem feasible, the problem is called a two-stage complete recourse SP. The relative complete recourse, which is a weaker condition, is expected that any feasible first-order decision variable x makes the second stage problem feasible. If the recourse matrix has a special structure such as, $W = [I, -I]$, and the second stage decision variables are continuous variables that can take positive real numbers and the constraint (1.2b) has the equality instead of the inequality, the problem is a simple recourse SP. The newspaper vendor problem is an example of this (Birge and Louveaux, 2011: 15).

4.2.1. Multi-stage Stochastic Programming

Multi-stage SP problems can be regarded as an extension of two-stage programming to a multi-stage setting (Shapiro and Philpott, 2007). In practice, most decision problems show sequential decision processes in a certain period. Observations are made in different periods T and are stored in $\{I_t\}^T_{t=1}$ information index. The decision problem in each t phase depends on information index I_t which is a component of $\{I_t\}^T_{t=1}$, and information index $\{I_t\}^T_{t=t+1}$ whicjh containes the information about the future.

$y_1 \in \Re^{n_1}$ first-stage decision variablet, A and b are considered constraints respectively; for each $t=2,3\ldots,T$ stage, the future step decision vector $y_t \in \Re^{n_t}$ depends on both the set of $w_t \in \Omega_t$ random variables and the decisions taken in the previous stage. In each step, the random cost function is expressed as $q_t, (y_t, w_t)$ and the random parameters as $T_t(w_t), h_t(w_t)|w_t \in \Omega_t$.

The multi-stage model, which is the extension of the two-stage model, is as follows:

$$Min\ Z = f(y_1) + E_{w2}\left[min\ q_2, (y_2, w_2) + \cdots + E_{w_T}[min\ q_T, (y_T, w_T)] \ldots\right], \quad (1.3a)$$

$$\text{subject to } Ay_1 \geq b, \quad (1.3b)$$

$$W_2, (y_2, w_2) = r_2, (w_2) - T_2, (w_2)y_1, \quad (1.3c)$$

$$W_3, (y_3, w_3) = r_3, (w_3) - T_3, (w_3)y_2,$$

$$W_T, (y_T, w_T) = r_T, (w_T) - T_T, (w_T)y_{T-1},$$

$$y_t \geq 0,\ y_t \text{ integer},\ t \in T \quad (1.3d)$$

As already mentioned, the mathematical programming models that reflect real-life practices, are very complex and contains many parameters and variables. A large number of parameters and variables make the problem difficult to solve. Similarly, as the number of stages increases, the solution of the problem becomes difficult as well. On the other hand, the increase in the number of scenarios also reduces the likelihood of the problem staying within solvable boundaries. Therefore, all these factors should be taken into consideration when SP models are established.

In this dissertation, although the weekly container demands are different from each other and a SP model for meeting these weekly demands has been developed, three different scenarios with the same weekly weights have been considered in order to facilitate the solution of the problems and allocate the costs more easily. Therefore, the problem structure has been formulated as a one-staged problem.

4.2.2. Scenario Tree and Scenario Generation

The goal in SP is to make the best possible decision under difficult constraints. In real problems, the uncertainty can be formulated with one or more parameters that can be modeled with a probability distribution. Essentially, each random variable is represented by a canonical probability space, which makes the uncertainty numerical (Birge and Louveaux, 2011: 62-66). SP integrates this uncertainty digitized in the specified optimization model and combines the dynamic linear programming model with the random parameter model to formulate the optimum model against future uncertainty.

In dynamic optimization problems with a multi-stage structure that is decided in successive periods, the obtainment of random variables is defined by the scenario tree. This structure is a critical input to SP. In the scenario tree, the starting node shows the current values and the branches from that node express the values that the random variables in the following period can take. At the end of each branch, there is a node showing a following period, from which the branches appear which indicate the values that the random variables may take in the next period. This process continues according to the stages of dynamic programming. For each stage, deterministic optimization programs can be applied using the relevant decision variables in the nodes and the random variables associated with that node. Thus, the optimization problem becomes a deterministic one.

The first step of the scenario tree is the determination of the number of stages and the creation of the branching diagram. Stages show certain points over time. Additional information received at these points is also used for decisions. These points are selected at regular intervals, such as hours, days and weeks. The scenario tree is constructed to show the values that the random variables can take in each planned period. In the case of a multi-stage decision problem, an example of scenario tree is shown in Figure 7.

A specific planning time is divided into periods $t=0,1,2,\ldots,T,$ where decisions are taken to re-evaluate the plans. The size of the scenario tree equals the number of periods. The start node is related to the time *(t=0)* and expresses the initial state. All values in the starting node are known precisely. All branches from the starting node express the values that the random variables in the following period can take. These values form the values of the following nodes. Similarly, the branches from the following node show the discrete states that the random variable can take in the next period (Gökmen, 2009: 59).

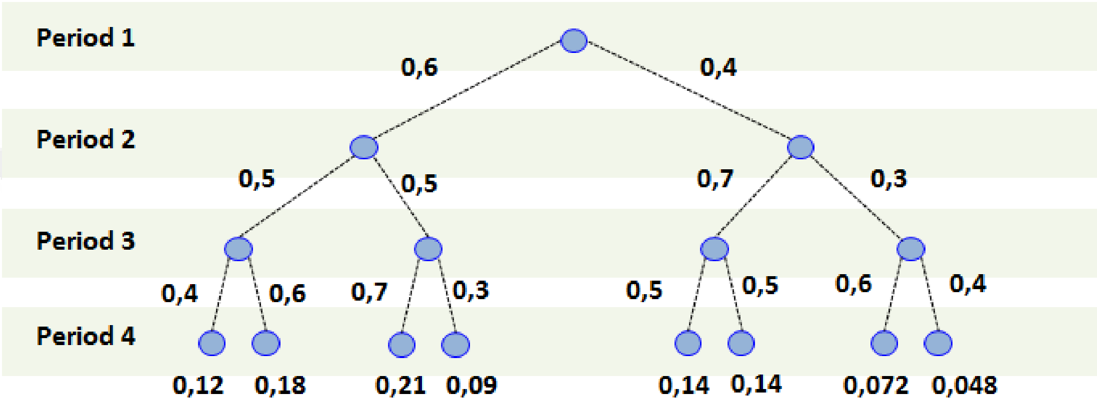

Figure 7. A Scenario tree example for multi-stage SP

Each node represents the values in the relevant time period and expresses the bound values of the random variables for that period. For example, if 2 branches from the initial node, 2 branches from the second node, and 2 branches from the third node, a total of 8 scenarios are obtained.

As can be seen in Figure 7, each scenario is separated by the different ordering of the dependent values of the random variables at a specific scheduled time interval. That is, beginning from the starting node to the last node can be done on different paths. Each of these paths forms a scenario and the number of scenarios can be obtained as a result of multiplication of branch numbers from each node in each period. In a multi-period problem, the probability of any state is obtained by calculating the conditional probabilities of the path from the initial node to that node. At any decision stage, the sum of the probabilities of all nodes is 1.

The scenario tree is a logical structure that shows the variation of multivariate random variables over time. The nodes at each step of the scenario tree show the values of the connected random variables at the next period by means of branches out of the node. Namely, each node is associated with the next node following it (Topaloglou, 2004: 85).

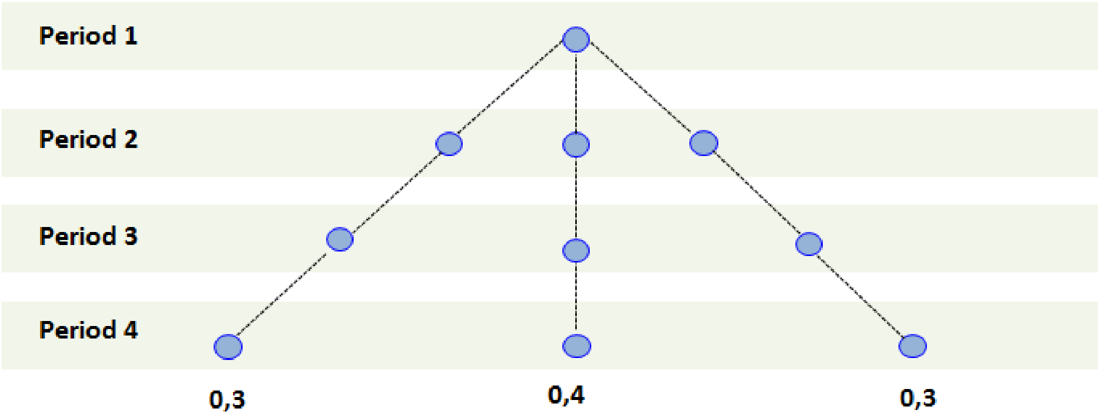

Figure 8. A Scenario tree example for one-stage SP

In the case of SP, the decision variables need to provide non-anticipativity. Scenarios use common information that is linked to a specific time period. This feature is defined as the independence of each decision variable in each stage. In other words, the first period decisions are independent of the second period scenarios. The future is uncertain and today's decisions are made without obtaining future information. Figure 8 shows an exemplary scenario approach taken into account for the SP model developed in this dissertation. The nodes in each period represents the weekly container demand for that scenario. As mentioned before, the weekly container demands of the scenarios are different from each other. However, the weights of the scenarios are the same every week. Depending on the scenarios, all the weekly demands will be affected by the decision variables in the other weeks. An approach in Figure 8 provides scenario reduction and facilitates solution of the ECR problem.

Scenario generation is one of the most critical phases of the modeling process. A set of generated scenarios should accurately describe the planning process and be consistent with real applications. Scenarios should be matched to SP theory and derived from historical, realistic data. This can be achieved by creating a large number of scenarios, but this affects the solvability of the model. Scenarios can be generated from a discrete distribution, from a continuous distribution calculated from historical data, from forecasting methods, historical data, as well as by participating in expert comments. Scenarios generated in SP are used to define the uncertainty model and to determine the algebraic structure of decision variables and constraints (Domenica et al., 2003).

4.2.3. Stochastic Programming Model for Empty Container Repositioning

One of the most challenging situations for the shipping companies is the uncertainty in container demands. A sudden increase in container demand can cause all plans to be overturned, as well as unanticipated costs. Moreover, the failure to meet container demands can also lead to customer losses. Therefore, the uncertainty or change in the container demands should be taken into consideration when making ECR plans. By considering the uncertainty in container demands, the unit ECR cost for each container type in each location will be more accurately calculated and reflected in the freight costs. When making the ECR plans, it is taken into account that the booking numbers in the first week, i.e. the container demands, are exactly known. For this purpose, three different scenarios were taken into consideration for weekly demand for each container type in the deficit locations after the first week in line with the needs of the shipping company examined in the dissertation. The shipping company uses a forecasting program where the weekly container demands are entered at the beginning of each month. If there are changes in the container demands, this change is updated in the second and third weeks of that month. These container demands are made according to the data of past weeks and the views of the company managers. Similarly, the probabilities of the scenarios were generated according to the discrete distribution of past data as well as the opinions of company managers. The managers' opinions were consulted about the seasonality effect and the possibility of realization of the bookings that set up container demands in that week. The discrete distribution was readily available from the business intelligence program that the shipping company uses, and was determined to be proportional to the frequency percentages of the container demands. Other assumptions are as the same as in the deterministic model.

<u>Sets:</u>

E= {1…|E|} set of the surplus locations- indexed by e.

D= {1…|D|} set of the deficit locations – indexed by d.

I= {1…|I|} set of the transportation connections between the locations – indexed by i.

T= {1…|T|} set of the container types – indexed by t.

W= {1…|W|} set of the weeks – indexed by w.

C= {1…|C|} set of the inventory levels – indexed by c.

S= {1…|S|} set of the scenarios – indexed by s.

