Erasmus University Rotterdam

MSc in Maritime Economics and Logistics

2015/2016

Revenue Management methods in Liner Shipping

by

Dimitrios Varveris

Acknowledgements

The completion of this thesis marks the end of a very challenging year and I cannot help but reflect on the journey that brought me one step closer to my professional career. As my graduation approaches, I would like to mention all the people that have supported me throughout this year and assisted the completion of this final project.

I would first like to thank my thesis advisor Prof. Dr. Michele Acciaro of the Kühne Logistics University. This being my first research thesis, since our first meeting he was able to guide and help me towards understanding what is required of me. Despite his very busy schedule, his door was always open to discuss whenever I ran into trouble or had a question and while he allowed this paper to be my own work, he always steered me in the right direction whenever he thought it was required.

Furthermore, I would like to thank all my MEL classmates and friends, who made this year an enjoyable experience, allowing me to take much needed breaks from studying throughout the academic year. In addition, as they were going through the same process as I, their advice was always much needed and on point, regarding assignments over the year but also my final thesis paper.

Last but not least, I would like to express my sincere gratitude to my family that have supported my academic and professional decisions throughout the years, especially when it comes to studying and living abroad. With the good and the bad times, you have been the most important influence in my life and have shaped me into the person I am today.

Abstract

Over the recent decade, rapid changes in the supply chain sector have forced liner shipping companies to reevaluate their pricing strategies. Until 2008, carriers did not have the ability to price differentiate as liner conferences set the prices globally. Since then, shipping companies have been looking for ways to increase their revenue generation and differentiate against the competition, but the recent shipping crisis and the current overcapacity of vessels in the market are not helping.

Revenue management allows one to control the availability and pricing of different services and it has had a history of success in other transportation industries in the past, especially airliners. In an attempt to transfer some of those revenue management methods from other industries into liner shipping, a number of researches were conducted, which we will review in this paper. Our goal is to analyze and compare three of the most representative revenue management models that introduce revenue management in liner shipping. In contrast to other studies, the focus is on how those models reflect real container carrier market circumstances as well as how complex they are to comprehend and solve.

The three representative models we chose have different formulation as well as assumptions and parameters that make their comparison, based on simulation outcomes, weak. Therefore, in order to select and compare the models, a number of criteria are set, concerning the network structure and market segmentation of each of those models. After analyzing each model formulation in depth and seeing the various parameters and assumptions as well as simulation results, a multi-criteria analysis approach is used, with each criteria having identical weight, to examine how those models fare against each other.

Firstly, we find that the model of Zurheide and Fischer (2015) is the one that best as it represents a real network in detail, however also being overly complicated. Its use would be suggested for large global container carriers with sizeable networks and adequate revenue management departments. Ting and Tzeng’s (2004) model is definitely the easiest model to use and apply, at the same time taking some extreme assumptions that could not be easily applied in real liner shipping business. Lu et. al (2010) appear to have the best combination of reality and complexity of the model, but are more focused on short-haul transportation, thus making their model best applicable in liner companies operating short-sea services and not global networks.

Table of Contents

List of Figures

List of Abbreviations

RM	Revenue Management
BL	Booking Limits
NBL	Nested Booking Limits
BP	Bid Pricing

1. Introduction

1.1 Revenue Management Background and Problem Statement

With the emergence of globalization, liners are faced with a change of trends in their managerial strategies, as in turn, their clients – the shippers – are restructuring their supply chain organization. As a result, this is forcing container liner companies to be more flexible both in terms of the services offered but also slot allocation on their vessels while also attempting to maximize revenues and utilizing as much of the available capacity as possible. Undoubtedly, this also gives liners the chance to reshape their competitive position in the market through the use of revenue management strategies, in order to differentiate themselves from competition. However, while revenue management has been a thoroughly researched topic in other industries such as air and rail passenger and passenger transportation, we cannot say the same for liner shipping. It was only after 2006, when the talks about eradicating the liner conference system started (European Commission , 2006), that researches started looking into implementing revenue management methods in liner shipping. With the above fact and if we add the recent economic crisis of 2008 that slowed progress down globally, we can easily conclude that revenue management is relatively undeveloped in the liner shipping industry.

In general, revenue management can be considered a special case of pricing strategy where the supply is constrained (Phillips, 2005). Its importance emerged in the 1980s, when air liners attempted to differentiate prices between leisure and business passengers. In particular, American Airlines developed a “yield-management” system in order to compete with its main rival PeopleExpress Airlines who was offering low fares on many of the key U.S. routes. This approach was largely successful for American Airlines and resulted in the eventual downfall of PeopleExpress. After American Airlines made their revenue management methods public in its annual report, public interest rose significantly. In fact, after a short while, a number of consultancy companies started appearing, which primarily focused on developing revenue management software and selling it to companies that wanted to use them for their pricing strategy. Revenue management was spreading to airliner companies but also other industries.

While it seems like revenue management strategies would be applicable and beneficial in any industry, Phillips (2005) states that, for RM to be applied in an industry, certain conditions are required:

- Capacity must be limited and immediately perishable;
- Customers must be able to book capacity ahead of time and
- Prices have to be changed by opening and closing predefined booking classes (fare classes)

He adds that an RM strategy consists of identifying customer segments and establishing the services or products targeted at these segments. Moreover, once services and fares have been established, RM focuses on setting and updating limits on how much and at what price a service can be sold to each segment for a period of time.