Parameters:

C_{edit}: $transportation\ cost\ of\ an\ empty\ container\ type\ of\ t\ from\ location\ e\ to\ d\ via\ i,$
$e \in E, d \in D, i \in I, t \in T$

EC_{etc}: $weekly\ storage\ cost\ of\ an\ empty\ container\ type\ of\ t\ at\ location\ e,\quad e \in E, t \in T, c \in C$

DC_{dtc}: $weekly\ storage\ cost\ of\ an\ empty\ container\ type\ of\ t\ at\ location\ e,\quad d \in D, t \in T, c \in C$

F_{etw}: $number\ of containers\ of\ type\ t\ that\ can\ be\ sent\ out\ of\ location\ e\ in\ week\ w,$
$e \in E, t \in T, w \in W$

Y^{s}_{dtw} : $number\ of containers\ of\ type\ t\ that\ are\ needed\ at\ location\ d\ in\ week\ w\ for\ scenario\ s,$
$d \in D, t \in T, w \in W, s \in S$

Kap_{edi}: $total\ capacity\ of\ the\ connection\ i\ from\ location\ e\ to\ d,\ e \in E, d \in D, i \in I$

B_t: $Size\ of\ the\ container\ type\ t\ in\ terms\ of\ TEU,\ t \in T$

Z_{ediw}: $transportation\ time\ from\ location\ e\ to\ d\ via\ i\ in\ week\ w,\ e \in E, d \in D, i \in I, w \in W$

SQE_{ewc}: $total\ stock\ quantity\ in\ terms\ of\ TEU\ at\ location\ e\ for\ stock\ level\ c\ in\ week\ w\ for\ scenario\ s,$
$e \in E, w \in W, c \in C, s \in S$

SQD_{dwc}: $total\ stock\ quantity\ in\ terms\ of\ TEU\ at\ location\ d\ for\ stock\ level\ c\ in\ week\ w\ for\ scenario\ s,$
$d \in D, w \in W, c \in C, s \in S$

P^{s} : $probability\ of\ \ scenario\ s,\ s \in S$

Decision variables:

O^{s}_{editw}: $number\ of\ containers\ of\ type\ t\ sent\ from\ location\ e\ to\ d\ via\ i\ in\ week\ w\ for\ scenario\ s,$
$e \in E, d \in D, i \in I, t \in T, w \in W, s \in S$

G^{s}_{editw}: $number\ of\ containers\ of\ type\ t\ coming\ from\ location\ e\ to\ d\ via\ i\ in\ week\ w\ for\ scenario\ s,$
$e \in E, d \in D, i \in I, t \in T, w \in W, s \in S$

R^{s}_{etw}: $number\ of\ containers\ of\ type\ t\ remaining\ at\ location\ e\ in\ week\ w\ for\ scenario\ s,$
$e \in E, t \in T, w \in W, s \in S$

K^{s}_{dtw}: $number\ of\ containers\ of\ type\ t\ remaining\ at\ location\ d\ in\ week\ w\ for\ scenario\ s,$
$e \in E, t \in T, w \in W, s \in S$

$TC_{ewc}: \begin{cases} 1, if\ location\ e\ has\ stock\ level\ c\ for\ scenario\ s\ in\ week\ w, & e \in E, w \in W, c \in C, s \in S \\ 0, otherwise \end{cases}$

$IC_{dwc}: \begin{cases} 1, if\ location\ d\ has\ stock\ level\ c\ for\ scenario\ s\ in\ week\ w, & d \in D, w \in W, c \in C, s \in S \\ 0, otherwise \end{cases}$

Objective function:

$$\sum_s P^s \sum_t \sum_w [\sum_c [\sum_e R^s_{etw} * EC_{et} * TC^s_{ewc} + \sum_d K^s_{dtw} * DC_{dt} * IC^s_{dwc}] + \sum_e \sum_d \sum_i G^s_{editw} * C_{edit}]$$

Constraints:

$O^s_{editw} = G^s_{edit(w+z_{ediw})}$	$\forall\, e, d, i, t, w, s$	(1)
$\sum_e \sum_i G^s_{edit1} \geq Y^s_{dt1}$	$\forall\, d, t, s$	(2)
$\sum_e \sum_i G^s_{editw} + K^s_{dt(w-1)} \geq Y^s_{dtw}$	$\forall\, d, t, w \in \{2 \ldots \lvert W \rvert\}, s$	(3)
$K^s_{dt1} = \sum_e \sum_i G^s_{edit1} - Y^s_{dt1}$	$\forall\, d, t, s$	(4)
$K^s_{dtw} = \sum_e \sum_i G^s_{editw} - Y^s_{dtw} + K^s_{dt(w-1)}$	$\forall\, d, t, w \in \{2 \ldots \lvert W \rvert\}, s$	(5)
$\sum_t G^s_{editw} * B_t \leq Kap_{edi}$	$\forall\, e, d, i, w, s$	(6)
$\sum_d \sum_i O^s_{edit1} \leq F_{et1}$	$\forall\, e, t, s$	(7)
$\sum_d \sum_i O^s_{editw} \leq F_{etw} + R^s_{et(w-1)}$	$\forall\, d, t, w \in \{2 \ldots \lvert W \rvert\}, s$	(8)
$\sum_t K^s_{dtw} * B_t \leq \sum_c IC^s_{dwc} * SQD_{dwc}$	$\forall\, d, w, c, s$	(9)
$\sum_c IC^s_{dwc} \leq 1$	$\forall\, d, w, s$	(10)
$R^s_{et1} = F_{et1} - \sum_d \sum_i O^s_{edit1}$	$\forall\, e, t, s$	(11)
$R^s_{etw} = F_{etw} - \sum_d \sum_i O^s_{editw} + R^s_{et(w-1)}$	$\forall\, e, t, w \in \{2 \ldots \lvert W \rvert\}$	(12)
$\sum_t R^s_{etw} * B_t \leq \sum_c TC^s_{ewc} * SQE_{ewc}$	$\forall\, e, w, c, s$	(13)
$\sum_c TC^s_{ewc} \leq 1$	$\forall\, e, w, s$	(14)
$O^s_{editw}, G^s_{editw}, R^s_{etw}, K^s_{dtw} \in Z$	$\forall\, e, d, i, t, w, s$	(15)

$TC^{s}_{ewc}, IC^{s}_{dwc} \in \{0,1\}$ $\qquad \forall\ e, d, w, c, s \qquad (16)$

The objective function minimizes the total ECR costs for all scenarios in the four-week period. Constraint set (1) indicates for each scenario s when the empty containers' type of *t* that are sent from location *e* via connection *i* will be in location *d*. Constraints (2) and (3) ensure that all the weekly demands of each type of container *t* for each scenario *s* in each deficit location *d* must be covered. Constraint sets (4) and (5) show the number of empty containers for each type of *t* left in deficit location *d* in each week for scenario *s*. Constraint (6) guarantees that the total number of TEUs of empty containers in each week to be transported from surplus location *e* to deficit location *d* for each scenario *s* cannot excess the capacity of connection *i*. Constraints (7) and (8) ensure that each surplus location *e* cannot send more empty containers type of *t* for each scenario *s* than existing containers in this location in each week. Constraint (9) showes the weekly stock level for each scenario *s* in each deficit location *d* in terms of TEU. Constraint (10) ensures that each deficit location *d* will have one stock level for each scenario *s*. Constraint sets (11) and (12) show the number of empty containers for each type of *t* left in surplus location *e* in each week for scenario *s*. Constraint (13) show the weekly stock level for each scenario *s* in each surplus location *e* in terms of TEU. Constraint set (14) indicates that each surplus location *e* will have one stock level for each scenario *s*. Constraints (15) and (16) represent the range of decision variables.

4.3. Numerical Experiments

All the mathematical models in the dissertation were developed for real life applications in container shipping. That is, although the models are theoretically seen, they have been formulated to best reflect the real life practices. In this regard, the development of the costing models and mathematical programming models can be regarded as an application. However, it is also important how the models provide solutions and results with the real data. For this purpose, the models were tested with the real data of the shipping company examined in the dissertation. Because the total of 8 weeks from the first and last weeks in a one-year data of the shipping company were not clear, they have not been used for the numerical experiment. Numerical results for the models are shown separately below.

4.3.1. Numerical Results for the Mixed-Integer Linear Programming Model

Experimental studies were carried out to measure the applicability and effectiveness of the MILP model. The proposed model was solved with the 44 weeks of data of the shipping company. The solutions were compared with the ECR plans made and implemented by the shipping company in terms of cost efficiency and solution time. The experimental studies are carried out via IBM ILOG CPLEX 12.6 on a computer of Intel(R) Core(TM) i5-4210U CPU 2.40 Ghz processor - 4 GB RAM. IBM ILOG CPLEX 12.6 is a commercial optimization solver based on the Simplex Algorithm. It is a frequently used software in the literature, and has a very useful interface as well as the coding process is very easy. The encoding of the MILP model in the CPLEX software is shown in Appendix A.1. The first data set entered in CPLEX software is shown in Appendix A.2.

A total of 11 data sets were tested since the MILP model covers a period of 4 weeks. There are 19 locations in each data set. The weekly full container import and export numbers in these locations may vary. There are 4 export dominant locations, and 20DV, 40VD and 40HC containers must be sent to meet the weekly container demand in these locations. The other 15 locations are import dominant locations in terms of full 20DV, 40DV and 40HC containers, and the surplus empty containers are sent to the export dominant locations from these locations. As already mentioned before, there are more than one transportation providers between the locations, and the capacities and prices of the transportations are different. According to shipping company's policy, some of the surplus containers at these import dominant locations are sent out of the region. Therefore, these surplus empty containers that are sent out of the region are not considered in the experimental studies.

Table 6 shows the solution times of the data sets. Each problem data has 3884 constraints, 190 binary and 5685 integer variables out of 5876 variables. As can be seen, the longest solution time is 6,61 CPU seconds. So the MILP model solves the real-life problems very quickly. The first data set entered in CPLEX software is presented in Appendix A.2. The comparison of the results of the MILP with real life applications is given in Table 7.

Table 6. Computational solution time of the data sets with MILP model

Data set	CPU	Real time
1	6,50 seconds	6,03 seconds
2	3,83 seconds	4,36 seconds
3	4,77 seconds	5,50 seconds
4	4,19 seconds	4,79 seconds
5	3,42 seconds	3,98 seconds
6	6,17 seconds	6,81 seconds
7	5,52 seconds	6,10 seconds
8	3,94 seconds	4,47 seconds
9	3,26 seconds	3,88 seconds
10	4,56 seconds	5,19 seconds
11	6,61 seconds	7,24 seconds

Table 7. Comparison of the MILP model solution with the real-life applications

Data set	MILP Model (Total ECR costs in USD)	Shipping company's application (Total ECR costs in USD)	Improvement
1	189237	207425	8,76 %
2	177565	183294	3,12 %
3	167738	171190	2,01 %
4	185412	194853	4,84 %
5	186290	196084	4,99 %
6	179424	185412	3,22 %
7	194325	202770	4,16 %
8	174606	184920	5,57 %
9	185553	198366	6,45 %
10	168506	177934	5,29 %
11	212169	221147	4,05 %

As Table 7 shows, MILP model solutions provide up to 8,76 % cost savings over real life applications. Although the model's improvement rate is low, it can be said that it has improved the decisions significantly taking into account the total cost of hundreds of thousands of dollars. In real-life applications, plans are updated everyday and every week so that better decisions can be made in the direction of more up-to-date information and data. The developed MILP model can also be used in this way. Namely, if the model is thought to be run dynamically on a daily or weekly basis, it would provide better results depending on the more current data. Consequently, the implementation of the MILP model will enable logistics and operations departments of the shipping companies to make faster and more accurate ECR plans.

Table 8 shows the empty container surpluses and deficiencies in the locations in the first week for data set 1. While the *D* locations indicate the deficit locations, *S* locations show the surplus locations. The numbers indicated by minus shows the number of empty containers required in the first week for that type of container in the deficit locations. Cells marked only with a minus sign indicate that there exist an import/export balance for that container type in the locations, and the plus numbers represent the maximum number of empty containers that can be sent from surplus locations in the first week.

Table 8. Empty container situation of the locations in the first week of the data set 1

Locations	20DV	40DV	40HC
D_1	-50	-5	-10
D_2	-80	-	-
D_3	-40	-5	-20
D_4	-100	-5	-30
S_1	25	10	30
S_2	20	5	15
S_3	60	10	30
S_4	60	10	50
S_5	20	10	30
S_6	5	-	10
S_7	15	-	15
S_8	60	-	20
S_9	40	15	25
S_{10}	50	10	30
S_{11}	10	5	20
S_{12}	25	20	20
S_{13}	30	10	20
S_{14}	10	-	10
S_{15}	15	5	10

Table 9 demonstrates the ECR plans obtained with the MILP model for the first week of the data set 1. *C* denotes the transportation connections between the locations. Different numbers and types of containers are supplied from different surplus locations with different connection options depending on the vessel capacities, transportation costs, and empty container numbers in surplus locations. The transportation costs between the locations can be different from each other, and these costs also change according to the connection type. All this leads to the formation of different unit ECR costs for different types of containers in each location.

Table 9. ECR plans for the first week of the data set 1 solved by MILP model

Location	S_1	S_2	S_3	S_4	S_5	S_6	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	Transportation Connection	Container Type
D_1															C_1	20DV
				35					5	10					C_2	
												10			C_1	40DV
												10			C_1	40HC
												10			C_2	
D_2				2	13							10		15	C_1	20DV
								10				20	10		C_2	
D_3	15								25						C_1	20DV
										1					C_1	40DV
	2											2			C_2	
										14					C_1	40HC
										6					C_2	
D_4						5	5								C_1	20DV
	10	20	60												C_2	
	5														C_2	40DV
						7									C_1	40HC
			5								15				C_2	
	20														C_3	

In addition to transportation costs, storage costs also affect the decisions about ECR. Table 10 shows the number of empty containers left in each location in the first week for the data set 1. Depending on the storage costs in the locations and container demands in the following weeks, different number of containers remained in the locations. For example, as it is known that they will be used in the following weeks, more 40HC containers are sent to deficit locations D_1, D_3 and D_4 than needed in the first week. Like the transportation costs and number of empty containers repositioned, storage costs and number of empty containers stored also affect the unit cost of ECR for each location and container type.

Table 10. Number of empty containers remaining in the locations in the first week for data set 1 solved by MILP model

Location	20DV	40DV	40HC
D_1	-	5	10
D_2	-	-	-
D_3	-	-	8
D_4	-	-	17
S_1	-	3	10
S_2	-	5	15
S_3	-	10	25
S_4	23	10	50
S_5	7	10	30
S_6	-	1	3
S_7	15	2	15
S_8	55	5	20
S_9	-	10	25
S_{10}	20	10	30
S_{11}	-	-	-
S_{12}	-	20	5
S_{13}	-	-	-
S_{14}	-	-	2
S_{15}	-	5	10

Table 11 shows the unit ECR costs for each container type and how these costs should be interpreted when full imports come to the locations in the first week for the data set 1. The unit cost for each location and container type was found by using the costing models in Chapter 3. When calculating the unit ECR costs, container handling costs such as THC and lift on/off costs are also taken into account. The positive numbers for surplus locations exhibit the unit ECR costs of full import containers that would arrive in these locations within the first week. In other words, ECR costs will be incurred because the full containers that are imported to these locations will be repositioned to other locations after being emptied. Therefore, these costs should be added to the freight price of full import containers coming to those locations. The numbers indicated by minus for deficit locations exhibit the unit ECR imbalance costs of full import containers that would arrive in these locations within the first week. These ECR imbalance costs will be incurred because empty containers will be repositioned to these locations to cover the demand. Therefore, these costs should be substracted from the freight price of full import containers coming to these locations in the first week. In other words, these costs can be reflected as a bonus to the freight prices. So, instead of sending an empty container to this location to meet the demand, the shipping company can save this cost by making a full import to this location as the container will definitely be reused once it is empty. The minus sign in deficit location D_2 shows that there is a balance for 40DV and 40HC container types in this location.

Table 11. Unit ECR costs for full import containers coming to the locations in the first week for data set 1 solved by MILP model

Location	20DV	40DV	40HC
D_1	-97	-125	-105
D_2	-74	-	-
D_3	-116	-115	-197
D_4	-112	-108	-137
S_1	103	267	273
S_2	130	224	209
S_3	93	91	85
S_4	164	215	220
S_5	58	116	110
S_6	133	217	216
S_7	114	246	238
S_8	81	173	158
S_9	224	320	311
S_{10}	267	397	402
S_{11}	110	122	106
S_{12}	56	211	162
S_{13}	195	308	300
S_{14}	124	269	275
S_{15}	75	119	113

Table 12 shows the unit ECR costs for each container type and how these costs should be interpreted when full exports are carried out of the locations in the first week for the data set 1. These costs were also obtained with the models introduced in Chapter 3. The positive numbers for deficit locations exhibit the unit ECR costs of full export containers that would be carried out of these locations within the first week. The ECR costs will be incurred because the empty containers from surplus locations will be repositioned to these locations to meet the demand. Therefore, these costs should be added to the freight price of full export containers to be carried out of these locations. The numbers indicated by minus for surplus locations demonstrate the unit ECR imbalance costs of full export containers that would be carried out of these locations within the first week. These unit ECR imbalance costs will be incurred because surplus empty containers will be sent to deficit locations from these locations. Therefore, these costs should be substracted from the freight price of full export containers carrying out of these locations in the first week. These unit ECR imbalance costs can be reflected as a bonus to the freight prices. More specifically, instead of sending an empty container to a deficit location, the shipping company can save this cost by making a full export from the surplus location. The unit ECR costs for 40DV and 40HC containers in the location D_2, where an import/export balance exists, consist of the transportation costs between depot and terminal, the lift on/off costs and the storage costs at terminal and depot. These costs are quite low, but they affect the freight price decisions of the shipping company when making a full export from this location.

Table 12. Unit ECR costs for full export containers to be made from the locations in the first week for data set 1 solved by MILP model

Location	20DV	40DV	40HC
D_1	112	147	129
D_2	95	18	23
D_3	132	129	215
D_4	126	117	160
S_1	-92	-250	-264
S_2	-114	-206	-191
S_3	-79	-77	-64
S_4	-153	-201	-198
S_5	-44	-95	-93
S_6	-120	-202	-208
S_7	-99	-228	-216
S_8	-65	-157	-140
S_9	-209	-307	-193
S_{10}	-251	-374	-380
S_{11}	-96	-105	-94
S_{12}	-40	-202	-147
S_{13}	-182	-295	-284
S_{14}	-115	-252	-259
S_{15}	-62	-104	-101

Table 13 and Table 14 show the unit ECR costs of the locations in the second week for data set 1 and how these costs should be added to or subtracted from the freight price. In other words, while the unit ECR costs indicated with positive numbers will be added to the freight price, the unit ECR costs shown with minus will be substracted from the freight price. Although the difference between the unit costs in the first week and the second week is not very large, the effect of the unit costs on the total freight costs will be high considering that container shipping is a two-sided trade and thousands of containers are carried every week. In particular, as the unit ECR costs of the two locations subject to the freight price reach hundreds of dollars, the decision to accept or reject the cargo will be directly affected. In this respect, the weekly calculation of ECR costs in each location allows to offer more accurate freight price and ensures that profit and loss analysis is done correctly.

Table 13. Unit ECR costs for full import containers coming to the locations in the second week for data set 1 solved by MILP model

Location	20DV	40DV	40HC
D_1	-104	-143	-129
D_2	-68	-	-
D_3	-109	-134	-211
D_4	-105	-	-127
S_1	114	253	265
S_2	144	221	217
S_3	84	98	81
S_4	176	228	212
S_5	67	128	103
S_6	145	203	225
S_7	132	223	234
S_8	96	163	142
S_9	213	341	328
S_{10}	243	379	412
S_{11}	123	107	118
S_{12}	67	219	155
S_{13}	179	316	317
S_{14}	136	284	261
S_{15}	68	108	128

Since the demmurrage, detention and drop off costs of the shipping company could not be reached, these costs have not been taken into account in the allocation of ECR costs. However, as these cost items, which are included in the costing models introduced in Chapter 3, have no effect on the MILP model, can be conveniently used for the cost allocation as well.

Table 14. Unit ECR costs for full export containers to be made from the locations in the second week for data set 1 solved by MILP model

Location	20DV	40DV	40HC
D_1	119	165	143
D_2	82	-	-
D_3	124	156	229
D_4	116	27	144
S_1	-102	-234	-247
S_2	-128	-205	-196
S_3	-71	-82	-63
S_4	-155	-212	-193
S_5	-50	-109	-86
S_6	-124	-187	-208
S_7	-117	-203	-211
S_8	-79	-148	-123
S_9	-189	-323	-308
S_{10}	-224	-362	-394
S_{11}	-105	-184	-97
S_{12}	-53	-204	-138
S_{13}	-161	-294	-302
S_{14}	-118	-268	-245
S_{15}	-53	-92	-115

4.3.2. Numerical Results for the Stochastic Programming Model

As mentioned earlier, the SP model considers three different scenarios for weekly demand of each deficit location and three container types. The demand quantities and probabilities in these three scenarios were taken from the shipping company's business intelligence program. The experimental studies for the SP model were also carried out via IBM ILOG CPLEX 12.6 on the same computer. The encoding of the SP model in the CPLEX software is shown in Appendix A.3. The data except for the demands are exactly the same as the data used in the MILP model. For the SP model, the first data set entered in CPLEX software is shown in Appendix A.4.

Table 15 shows the solution times of the data sets. Each problem data has 11458 constraints, 570 binary and 17055 integer variables out of 17626 variables. As can be seen, the increase in the number of scenarios in the demands has also enlarged the problem size and extended the solution time significantly.

Table 15. Computational solution time of the data sets with SP model

Data set	CPU	Real time	Optimality gap
1	46,50 seconds	48,04 minutes	Exact solution
2	2957,51 seconds	49,28 minutes	Exact solution
3	73,01 seconds	1,23 minutes	0,10%
4	2515,76 seconds	40,33 minutes	0,10%
5	481,11 seconds	9,33 minutes	0,10%
6	1040,59 seconds	18,41 minutes	0,10%
7	355,34 seconds	8,23 minutes	0,10%
8	119,27 seconds	2,01 minutes	Exact solution
9	100,08 seconds	1,41 minutes	Exact solution
10	197,25 seconds	4,56 minutes	0,10%
11	121,98 seconds	2,3 minutes	0,10%

Depending on the difficulty of the problems in the data sets, some problems have exact solutions within a few minutes, while the computational time of some exact solutions have exceeded 14 hours in real time. When these solution results were examined, it was noticed that there was no significant improvement in the objective function after one hour. For this purpose, a 0,1 % gap is set for the data sets that take more than one hour for the optimal solution. This 0,1 % is the optimality gap or the distance from the possible optimal solution to the problem. This indicates that there might be a better result of 0,1 %. Accordingly, the optimal solution for any data set which have a 0,1 % gap will not be less than a few hundred of dollars of the total cost. All of the SP model solutions give essentially better results than real life applications of the shipping company.

As Table 16 shows, the SP model solutions provide up to 2,99 % cost savings over real life applications of the shipping company. Like the MILP model, if the SP model is thought to be run dynamically on a daily or weekly basis, it would also provide better results depending on the more current data. The comparison of the MILP model’s and the SP model’s results is given in Table 17.

Table 16. Comparison of the SP model solution with the real-life applications

Data set	SP Model (Total ECR costs in USD)	Shipping company's application (Total ECR costs in USD)	Improvement
1	201203,9	207425	2,99 %
2	181706,4	183294	0,86 %
3	167911,2	171190	1,91 %
4	192239,4	194853	1,34 %
5	192454,1	196084	1,85 %
6	183921	185412	0,8 %
7	197070	202770	2,81 %
8	182803,5	184920	1,14 %
9	195223,2	198366	1,58 %
10	172884,2	177934	2,83 %
11	216860,6	221147	1,93 %

Table 17. Comparison of the MILP and SP model

Data set	MILP	SP	EVPI
1	189237	201203,9	11966,9
2	177565	181706,4	4141,4
3	167738	167911,2	173,2
4	185412	192239,4	6827,4
5	186290	192454,1	6164,1
6	179424	183921	4497
7	194325	197070	2745
8	174606	182803,5	8197,5
9	185553	195223,2	9670,2
10	168506	172884,2	4378,2
11	212169	216860,6	4691,6

As expected, the SP model solutions gave higher results than the MILP model. In other words, since the uncertainties in demands have been taken into consideration, the costs have increased in order to reduce the risk of meeting the demands. The difference between the MILP model and SP model is quite low since the shipping company keeps its demand forecasts high. Indeed, it was observed that the shipping company has a tendency to make choices that are close to the worst possible scenario for meeting the container demands. This has resulted in higher costs with the MILP model. In fact, the MILP model may provide lower results if the shipping company considers a more moderate value in meeting the container demands in the deficit locations. This would further increase the differences in results between the MILP model and the SP model.

The difference between the MILP model and the SP model is called the Expected Value of Perfect Information (EVPI). It can be considered as the monetary value of information (Birge and Louveaux, 1997: 139). That is, the shipping company would be willing to pay this amount of EVPI to learn the information of container demands when making ECR plans. Because the shipping company's plans for real-life applications do not accurately estimate the container demands, the containers that are sent more than the weekly demand cause extra transportation and storage costs. In the SP model, the tendency to send extra containers is prevented because both the transportation connections between the two locations and the number of containers remaining in each location also depends on the scenarios. Namely, since the SP model includes the uncertainties in container demands and gives better information, it ensures the ECR plans at a lower cost. In other words, the shipping company can at best minimizes its expected ECR costs by solving the SP model.

Since there is no uncertainty in the container demands of the first week for the SP model, the solutions of the SP model and the MILP model are the same. Therefore, the solutions of the first week for data set 1 are not shown. Table 18 and Table 19 show the unit ECR costs of the locations in the second week according to the solution of SP model for data set 1. Positive and negative numbers show how these costs should be added to or subtracted from the freight price. The cost allocation of the SP model results were also made according to the costing models introduced in Chapter 3. This time, however, the costing models were used separately for each scenario. Costs calculated separately for each scenario were multiplied by the weight of each scenario to find the average unit ECR costs. Thus, the uncertainty in container demands was also reflected in the unit ECR costs. As the total costs found with the SP model are higher than those of the MILP model, the unit ECR costs are generally higher as well. Nevertheless, depending on the demands and weights of the scenarios the unit ECR costs for some container types are lower in some locations. For example, the unit ECR imbalance cost for 20dv and 40HC containers in the deficit location D_1 was found to be lower in cost allocation with SP model solution.

The deterministic consideration of container demands may change both the total ECR costs and the unit ECR costs in the direction of container demand that may change over the following weeks. This will cause the unit ECR costs to be incorrectly reflected in the freight price and the profit/loss analysis not to be done correctly. Consequently, as SP considers the uncertainty in container demand, it can be used as a hedging strategy to determine the unit ECR costs and to see the impact on the freight price by allocation of the costs that will arise depending on ECR operations.

Table 18. Unit ECR costs for full import containers coming to the locations in the second week for data set 1 solved by SP model

Location	20DV	40DV	40HC
D_1	-101	-152	-125
D_2	-74	-	-
D_3	-102	-138	-218
D_4	-109	-	-132
S_1	123	246	270
S_2	141	226	211
S_3	92	95	87
S_4	167	231	217
S_5	73	124	109
S_6	142	196	234
S_7	135	228	232
S_8	91	170	147
S_9	216	337	331
S_{10}	254	373	409
S_{11}	119	112	115
S_{12}	74	224	146
S_{13}	183	319	313
S_{14}	144	280	266
S_{15}	75	101	133

Table 19. Unit ECR costs for full export containers to be made from the locations in the second week for data set 1 solved by SP model

Location	20DV	40DV	40HC
D_1	124	158	147
D_2	78	-	-
D_3	121	163	225
D_4	124	22	152
S_1	-113	-230	-244
S_2	-136	-198	-194
S_3	-77	-85	-60
S_4	-159	-204	-197
S_5	-54	-103	-89
S_6	-128	-185	-211
S_7	-115	-208	-223
S_8	-74	-151	-127
S_9	-196	-320	-312
S_{10}	-233	-356	-388
S_{11}	-114	-180	-95
S_{12}	-58	-207	-141
S_{13}	-166	-289	-306
S_{14}	-122	-263	-249
S_{15}	-58	-93	-106

4.4. Chapter Summary

One of the initial objectives of container shipping companies is to minimize the total ECR costs. This chapter introduced two optimization models which minimize the total ECR costs in container liner shipping. The first model is a MILP model that minimizes the ECR cost assuming that the weekly container demands are exactly known, as in other parameters and variables. The second model is a SP model which takes into account the uncertainties in container demands.

The MILP model is similar to many mathematical programming models in the literature, but it also includes different types of containers that have been taken into consideration only in a few articles. Moreover, unlike other studies in the literature, the model also takes into account the incremental stock level applied in many container terminals in real life. It has been proven that the MILP model provides improvements up to 8,76 % compared to life applications. The comparison made is based on the shipping company's practices which was examined in the dissertation. If the shipping company were to use the MILP model for its all ECR applications, much better results would have been possible as well.

The results of the MILP model were combined with the costing models presented in Chapter 3, and for the first and second week of data set 1 the unit ECR cost for each location and container type was presented. It was also revealed how these costs should be interpreted when offering freight price for full containers according to the imports and exports to be made in locations where the shipping company's data were examined.

The SP method gives much more robust results when there are uncertainties in some parameters and decision variables. The SP model presented in this chapter includes three possible scenarios for the container demands in the deficit locations in the second, third and fourth week. This has enlarged the problem size and extended the computational solution times. Nevertheless, the solutions of the SP model provided better results for the real-life applications within a reasonable computational time. This chapter also demonstrated how the ECR costs obtained with the SP model can be allocated according to the location and the container type with the costing models presented in Chapter 3. The allocation of ECR costs based on the SP model results are more accurately reflected in the freight prices as it provides more robust unit ECR costs.

5. CHAPTER
CONCLUSION

This dissertation examines the ECR operations in container liner shipping. It focuses on cost management and optimization of ECR. The costing models presented in the dissertation provides not only the calculation and allocation of the ECR costs, but also shows how these costs should be interpreted when offering freight rates. The mixed-integer linear programming (MILP) and stochastic programming (SP) models presented in the dissertation ensure better empty container distribution plans. It is also revealed that MILP and SP models can be combined with costing methods and applied very well to applications in container liner shipping.

5.1. Summary and Contribution of the Dissertation

The globalization of the world economy has significantly increased the circulation of goods on the world. This has further increased the demand for maritime transportation. As it is in other industries, maritime transportation industry is highly influenced by developing technology and users' demands. Containerization has become one of the most important technological developments that accelerate the globalization. Namely, the demand for container shipping has increased as a result of globalization tendency, but it has also become one of the most important factors affecting globalization. Besides, the imbalances in world trade affect container traffic and leads to commercial differences in many locations resulting with imbalances in the number of containers. While the empty containers are accumulated in the locations where there are many imports, there is a need for containers in the locations where there are a lot of exports. Storage, transportation and handling of the empty containers cause high costs for shipping companies. Likewise, worldwide total ECR costs reach billions of dollars. On the other hand, other than the commercial imbalances, because of the high competition in the container shipping industry, shipping companies focus on specific trade routes depending on their resources, strengths and customer portfolio. Namely, shipping companies head to reposition empty containers in accordance with their strategy or pricing policy eventhough they are able to find full cargo from many import dominant locations. Furthermore, empty containers are needed for the vessel utilization to some extent. In other words, almost every container vessel carries at least some empty containers to utilize its capacity in terms of TEU or due to stowage reasons. This is a typical application of many big shipping lines on their own vessels. Eventually, ECR is unavoidable in container shipping. The important thing is to carry out with the lowest cost of ECR and the most accurate cost management system. In this respect, the dissertation topic has a special significance in terms of originality.

Logistics has become a significant cost item for the companies in many industries. Through logistical activities, companies have the opportunity to make competitive advantage against their competitors. ECR is the main logistics activity in container shipping. Although ECR does not add value to the customers, shipping companies can provide competitive advantage to its rivals through cost reduction and freight pricing. Indeed, reducing the ECR costs is one of the first goals of all the shipping companies. That is why most of the studies in the literature have focused on minimizing the ECR costs. Nevertheless, this is not enough, because the ECR costs need to be analyzed and allocated accurately according to the locations and container type. This requires very careful and detailed empty container operations follow-up and advanced MIS softwares.

The third chapter of the dissertation deals with the ECR operations and costs in liner shipping. It demonstrates all the ECR operations and costs of a shipping company using third party service providers in a specific region. According to the analysis' of the ECR costs and operations in each location in that region, company's resources, activities, cost drivers are determined, and costing models are introduced in that chapter. The costing models calculate the weekly unit ECR cost of each container type in each location. Moreover, the unit imbalance cost, which is caused by import and export differences, can also be calculated with the costing models. The costing models clearly show which operations originate the costs that occur in a location. Since the ECR costs constitute a part of the freight costs, shipping companies should also consider the ECR costs when offering freight prices. Accordingly, shipping companies should take into account the empty container situation in the POL and POD that are subject to the freight price. The costing models also reveal how the unit ECR costs should be interpreted when offering a freight rate between two locations on the service routes depending on the commercial situation. Consequently, it is very obvious that unnecessary and gainless ECR can be easily prevented by the shipping companies. Although container shipping is a very convenient area for cost management and accounting researches, no single study has been done on this subject in the literature. In this regard, the costing models developed in the third chapter provide the initial contribution to the literature in this field.

The fourth chapter of the dissertation introduces the MILP model and the SP model which deal with the distribution of available scarce resources in an efficient way to minimize the ECR costs. The MILP model addresses the ECR problem from a deterministic perspective and has provided cost savings of up to 8,76 %. The computational solution time of the SP model, which has a lot of decision variables and constraints, is quite long. Taking into account the fact that 4-week plans are made, it was observed that the solutions of the SP model provide up to 2,99 % better results than real-life applications in a reasonable computational time.

The tendencies direct the decisions in real-life applications. The shipping company, whose data were analyzed, has a tendency to meet the container demand at the highest possible number which leads to higher ECR costs. Therefore, scenarios involving more realistic values need to be taken into account when estimating the weekly container demand. It has also been found that models with accurate prediction of demand and multiple possibilities give more robust results in ECR plans. This provides even more accurate costing and pricing opportunities for the shipping company.

In summary, the dissertation provides a significant concrete contribution to the following aspects:

- Providing detailed information on ECR activities and costs made before and after the full container shipping service.
- Obtaining better ECR plans.
- Ensuring that ECR between locations can be tracked more easily on weekly basis and container type basis.
- Showing how much the ECR activities consume company’s resources.
- Allowing the cost allocation with more accurate cost drivers to the ECR costs.
- Providing more efficient budgeting by interpreting the results and data obtained through the use of models.
- Allowing more accurate ECR cost analysis.

- Observing which shipping routes and services are more profitable depending on the ECR costs.

5.2. Discussion

Management and analysis of the costs in the companies is far more than cost accounting techniques. It is necessary to establish a correct and robust cost system in a company by coming together with many departments such as accounting, operations, logistics, marketing and sales. A decision in container shipping concerns all the departments in a shipping company, as it can affect many operations, costs and the quality of the transportation service. Although empty container operations are mostly under the responsibility of the logistics or equipment departments in the shipping companies, their operations costs are directly affected by the contracts of the marketing and management departments, and the applications of the ship operations departments. On the other hand, ECR decisions also affect the implementation of all these departments. In particular, the sales departments which are responsible for issuing the freight prices, and the finance and accounting departments analyzing the payments and cash flow, are directly influenced by the ECR and costs. This means that ECR costs must be reviewed across the entire company and other decisions must be made accordingly.

The costing models developed in the third chapter can be used by all the departments within the container shipping companies. Although these models appear to be developed for operational decisions, they can also be used for tactical and strategic decisions in container liner shipping. Eventhough the costing models calculate the weekly unit ECR costs, these costs will change continously according to the number of empty containers depending on the two-way full container flow in the locations. Therefore, the costing models and mathematical programming models have to be dynamically re-run.

Documentation, agency and tax fees can be different in every country and therefore in many locations. In the costing models, no extra variables were set for these cost. Since the shipping company examined in the dissertation did not record these costs, they were not taken into account in the numerical data in the dissertation. However, these costs can be shown in the operations costs related to ECR. As mentioned in the third chapter, shipping companies make money from container demmurage and drop-off fees. Since these data were not available, these costs were also not taken into consideration in the numerical examples. Nevertheless, they are shown in the costing models and can be easily applied in real-life practices. The two most important cost items that are not included in the models are the depreciation and leasing cost of the container. These costs were not taken into account because they were sunk costs and would not affect the operational decisions and freight rates in the short run.

As the shipping company's longest transportation service lasts four weeks, the mathematical programming models cover a four-week period in order to see the weekly unit ECR costs ain the locations. If the goal were to make only the lowest cost ECR plan, the mathematical models could be run instantaneously for only one period. In this way, the cost minimization problems can be solved faster. However, in this case the unit ECR cost in the following weeks can not be estimated correctly. This would make it inconsistent whether the freight price is profitable or not. Operations and costs can be tracked in more detail if the models take into account daily periods rather than weekly. In particular, storage costs will be calculated more accurately. But this would increase the computational time of the solutions and also make cost allocation difficult.

With the models developed in this dissertation, by focusing on a shipping company in a specific region, efficient management of the ECR and costs in container liner shipping were revealed. As the ECR operations in liner shipping are usually the same, the models can be tested and applied with different data. The purpose of the dissertation is essentailly to develop a system for empty container management of the shipping companies rather than examining the data. In this regard, the models in the dissertation can be used by all container shipping companies as a DSS. In particular, since the vessel sharing agreements are very popular nowadays, the use of models is even more prominent. Because shipping companies use other companies' vessels in the vessel sharing applications, they have the similar ECR practices that are presented in the costing models. Furthermore, freight forwarders and non-vessel operating common carriers (NVOCCs), which provide container shipping services in large quantities and do not have their own vessels, are also able to use these models directly. The shipping companies that use their own vessels can also implement these models, but they must identify and analyze the vessel operation costs in detail. Thus, they can calculate the unit ECR costs by placing the maritime transportation costs already existing in the costing models. The same applies to the shipping companies with their own trucks. These companies can also directly set the costs of land transportation by determining the fuel and labor costs spent on the transportation of empty containers by truck.

5.3. Future Research

ECR management is a very attractive research area. Besides the optimization models for ECR, this dissertation presented costing models for ECR costs in liner shipping which have not been studied in the literature. The models developed in the dissertation show the effects of the costs in making ECR plans, and how these costs are analyzed and will affect the freight price according to these ECR plans. The models also allow accurate and easy tracking of ECR costs on a weekly basis for different container types in all locations where transportation services provided. Nevertheless, this study can be expanded from different aspects.

As mentioned in the previous discussion section, the shipping companies carrying empty containers on their own vessels should analyze the maritime transportation costs according to their destination by taking vessel operation costs into account. The finding of unit maritime transportation cost of an empty container according to vessel operation costs will also provide the presence of full container transportation unit cost. This will provide a much more accurate and comprehensive cost analysis and will reveal almost all the cost items at freight cost. Moreover, the mathematical programming models can be transformed into vessel routing problems by taking into account full containers in order to make better decisions. With the mathematical programming models to be formulated in this respect, the unit ECR cost with the shadow price can be evaluated more easily. This will also provide a more powerful DSS for the shipping companies. From this standpoint, the models in the dissertation can be improved in this direction.

For the SP model in the fourth section, the number of scenarios in container demand in the locations can be increased. This will lead to prolongation of the computational solutions of the problems and also make it difficult to calculate the unit ECR costs in the locations. However, more robust results can be obtained on total and unit ECR costs. The SP model in the fourth chapter only takes into account the uncertainty in the container demands. In fact, there are other uncertainties in the container shipping industry such as vessel arrival times and number of containers returning from the customers. The models taking these uncertainties into consideration will provide much more robust ECR plans. Moreover, dynamic programming approach can also be a method for solving the ECR problem. In particular, dynamic programming models will provide better solutions when weekly container flow change. Accordingly, this will also ensure more accurate cost allocation depending on the changes in the number of containers in each location.

The mathematical programming models can be expanded to be formulated as multi-objective optimization problems. For example, the total ECR costs can be an objective function, while the amount of container stock in each location can be another. This will give the decision makers more solution options depending on the commercial flow and various constraints. The mathematical programming models can also be developed by including other parameters such as considering the cost of losing the clients or having backlog, but a very preliminary analyses will be required to estimate these costs.

REFERENCES

Akyüz, M.H. & Lee, C.Y. (2016). Service type assignment and container routing with transit time constraints and empty container repositioning for liner shipping service networks, *Transportation Research Part B: Methodological*, 88, 46-71.

Baird, A. J. (2015). Logistics strategy in container shipping. In Maritime Logistics: A Guide to Contemporary Shipping and Port Management (2nd ed.) (171-192), London: Kogan Page Limited.

Bandeira, D.L., Becker, J.L. & Borenstein, D. (2009). A DSS for integrated distribution of empty and full containers, *Decision Support Systems*, 47, 383-397.

Baykasoğlu, A. & Kaplanoğlu, V. (2008). Application of activity based costing to a land transportation company: A case study, *Int. J. Producion Economics*, 116, 308-324.

Beale, E.M.L. (1955). On Minimizing A Convex Function Subject to Linear Inequalities, *Journal of the Royal Statistical Society*, 17, 1955, 173–184.

Becker, J., Görke, M., Felix, C. & Schmidt, M. (2016). Model-based potential analysis of the distribution logistics, *Production Planning & Control*, 27(9), 698-707.

Bensghir, T.K. (1996). Information technology and organizational change, *TODAE Publications*, Ankara.

Birge, J.R. & Louveaux, F. (2011). *Introduction to Stochastic Programming*, Second Exdition, New York, Dordrecht, Heidelberg, London: Springer.

Boyd, L.H. & Cox, J.F. (2002). Optimal decision making using accounting information, *International Journal of Production Research*, 40 (8), 1879-1898.

Braekers, K., Janssens, G.K. & Caris, A. (2011). Challenges in Managing Empty Container Movements at Multiple Planning Levels, *Transport Reviews*, 31 (6), 681-798.

Caris, A., Macharis, C. & Janssens, G.K. (2008) Planning Problems in Intermodal Freight Transport: Accomplishments and Prospects, Transportation Planning and Technology, 31 (3), 277-302,

REFERENCES (continue)

Ceran, Y. & Alagöz, A. (2007). Lojistik Maliyet Yönetimi: Lojistik Maliyetler ve Lojistik Maliyet Muhasebesi, *Yönetim Bilimleri Dergisi*, 5 (2), 1-23.

Chang, H., Jula, H., Chassiakos, A. & Ioannou, P. (2008). A heuristic solution for the empty container substitution problem, *Transportation Research Part E: Logistics and Transportation Review*, 44(29, 203-216.

Charnes, A. & Cooper, W.W. (1959). Chance–constrained Programming, *Management Science*, 6 (1), 73–79.

Cheung, R.K. & Chen, C.Y. (1998). A Two-Stage Stochastic Network Model and Solutions Methods for the Dynamic Empty Container Allocation Problem, *Transportation Science*, 32 (2), 142-162.

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

Crainic, T.G., Dejax, P.J. & Delorme, L. (1989). Models for Multimodel Multicommodity Location Problems with Interdepot Balancing Requirements, *Annals of Operations Research*, 18, 279-302.

Crainic, T.G., Gendreau, M. & Dejax, P. (1993). Dynamic and stochastic models for the allocation of empty containers. *Operations Research*, 41 (1), 102-126.

Çağlar, T. & Esmer, S. (2015). Türkiye'de Boş Konteynerlerin Yeniden Konumlandırılması Sorunu Üzerine Nitel Bir Araştırma, *Mustafa Kemal Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 12 (31), 242-256.

Dang, Q.V., Yun, W.Y. & Kopfer, H. (2012). Positioning empty containers under dependent demand process, *Computers & Industrial Engineering*, 62, 708-715.

Dantzig, G. (1955). Linear Programming Under Uncertainty, *Management Science*, 1 (3-4), 197–206.

Dantzig, G. & Wolfe, P. (1960). Decomposition Principle for Linear Programs, *Operations Research*, 8, 101–111.

REFERENCES (continue)

Dejax, P.J. & Crainic, T.G. (1987). A review of empty flows and fleet management models in freight transportation, *Transportation Science*, 21 (4), 227–247.

Dekker, H.C. & Van Goor, A.D.R. (2000). Supply Chain Management Accounting: A Case Study of Activity-Based Costing, *International Journal of Logistics Research and Applications*, 3 (1), 41-52.

Demir, V. (2007). *Lojistik Yönetim Sisteminde Maliyet Hesaplaması*, Ankara: Nobel Yayın.

Dempster, M.A.H. (1980). *Stochastic Programming*, Academic Press, London.

Domenica, N.D., Birbilis, G., Mitra, G., & Valente, P. (2003). *Stochastic Programming and Scenario Generation within A Simulation Framework: An Information Systems Perspective*, Department of Mathematical Sciences and Department of Economics and Finance, Brunel University, Uxbridge, Middlesex.

Dong, J., Song, D. (2009). Container fleet sizing and empty repositioning in liner shipping systems, *Transportation Research Part E*, 45, 860–877.

Dong, J., Song, D. (2012). Cargo routing and empty container repositioning in multiple shipping service routes, *Transportation Research Part B*, 46, 1556–1575.

Dupacova, J. (2002). Applications of Stochastic Programming: Achievements and Questions, *European Journal of Operational Research*, 140, 281–290.

Epstein et al. (2012). A Strategic Empty Container Logistics Optimization, *Interfaces*, 42 (1), 5–16.

Erera, A.L., Morales, J.C & Savelsbergh, M. (2009). Robust optimization for empty repositioning problems, *Operations Research*, 57 (2), 468-483.

Ermolev, Y.M., Krivets, T.A. & Petukhov, V.S. (1976). Planning of shipping empty seaborne containers, *Cybernetics*, 12(4), 644–646.

Feng, C.M. & Chang, C.H. (2008). Empty container reposition planning for intra-Asia liner shipping, M*aritime Policy & Management*, 35(5), 469-489.

Flämig, H., Wolff, J. & Herz, N. (2011). A hotspot for empty flows, *Baltic Transport Journal*, 4, 48–49.

REFERENCES (continue)

Florez, H. (1986). *Empty Container Repositioning and Leasing: an Optimization Model*. Ph.D. Dissertation, Polytechnic Institute of New York.

Francesco, M., Craini, T.G. & Zuddas, P. (2009). The effect of multi-scenario policies on empty container repositioning, *Transportation Research Part E*, 45, 758–770.

Francesco, M., Lai, M., T.G. & Zuddas, P. (2013). Maritime repositioning of empty containers under uncertain port disruptions, *Computers & Industrial Engineering*, 64, 827-837.

Fransoo, J.C. & Lee, C.Y. (2013). The critical role of ocean container transport in global supply chain performance, *Production and Operations Management*, 22, 253-268.

Frémont, A. (2009) Shipping Lines and Logistics, *Transport Reviews*, 29 (4), 537-554.

Furio, S., Andres, C., Diaz, B.D. & Lozano, S. (2013). Optimization of empty container movements using street-turn: Application to Valencia hinterland, *Computers & Industrial Engineering*, 66, 909-917.

Goh, S.H. & Chan, Y. (2016). Operational shadow pricing in back haul container shipping, *Tranportation Research Part E*, 93, 3-15.

Gökmen, Y. (2009). *Optimal Portfolio Building With Stochastic Programming*. Unpublished PhD Thesis, Institute of Social Sciences, Gazi University, Ankara.

Griful-Miquela, C. (2001). Activity Based Costing Methodology for Third-Party Logistics Companies, *International Advances in Economic Research*, 7 (1), 133-146.

Gupta, M. & Galloway, K. (2003). Activity based-costing/management and its applications for operations management, *Technovation*, 23, 131-138.

Hajeeh, A.M. & Behbehani, W. (2011). Optimizing Empty Containers Distribution among Ports, *Journal of Mathematics and Statistics*, 7 (3): 216-221.

Hälinen, H. M. (2015). *Understanding the Concept of Logistics Costs in Manufacturing*. Unpublished Phd Thesis, University of Turku.

REFERENCES (continue)

Haneveld, W. K. & Van der Vlerk, M. H. (1999). Stochastic integer programming: General models and algorithms, *Annals of Operations Research*, 85, 39-57.

Hjortnaes, T., Wiegmans, B., Negenborn, R. R., Zuidwijk, R. A. & Klijnhout, R. (2017). Minimizing cost of empty container repositioning in port hinterlands, while taking repair operations into account, *Journal of Transport Geography*, 58, 209-219.

Horngren, C. T., Harrison, W. T. J. & Oliver, M. S. (2009). *Accounting* (8th edition), New Jersey: Pearson Education International.

Huang, Y.F., Hu, J.K.H. & Yang, B. (2015). Liner services netwrok design and fleet deployment with emtpy container repositioning, *Computer & Industrial Engineering*, 89, 116-124.

Hüttmann, B.K. (2013). *Empty Container Logistics in the Maritime Economy-Evidence from the North Range* (1st edition), Hamburg: Verlag Dr. Kovac.

INFORMS. Retrieved 11.06.2017, https://www.informs.org/About-INFORMS/News-Room/Press-Releases/CSAV-Competing-for-INFORMS-Edelman-Prize.

Jarke, M. (1981). *Überwachung und Steuerung von Container-Transportsystemen (Control und Logistics of Container Transport Systems)*, Wiesbaden, W. Germany: Springer Gabler.

Jarke, M. (1982). Developing Decision Support Systems: A Container Management Example, *Int. J. Policy Anal. Inform. Syst.*, 6, 351-372.

Jula, H., Chassiakos, A. & Ioannou, P. (2003). *Empty Container Interchange Report: Methods for Modeling and Routing of Empty Containers in the Los Angeles and Long Beach Port Area*, Final Report (Long Beach, CA: Center for the Commercial Deployment of Transportation Technologies, California State University).

Kall, P. & Wallace, S.W. (1994). *Stochastic Programming*, Chichester: John Wiley & Sons Ltd.

Kaplan, R. & Cooper, R. (1987). *Cost Effect: Using Integrated Cost Systems to Drive Profitability and Performance*, Boston: Harvard Business School Press, 1998.

Konings, R. & Thijs, R. (2001). Foldable containers: a new perspective on reducing container-repositioning costs. *European Journal of Transport and Infrastructure Research*, 1 (4), 333–352.

Lai, K. K., Lam, L. & Chan, W. K. (1995). Shipping Container Logistics and Allocation, *Journal of Operations Research Society*, 46, 687-697.

Lam, S.W., Lee, L.H. & Tang, L.C. (2007). An approximate dynamic programming approach for the empty container allocation problem. *Transportation Research Part C: Emerging Technologies*, 15 (4), 265–277.

Le, D.H. (2003). *The logistics of empty cargo containers in the Southern California Region*, Final Report (Long Beach, CA: METRANS Transportation Center).

Lee, C. Y. & Song, D. P. (2017). Ocean container transport in global supply chains: Overview and research opportunities, *Transportation Research Part B*, 95, 442-474.

Leeuwen, B. V. (2016). Intermodal Container Leasing. Retrieved 12 April 2017, from http://www.world-leasing-yearbook.com/feature-of-the-month-june-2016/.

Li, J.A., Liu, K., Stephen, C.S. & Lai, K.K. (2004). Empty container management in a port with long-run average criterion. *Math. Comput. Modell.*, 40, 85–100.

Li, J.A., Leung, S., Wu, Y. & Liu, K. (2007). Allocation of empty containers between multi-ports, *European Journal of Operational Research*, 182, 400-412.

Liu, D. & Yang, H. (2015). Joint slot allocation and dynamic pricing of container sea-rail multimodal transportation, *Journal of Traffic and Transportation Engineering* (English Edition), 2 (3), 198-208.

Lloyd's List. Retrieved 10.04.2017, from https://www.lloydslist.com/ll/sector/containers/.

Long, Y., Lee, L. H. & Chew, E. P. (2012). The sample average approximation method for empty container repositioning with uncertainties, *European Journal of Operational Research*, 222, 65-75.

Lopez, E. (2003). How do ocean carriers organize the empty containers reposition activity in the USA?, *Maritime Policiy & Management*, 30 (4), 339-355.

Lun, Y.H. V., Lai, K.H. & Cheng, T.C.E. (2010). *Managing Empty Containers*. In Shipping and Logistics Management, 151–164.

Meng, Q. & Wang, S. (2011). Liner shipping service network design with empty container repositioning, *Transportation Research Part E: Logist. Transport. Rev.*, 47 (5), 695–708.

Mittal, N., Boile, M., Baveja, A. & Theofanis, S. (2013). Determining optimal inland-empty-container depot locations under stochastic demand, *Research in Transportation Economics*, 42, 50-60.

Moon, I., Ngoc, A.D. & Konings, R. (2012). Foldable and standard containers in empty container repositioning, *Transportation Research Part E*, 49, 107-124.

Mortaji, S.T.H., Bagherpour, M. & Mazdeh, M.M. (2013), Fuzzy Time-Driven Activity-Based Costing, *Engineering Management Journal*, 25 (3), 63-73.

Myung, Y. S. & Moon, I. (2014). A network flow model for the optimal allocation of both foldable and standard containers, *Operations Research Letters*, 42, 484-488.

Notteboom, T. (2012). *Container Shipping*. In the Blackwell Companion to Maritime Economics (230-262). Blackwell Publishing Ltd.

Ogryczak, W. & Ruszczyński, A. (2002). Dual stochastic dominance and quantile risk measures, *International Transactions in Operational Research*, 9 (5), 661-680.

Panayides, P.M. & Song, D.W. (2013). Maritime logistics as an emerging discipline, *Maritime Policy & Management*, 40(3), 295-308.

Pirttilä, T. & Hautaniemi, P. (1995). Activity based costing and distribution logistics management, *Int. J. Production Economics*, 41, 327-333.

Potts, R.B. (1970). *Movement of Empty Containers within Australia*, paper presented at Operations Society of Virginia, Melbourne, Australia.

Prékopa, A. (1978/1985). Studies in Applied Stochastic Programming–I, *Magyar Tudományos Akadémia*, 80, Budapest.

REFERENCES (continue)

Prékopa, A. (1995). *Stochastic programming*, Netherlands: Springer.

Riis, M. & Schultz, R. (2003). Applying the minimum risk criterion in stochastic recourse programs, *Computational Optimization and Applications*, 24 (2-3), 267-287.

Rudi, N., Kapur, S. & Pyke, D. F. (2001). A two-location inventory model with transhipment and local decision making, *Management Science*, 47(12),1668-1680.

Rushton, A., Croucher, P. & Baker, P. (2014). *The Handbook of Logistics and Distribution Management* (5th edition), London: Kogan Page Limited.

Schultz, R. (2003). Stochastic programming with integer variables, *Mathematical Programming*, 97 (1-2), 285-309.

Schulze, M., Sering, S. & Ewering, C. (2012). Applying activity-based costing in a supply chain environment, *Int. J. Productin Economics*, 135, 716-725.

Sen, S. (2005). Algorithms for stochastic mixed-integer programming models, *Handbooks in Operations Research and Management Science*, 12, 515-558.

Seuring, S. & Goldbach, M. (2002). *Cost Managment in Supply Chains*, Heidelberg: Springer Verlag GmbH.

Shapiro, A. & Philpott, A. (2007). A Tutorial on Stochastic Programming, Retrieved 10.10.2017, from http://www2.isye.gatech.edu/people/faculty/Alex_Shapiro/TutorialSP.pdf.

Shapiro, J.F. (1999). On the connections among activity-based costing, mathematical programming models for analyzing strategic decisions, and the resource-based view of the firm, *European Journal of Operational Research*, 118, 295-314.

Shen, W.S. & Khoong, C.M. (1995). A DSS for empty container distribution planning, *Decision Support Systems*, 15 (1), 75-82.

Sherali, H. D. & Zhu, X. (2009). Sayfa 405-435. *Two-stage stochastic mixed-integer programs: Algorithms and insights*. In Advances in Applied Mathematics and Global Optimization, USA: Springer.

REFERENCES (continue)

Shintani, K. Imai, A., Nishimura, E. & Papadimitriou, S. (2007). The container shipping network design problem with empty container repositioning, *Transportation Research Part E: Logistics and Transportation Review*, 43 (1), 39-59.

Slack, B. & Gouvernal, E. (2011). Container freight rates and the role of surcharges, *Journal of Transport Geography*, 19, 1482-1489.

Song, D. P. (2006). Characterizing optimal empty container reposition policy in periodic-review shuttle service systems, *Journal of the Operational Research Society*, 58 (1), 122-133.

Song, D. P. (2007). *Analysis of a collaborative strategy in container fleet management*. 11th World Conference on Transport Research, University of California, Berkeley, 24–28 June.

Song, D.P. & Carter, J. (2009). Empty container repositioning in liner shipping, *Maritime Policy & Management*, 36 (4), 291-307.

Statista. Retrieved 08.06.2017, from https://www.statista.com/statistics/253988/estimated-containerized-cargo-flows-on-major-container-trade-routes/

Stopford, M. (2009). *Maritime Economics* (3rd ed.). Abingdon: Routledge.

Stougie, L. & Van Der Vlerk, M. H. (1996). *Stochastic integer programming*, Institute of Actuarial Sciences & Econometrics, University of Amsterdam.

Takriti, S. & Ahmed, S. (2004). On robust optimization of two-stage systems, *Mathematical Programming*, 99 (1), 109-126.

Theofanis, S. & Boile, M. (2009). Empty marine container logistics: facts, issues and management strategies, *GeoJournal*, 74, 51-65.

Topaloglou, N. (2004). *A Stochastic Programming Framework for International Portfolio Management*. PhD Thesis, Department of Public and Business Administration School of Economics and Management, University of Cyprus.

Tütek, H., Gümüşoğlu, Ş., Özdemir, A. (2012). Sayısal Yöntemler: Yönetsel Yaklaşım, İstanbul: Beta Basım Yayım Dağıtım A.Ş.

REFERENCES (continue)

UNCTAD (2016*). Review of Maritime Transport 2016*, United Nations Publication, Sales no. E.16.II.D.7, New York and Geneva. Retrieved 05.07.2017, from http://unctad.org/en/PublicationsLibrary/rmt2016_en.pdf.

UNCTAD (2016c). *Harnessing emerging technological breakthroughs for the 2030 Agenda for Sustainable Development*, Policy Brief No. 45. Retrieved 17.02.2017, from http://unctad.org/en/PublicationsLibrary/presspb2016d1_en.pdf.

Wang, S. & Meng, Q. (2012a). Liner ship fleet deployment with container transshipment operations. *Transportation Research Part E*, 48, 470-484.

Wang, S. & Meng, Q. (1212b). Liner ship route schedule design with sea contingency time and port time uncertainty, *Transportation Research Part B*, 46, 615-633.

Wang, B. & Tang G. (2010). Stochastic Optimization Model for Container Shipping of Sea Carriage, *Journal of Transportation Systems Engineering and Information Technology*, 10 (3),58-63.

Wang, B. & Wang, Z. (2007). Research on the Optimization of Intermodel Empty Container Reposition of Land-carriage, *Journal of Transportation Systems Engineering and Information Technology*, 7 (3), 29-33.

Wang, S., Wang, H. & Meng, Q. (2015). Itinerary provision and pricing in container liner shipping revenue management, *Transportation Research Part E*, 77, 135-146.

Weiyi, F. & Luming, Y. (2009). *The Discussion of Target Cost Method in Logistics Cost Management,* ISECS International Colloquium on Computing, Communication, Control and Management, 537-540.

White, W.W. (1972). Dynamic transshipment networks: An algorithm and its application to the distribution of empty containers, *Networks*, 2(3): 211-236.

Wong, E.Y., Allen, H.T. & Raman, M. (2015). A maritime container repositioning yield-based optimization model with uncertain upsurge demand, *Transportation Research Part E*, 82,147–161.

REFERENCES (continue)

Xie, Y., Liang, X., Lijun, M. & Yan, H. (2017). Empty container management and coordination intermodal transport, *European Journal of Operational Research*, 257, 223-232.

Xu, L., Govindan, K., Bu, X. & Yin, Y. (2015). Pricing and balancing of the sea-cargo service chain with empty equipment repositioning, *Computers & Operations Research*, 54, 286-294.

Yudin, D.B. (1974). *Mathematical Methods of Management under Incomplete Information, Problems and Methods of Stochastic Programming*, Soviet Radio, Moscow.

Zhang, Y. & Facanha, C. (2014). Strategic planning of empty container repositioning in the transpacific market: a case study, *International Journal of Logistics Research and Applications*, 17 (5), 420-439.

Zheng, J., Sun, Z. & Gao, Z. (2015). Empty container exchange among liner carriers, *Transportation Research Part E*, 83, 158-169.

APPENDICES

A.1. CPLEX Codes For the MILP Model

```
//Indices
int E=...;
range Exceed=1..E;
int D=...;
range Deficit=1..D;
int I=...;
range Mode=1..I;
int T=...;
range Type=1..T;
int W=...;
range Week=1..W;
int L=...;
range Level=1..L;


//Parameters

float C[Exceed][Deficit][Mode][Type]=...;//Transportation cost
float F[Exceed][Type][Week]=...;//Number of excess containers
float Y[Deficit][Type][Week]=...;//Number of containers required
float Kap[Exceed][Deficit][Mode]=...;//TEU capacitiy of the connection
float SCE[Exceed][Type][Level]=...;//Storage costs
float SCD[Deficit][Type][Level]=...;//Storage costs
float B[Type]=...;//TEU of container type
int Z[Exceed][Deficit][Mode]=...;//Transportation time
int SQE[Exceed][Week][Level]=...;//Weekly storage level
int SQD[Deficit][Week][Level]=...;//Weekly storage level
int M=...;//A very big integer value

//Decision Variables

dvar int+ O[Exceed][Deficit][Mode][Type][Week];//Number of containers sent
dvar int+ G[Exceed][Deficit][Mode][Type][Week];//Number of containers
received
dvar boolean TC[Exceed][Week][Level];//Stock level
dvar boolean IC[Deficit][Week][Level];//Stock level
dvar int+ R[Exceed][Type][Week];//Containers left in e
dvar int+ K[Deficit][Type][Week];//Containers left in d

//Objective function
minimize

sum(e in Exceed, t in Type, w in Week,l in
Level)SCE[e][t][l]*R[e][t][w]*TC[e][w][l]+sum(d in Deficit, t in Type, w in
Week,l in Level)SCD[d][t][l]*K[d][t][w]*IC[d][w][l]+ sum(e in Exceed, d in
Deficit,i in Mode, t in Type, w in Week)G[e][d][i][t][w]*C[e][d][i][t];

subject to {

//Constraint for the maximum number of containers to be sent from e
forall(e in Exceed, t in Type)
sum(d in Deficit,i in Mode)O[e][d][i][t][1]<=F[e][t][1];

forall(e in Exceed, t in Type,w in 2..W-1)
sum(d in Deficit,i in Mode)O[e][d][i][t][w]<=F[e][t][w]+R[e][t][w-1];

//Remaining containers
forall(e in Exceed, t in Type)
R[e][t][1]==F[e][t][1]-sum(d in Deficit,i in Mode)O[e][d][i][t][1];

forall(e in Exceed, t in Type,w in 2..W-1)
```

```
R[e][t][w]==F[e][t][w]-sum(d in Deficit,i in
Mode)O[e][d][i][t][w]+R[e][t][w-1];

//Arrival time of containers
forall(e in Exceed, d in Deficit,i in Mode, t in Type, w in 1..W-1)
 O[e][d][i][t][w]==G[e][d][i][t][w+Z[e][d][i]];


//Demand coverage constraints
forall(d in Deficit,t in Type)
sum(e in Exceed, i in Mode)G[e][d][i][t][1]>=Y[d][t][1];


forall(d in Deficit,t in Type, w in 2..W)
sum(e in Exceed, i in Mode)G[e][d][i][t][w]+K[d][t][w-1]>=Y[d][t][w];

 //Remaining containers
forall(d in Deficit, t in Type)
 K[d][t][1]==sum(e in Exceed,i in Mode)G[e][d][i][t][1]-Y[d][t][1];


forall(d in Deficit, t in Type,w in 2..W)
K[d][t][w]==sum(e in Exceed,i in Mode)G[e][d][i][t][w]-Y[d][t][w]+K[d][t][w-
1];

//Stock levels
 forall(e in Exceed,w in Week)
sum(l in Level)TC[e][w][l]<=1;

 forall(e in Exceed, w in Week)
 sum(t in Type)R[e][t][w]*B[t]<=sum(l in Level)SQE[e][w][l]*TC[e][w][l];


//Stock levels
 forall(d in Deficit,w in Week)
 sum(l in Level)IC[d][w][l]<=1;

 forall(d in Deficit, w in Week)
 sum(t in Type)K[d][t][w]*B[t]<=sum(l in Level)SQD[d][w][l]*IC[d][w][l];

//Capacity constraint
 forall(e in Exceed, d in Deficit, i in Mode, w in Week)
 sum(t in Type)G[e][d][i][t][w]*B[t]<=Kap[e][d][i];

 forall(d in Deficit)
 sum(e in Exceed,i in Mode,t in Type)G[e][d][i][t][W]<=0;

 forall(e in Exceed)
 sum(d in Deficit,i in Mode,t in Type)O[e][d][i][t][W]<=0;

   }
```

A.2. Data Set 1 For the MILP Model

```
E=15;
T=3;
D=4;
W=5;
I=3;
L=2;
M=99999;

//Container teu
B=[1,2,2];

 //Container arrival times

Z=[[[1,0,1],[1,1,0],[1,0,0,],[0,0,0]],[[1,1],[1,1],[0,0],[0,0]],[[1,1],[1,1]
,[0,0],[0,0]],[[0,0],[0,0],[1,0],[1,0]],

[[0],[0],[0],[1]],[[1],[1],[0],[0]],[[0],[0]],[[1,1],[1,1],[0,0],[0,0]],[[0,
0],[0,0],[1,0],[1]],[[0,0],[0,0],[1,0],[1]],

[[0,0],[0,0],[0,0],[1]],[[1,1],[1,1],[0,0],[0,0]],[[0,0][0,0],[1,1]],[[0,0],
[0,0],[0,0],[0,1]],[[0],[0],[1]]];


//Stock levels
SQE=[[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,10
00],[1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[100,1000],[100,1000],[10
0,1000],[100,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[100,200],[100,1000],[100
,1000],[100,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],
 [[1000,1000],[1000,1000],[1000,1000],[1000,1000]]];

SQD=[[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,10
00],[1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]]];

 //Storage costs

SCE=[[[3,3],[6,6],[6,6]],[[5,5],[7,7],[7,7]],[[3,3],[6,6],[6,6]],[[1,2],[2,4
],[2,4]],[[2,2],[4,4],[4,4]],[[5,5],[7,7],[7,7]],

[[4,4],[8,8],[8,8]],[[2,2],[4,4],[4,4]],[[5,5],[10,10],[10,10]],[[1,2],[2,4]
,[2,4]],[[4,4],[8,8],[8,8]],[[5,5],[10,10],[10,10]],
 [[10,10],[20,20],[20,20]],[[3,3],[6,6],[6,6]],[[4,4],[8,8],[8,8]]];


SCD=[[[5,5],[5,5],[5,5]],[[5,10],[5,10],[5,10]],[[2,2],[4,4],[4,4]],[[3,3],[
3,3],[3,3]]];
```

```
 //Number of container in surplus locations

F=[[[25,30,20,35],[10,5,8,15],[30,20,18,27]],[[20,15,10,15],[5,0,2,4],[15,5,
10,5]],[[60,45,40,50],[10,15,30,10],[30,20,42,34]],
 [[60,55,40,45],[10,5,12,7],[50,34,27,45]],

[[20,15,10,15],[10,5,5,5],[30,10,20,15]],[[5,0,0,5],[1,0,0,2],[10,5,0,5]],[[
15,5,10,5],[2,0,0,0],[15,5,10,7]],

[[60,50,45,55],[5,0,0,0],[20,14,12,10]],[[40,30,50,35],[15,10,8,5],[25,10,14
,17]],[[50,45,60,37],[10,4,12,14],[30,23,16,27]],

[[10,4,7,5],[1,0,0,2],[20,15,22,8]],[[25,16,30,22],[20,8,17,10],[20,17,12,22
]],[[30,42,25,33],[10,15,7,14],[20,27,13,15]],
 [[10,6,12,4],[2,0,0,5],[10,7,5,4]],[[15,7,5,9],[5,3,2,0],[10,5,8,3]]];


 //Container demand in deficit locations
Y=[[[50,30,70,50],[5,2,10,5],[10,20,15,12]],[[80,50,70,100]],[[40,50,35,45],
[5,3,7,5],[20,10,15,8]],
 [[100,60,70,110],[5,0,0,10],[30,20,15,25]]];

//Connection capacities
Kap=[[[20,25,20],[20,10,20],[20,20,20],[30,20,40]],[[10,20],[10,20],[15,20],
[20,20]],[[15,20],[15,20],[20,20],[60,70]],
[[40,50],[40,50],[30,25],[10]],[[60],[40],[20],[10]],[[30],[30],[30],[20]],
[[30],[30]],[[40,40],[40,40],[50,60],[100,80]],[[50,30],[50,30],[40,30],[20]
],
[[60,50],[50,40],[40,30],[20,0]],[[30,20],[30,20],[30,20],[20]],[[30,20],[30
,20],[20,20],[60,30]],
[[40,20],[40,20],[20,15]],[[20,10][20,10],[30,20],[20,10]],[[30],[40],[10]]];

//Transportation costs
C=[[[[130,260,260],[120,240,240],[120,240,240]],[[130,260,260],[120,240,240]
,[120,240,240]],[[120,240,240],[110,220,220],[120,240,240]],[[110,220,220],[
100,200,200],[100,200,200]]],
[[[140,280,280],[130,260,260]],[[140,280,280],[130,260,260]],[[130,260,260],
[120,240,240]],[[120,240,240],[100,200,200]]],
[[[130,260,260],[130,260,260]],[[130,260,260],[120,240,240]],[[120,240,240],
[120,240,240]],[[120,240,240],[100,200,200]]],
[[[120,240,240],[120,240,240]],[[120,240,240],[120,240,240]],[[130,260,260],
[120,240,240]],[[140,280,280]]],
[[[100,200,200]],[[100,200,200]],[[120,240,240]],[[130,260,260]]],
[[[130,260,260]],[[130,260,260]],[[120,240,240]],[[100,200,200]]],
[[[130,260,260]],[[130,260,260]],[[120,240,240]]],
[[[140,280,280],[130,260,260]],[[140,280,280],[130,260,260]],[[150,300,300],
[135,270,270]],[[110,220,220],[120,240,240]]],
[[[120,240,240],[120,240,240]],[[120,240,240],[120,240,240]],[[120,240,240],
[130,260,260]],[[140,280,280]]],
[[[140,280,280],[120,240,240]],[[140,280,280],[120,240,240]],[[160,320,320],
[120,240,240]],[[170,340,340]]],
[[[120,240,240],[110,220,220]],[[120,240,240],[110,220,220]],[[110,220,220],
[110,220,220]],[[120,240,240]]],
[[[130,260,260],[120,240,240]],[[130,260,260],[120,240,240]],[[120,240,240],
[120,240,240]],[[110,220,220],[100,200,200]]],
[[[120,240,240],[120,240,240]],[[120,240,240],[120,240,240]],[[130,260,260],
[140,280,280]]],
[[[120,240,240],[110,220,220]],[[120,240,240],[110,220,220]],[[120,240,240],
[110,220,220]],[[130,260,260],[120,240,240]]],
[[[120,240,240]],[[120,240,240]],[[130,260,260]]]];
```

A.3. CPLEX Codes For the SP Model

```
//Indices
int E=...;
range Exceed=1..E;
int D=...;
range Deficit=1..D;
int I=...;
range Mode=1..I;
int T=...;
range Type=1..T;
int W=...;
range Week=1..W;
int S=...;
range Scenario=1..S;
int L=...;
range Level=1..L;


//Parameters

float C[Exceed][Deficit][Mode][Type]=...;//Transportation cost
float F[Exceed][Type][Week]=...;//Number of excess containers
float Y[Deficit][Type][Week][Scenario]=...;//Number of containers required
float Kap[Exceed][Deficit][Mode]=...;//TEU capacitiy of the connection
float SCE[Exceed][Type][Level]=...;//Storage costs
float SCD[Deficit][Type][Level]=...;//Storage costs
float B[Type]=...;//TEU of container type
int Z[Exceed][Deficit][Mode]=...;//Transportation time
int SQE[Exceed][Week][Level]=...;//Weekly storage level
int SQD[Deficit][Week][Level]=...;//Weekly storage level
float P[Scenario]=...;//Scenario coefficien
float M=...;//A very big integer value

//Decision Variables

dvar int+ O[Exceed][Deficit][Mode][Type][Week][Scenario];//Number of
containers sent
dvar int+ G[Exceed][Deficit][Mode][Type][Week][Scenario];//Number of
containers received
dvar boolean TC[Exceed][Week][Level][Scenario];//Stock level
dvar boolean IC[Deficit][Week][Level][Scenario];//Stock level
dvar int+ R[Exceed][Type][Week][Scenario];//Containers left in e
dvar int+ K[Deficit][Type][Week][Scenario];//Containers left in d

//Objective function
minimize

 sum(e in Exceed, d in Deficit,i in Mode, t in Type, w in Week, s in
Scenario)P[s]*G[e][d][i][t][w][s]*C[e][d][i][t]+sum(e in Exceed, t in Type,
w in Week,l in Level, s in
Scenario)P[s]*SCE[e][t][l]*R[e][t][w][s]*TC[e][w][l][s]+sum( d in Deficit, t
in Type, w in Week,l in Level, s in
Scenario)P[s]*SCD[d][t][l]*K[d][t][w][s]*IC[d][w][l][s];

 subject to {

//Demand coverage constraints
forall(d in Deficit,t in Type, s in Scenario)
sum(e in Exceed, i in Mode)G[e][d][i][t][1][s]>= Y[d][t][1][s];


forall(d in Deficit,t in Type, w in 2..W,s in Scenario)
sum(e in Exceed, i in Mode)G[e][d][i][t][w][s]+K[d][t][w-1][s]>=
Y[d][t][w][s];
```

```
//Arrival time of containers
forall(e in Exceed, d in Deficit,i in Mode, t in Type, w in 1..W-1, s in Scenario)
O[e][d][i][t][w][s]==G[e][d][i][t][w+Z[e][d][i]][s];

//Constraint for the maximum number of containers to be sent from e
forall(e in Exceed, t in Type, s in Scenario)
sum(d in Deficit,i in Mode)O[e][d][i][t][1][s]<=F[e][t][1];

forall(e in Exceed, t in Type,w in 2..W-1, s in Scenario)
sum(d in Deficit,i in Mode)O[e][d][i][t][w][s]<=F[e][t][w]+R[e][t][w-1][s];

//Remaining containers
forall(e in Exceed, t in Type, s in Scenario)
R[e][t][1][s]==F[e][t][1]-sum(d in Deficit,i in Mode)O[e][d][i][t][1][s];

forall(e in Exceed, t in Type,w in 2..W-1,s in Scenario)
R[e][t][w][s]==F[e][t][w]-sum(d in Deficit,i in Mode)O[e][d][i][t][w][s]+R[e][t][w-1][s];


forall(d in Deficit, t in Type, s in Scenario)
K[d][t][1][s]==sum(e in Exceed,i in Mode)G[e][d][i][t][1][s]-Y[d][t][1][s];

forall(d in Deficit, t in Type,w in 2..W-1, s in Scenario)
K[d][t][w][s]==sum(e in Exceed,i in Mode)G[e][d][i][t][w][s]-Y[d][t][w][s]+K[d][t][w-1][s];


forall(e in Exceed, w in Week,s in Scenario)
sum(t in Type)R[e][t][w][s]*B[t]<=sum(l in Level)SQE[e][w][l]*TC[e][w][l][s];

//Stock levels
forall(e in Exceed, w in Week, s in Scenario)
M*sum(l in Level)TC[e][w][l][s]>=sum(t in Type)R[e][t][w][s]*B[t];

forall(e in Exceed,w in Week, s in Scenario)
sum(l in Level)TC[e][w][l][s]<=1;


forall(d in Deficit, w in Week,s in Scenario)
M*sum(l in Level)IC[d][w][l][s]>=sum(t in Type)K[d][t][w][s]*B[t];

forall(d in Deficit,w in Week,s in Scenario)
sum(l in Level)IC[d][w][l][s]<=1;

forall(d in Deficit, w in Week,s in Scenario)
sum(t in Type)K[d][t][w][s]*B[t]<=sum(l in Level)SQD[d][w][l]*IC[d][w][l][s];

//Capacity constraint
forall(e in Exceed, d in Deficit, i in Mode, w in Week, s in Scenario)
 sum(t in Type)(G[e][d][i][t][w][s]*B[t])<=Kap[e][d][i];

forall(d in Deficit)
sum(e in Exceed,i in Mode,t in Type,s in Scenario)G[e][d][i][t][W][s]<=0;

forall(e in Exceed)
sum(d in Deficit,i in Mode,t in Type,s in Scenario)O[e][d][i][t][W][s]<=0;

      }
```

A.4. Data Set 1 For the SP Model

```
E=15;
T=3;
D=4;
W=5;
I=3;
L=2;
M=99999;
S=3;

//Scenario Coefficients
P=[0.1,0.4,0.5];

//Container teu
B=[1,2,2];

 //Container demand in deficit locations
Y=[[[[50,50,50],[20,30,40],[60,70,80],[40,50,60]],
[[5,5,5],[1,3,5],[5,10,15],[2,5,9]],
[[10,10,10],[15,25,35],[10,15,20],[5,8,10]]],
[[[80,80,80],[40,50,60],[60,70,80],[90,100,110]],
[[0],[0],[0],[0]],
[[0],[0],[0],[0]]],
[[[40,40,50],[40,50,60],[25,35,45],[35,45,50]],
[[5,5,5],[2,4,5],[5,7,10],[3,5,7]],
[[20,20,20],[5,15,20],[10,15,20],[5,10,12]]],
[[[100,100,100],[50,60,70],[60,70,80],[95,105,120]],
[[5,5,5],[0],[0],[5,10,15]],
[[30,30,30],[20,20,20],[10,15,20],[20,25,30]]]];


 //Container arrival times
Z=[[[1,0,1],[1,1,0],[1,0,0,],[0,0,0]],[[1,1],[1,1],[0,0],[0,0]],[[1,1],[1,1]
,[0,0],[0,0]],[[0,0],[0,0],[1,0],[1,0]],

[[0],[0],[0],[1]],[[1],[1],[0],[0]],[[0],[0]],[[1,1],[1,1],[0,0],[0,0]],[[0,
0],[0,0],[1,0],[1]],[[0,0],[0,0],[1,0],[1]],

[[0,0],[0,0],[0,0],[1]],[[1,1],[1,1],[0,0],[0,0]],[[0,0][0,0],[1,1]],[[0,0],
[0,0],[0,0],[0,1]],[[0],[0],[1]]];


//Stock levels
SQE=[[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,10
00],[1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[100,1000],[100,1000],[10
0,1000],[100,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[100,200],[100,1000],[100
,1000],[100,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],

[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[
1000,1000],[1000,1000]],
 [[1000,1000],[1000,1000],[1000,1000],[1000,1000]]];

SQD=[[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,10
00],[1000,1000],[1000,1000]],
```

```
[[1000,1000],[1000,1000],[1000,1000],[1000,1000]],[[1000,1000],[1000,1000],[1000,1000],[1000,1000]]];


 //Storage costs

SCE=[[[3,3],[6,6],[6,6]],[[5,5],[7,7],[7,7]],[[3,3],[6,6],[6,6]],[[1,2],[2,4],[2,4]],[[2,2],[4,4],[4,4]],[[5,5],[7,7],[7,7]],

[[4,4],[8,8],[8,8]],[[2,2],[4,4],[4,4]],[[5,5],[10,10],[10,10]],[[1,2],[2,4],[2,4]],[[4,4],[8,8],[8,8]],[[5,5],[10,10],[10,10]],
 [[10,10],[20,20],[20,20]],[[3,3],[6,6],[6,6]],[[4,4],[8,8],[8,8]]];


SCD=[[[5,5],[5,5],[5,5]],[[5,10],[5,10],[5,10]],[[2,2],[4,4],[4,4]],[[3,3],[3,3],[3,3]]];

F=[[[25,30,20,35],[10,5,8,15],[30,20,18,27]],[[20,15,10,15],[5,0,2,4],[15,5,10,5]],[[60,45,40,50],[10,15,30,10],[30,20,42,34]],
 [[60,55,40,45],[10,5,12,7],[50,34,27,45]],

[[20,15,10,15],[10,5,5,5],[30,10,20,15]],[[5,0,0,5],[1,0,0,2],[10,5,0,5]],[[15,5,10,5],[2,0,0,0],[15,5,10,7]],

[[60,50,45,55],[5,0,0,0],[20,14,12,10]],[[40,30,50,35],[15,10,8,5],[25,10,14,17]],[[50,45,60,37],[10,4,12,14],[30,23,16,27]],

[[10,4,7,5],[1,0,0,2],[20,15,22,8]],[[25,16,30,22],[20,8,17,10],[20,17,12,22]],[[30,42,25,33],[10,15,7,14],[20,27,13,15]],
 [[10,6,12,4],[2,0,0,5],[10,7,5,4]],[[15,7,5,9],[5,3,2,0],[10,5,8,3]]];

//Connection capacities
Kap=[[[20,25,20],[20,10,20],[20,20,20],[30,20,40]],[[10,20],[10,20],[15,20],[20,20]],[[15,20],[15,20],[20,20],[60,70]],
[[40,50],[40,50],[30,25],[10]],[[60],[40],[20],[10]],[[30],[30],[30],[20]],
[[30],[30]],[[40,40],[40,40],[50,60],[100,80]],[[50,30],[50,30],[40,30],[20]],
[[60,50],[50,40],[40,30],[20,0]],[[30,20],[30,20],[30,20],[20]],[[30,20],[30,20],[20,20],[60,30]],
[[40,20],[40,20],[20,15]],[[20,10][20,10],[30,20],[20,10]],[[30],[40],[10]]];

//Transportation cost
C=[[[[130,260,260],[120,240,240],[120,240,240]],[[130,260,260],[120,240,240],[120,240,240]],[[120,240,240],[110,220,220],[120,240,240]],[[110,220,220],[100,200,200],[100,200,200]]],
[[[140,280,280],[130,260,260]],[[140,280,280],[130,260,260]],[[130,260,260],[120,240,240]],[[120,240,240],[100,200,200]]],
[[[130,260,260],[130,260,260]],[[130,260,260],[120,240,240]],[[120,240,240],[120,240,240]],[[120,240,240],[100,200,200]]],
[[[120,240,240],[120,240,240]],[[120,240,240],[120,240,240]],[[130,260,260],[120,240,240]],[[140,280,280]]],
[[[100,200,200]],[[100,200,200]],[[120,240,240]],[[130,260,260]]],
[[[130,260,260]],[[130,260,260]],[[120,240,240]],[[100,200,200]]],
[[[130,260,260]],[[130,260,260]],[[120,240,240]]],
[[[140,280,280],[130,260,260]],[[140,280,280],[130,260,260]],[[150,300,300],[135,270,270]],[[110,220,220],[120,240,240]]],
[[[120,240,240],[120,240,240]],[[120,240,240],[120,240,240]],[[120,240,240],[130,260,260]],[[140,280,280]]],
[[[140,280,280],[120,240,240]],[[140,280,280],[120,240,240]],[[160,320,320],[120,240,240]],[[170,340,340]]],
[[[120,240,240],[110,220,220]],[[120,240,240],[110,220,220]],[[110,220,220],[110,220,220]],[[120,240,240]]],
[[[130,260,260],[120,240,240]],[[130,260,260],[120,240,240]],[[120,240,240],[120,240,240]],[[110,220,220],[100,200,200]]],
[[[120,240,240],[120,240,240]],[[120,240,240],[120,240,240]],[[130,260,260],[140,280,280]]],
```

```
[[[120,240,240],[110,220,220]],[[120,240,240],[110,220,220]],[[120,240,240],
[110,220,220]],[[130,260,260],[120,240,240]]],
[[[120,240,240]],[[120,240,240]],[[130,260,260]]]];
```

BRIEF CURRICULUM VITAE

Hüseyin Gençer graduated from the Ege University, Business Administration Department in 2008. He completed his master’s degree in International Business Administration at the University of Hamburg. He started his PhD studies at the Yaşar University in 2013 and plans to defend his thesis titled "Optimization of Costs and Operations in Empty Container Repositioning" in January 2018. Hüseyin Gençer is currently working as a full time lecturer at the Piri Reis University.