It is easy to understand that not every company in every field can apply RM methods. Particularly, most industries do not face such capacity constraints such as those airlines face. For example, a manufacturer can adjust production levels and store finished products in order to deal with fluctuations in demand. Similarly, retailers simply adjust their stocks in response to changes in demand. In fact, we can notice that the industries that benefited the most from the introduction of revenue management, are exactly those that meet each and every one of these conditions, such as hotels, rental car companies, cruise lines, railroads, tour operators and freight transportation. Here, it would be very important to mention that the growth of e-commerce has also largely assisted the application of RM. With the introduction of the internet in the 1990s, analysts were predicting that it would take the control of pricing out of the hands of a seller, however we have seen that the result has been the complete opposite. In fact, the Internet increased the need for revenue optimization, according to Phillips (2005) for four reasons:

- It increases the velocity of pricing decisions as companies can now change their price lists almost daily;
- It makes a vast amount of information on the clients available to the seller, such as who bought what item, which items they looked at and for how long etc;
- It allows companies to experiment with pricing alternatives and pricing models and
- Even in cases where a customer does not buy online, he usually resorts online to find relevant information about costs and competitive prices.

Therefore, it is also important to factor the growth of e-commerce as a reason for the immense growth of revenue management as well.

In order to describe the situation in liner shipping the last few years, we would say it shows remarkable similarities to the air liner industry in the U.S. before 1983, where the Airline Deregulation Act was completed, effectively removing all fare regulation (Williams, 1994). Before that, there was no price differentiation allowed, as carriers did not have direct control over fares, which were set by the Civil Aeronautics Board. Therefore, airliners in the U.S. focused exclusively on filling up the planes, using load factor as their primary performance measure. In other words, filling up passenger seats in a plane was the most important task for airliners and prices were regulated in such a way, that a 75% fill rate would be the so called *break-even* load factor (Phillips, 2005). Similarly, in the container liner industry until the elimination of liner conferences in 2008, load factor was and to this day still remains the most important performance measure for the industry. The break-even load factor for container shipping varies per route, company and period but based on several reports and expert opinions is considered to be between 80% and 90% throughout the years. This means that a company operating their vessels loaded by 80% or less would struggle to cover its operating costs, let alone be profitable. One would expect that after 2008 liners would adapt their pricing strategies to the new reality, however we have seen little progress in that regard. In fact, the pricing strategy most often used by the majority of the liners is "First Come First Serve". There are a lot of reasons for that and most importantly the shipping crisis of 2008, that created fierce competition for survival, but also severe trade imbalances throughout the world, low fuel prices and the overcapacity of vessels as well as the fact that shipping industry has always been a very conservative industry in which change comes slowly (McKinsey, 2014).

Based on the situation described above, we can conclude that there is a lot of room for research aiming at the improvement of container liner's pricing strategies. Revenue management could become a key strategy for liners, in order to differentiate from their competition and increase their revenue generation. The importance of implementing revenue management and reshaping container liner's pricing strategies becomes even greater nowadays, when most of them are struggling to reach the break-even load factor, resulting in losses even by the leaders of the market (Drewry, 2015).

1.2 Scope and limitations

Based on the problem stated in the above chapter, we will try to analyze different revenue management methods, with the help of relevant past research on the subject. As there is a large number of suggested models in existing literature, we will attempt to categorize three revenue management models applied in liner shipping which we believe best represent the majority, depending on the different parameters they have, set by their creators. Of course, this means that we will limit our research to models that are comparable. Correlating them will help us achieve our main goal which is to compare how they fare against each other. We will attempt to compare them by conducting a multi-criteria analysis on all three of those models.

A significant limitation in our research is the lack of a quantitative comparison. Comparing the models we select with each other through the use of simulation would require reformulating them into having the same assumptions and parameters and coming up with similar outcomes. We believe that the authors of the models we select have chosen different parameters and decision variables due to their focus in different aspects of liner shipping and as a result, each model excels in different situations, which must be mentioned. Furthermore, because of time limitations, such an approach would be infeasible and therefore, is beyond the scope of this research.

1.3 Research questions and objectives

As mentioned earlier, we believe there is a lot of room for improvement in container liner companies' pricing strategy and RM strategies can significantly aid in that direction. Our main objective is not only to examine how valuable the implementation of revenue management strategies in liner shipping is, but also estimate the outcome of different strategies to define the most beneficial one in different realistic situations. Our primary concern is revenue and therefore we will consider an RM strategy more beneficial than another if it generates more revenue. Utilization rate and load factor are also very important in liner shipping, as a vessel trip can last for many days or even months and a container liner should also consider attracting as much market share as possible. Furthermore, for a model to be applicable in liner shipping, it has to reflect as much as possible a realistic situation in the market. At the same time, a model should not be overly complex as that would create problems for those responsible for applying it, as it would be hard to comprehend and use as well as require a significant amount of time for its solving. Thus, we will present all those factors for each of the models selected, in order to reach a conclusion. Our main research and sub-research questions are presented below:

Main Research Question:

Which Revenue Management method would be most beneficial for a container liner operator?

Sub-Research Questions:

1. What are the criteria used to select Revenue Management methods?
2. What are the differences of the selected Revenue Management methods and how can they be compared?
3. What results deem a Revenue Management method more beneficial than another?

Our first sub-research question is focused on selecting the RM methods out of the pool of RM methods in the existing literature. We will analyse their different criteria and parameters and explain why we believe those methods are the most representative in the interest of conducting our research. In order to answer our second sub-research question, we will categorize the individual RM methods by finding their similarities and differences and examining which ones can be compared and how. In our third sub-research question, our objective is to examine what outcome of the RM methods is considered most important. In other words, we will state which criteria in our results make us believe that a method works better than another one and that will help us conclude with a most efficient method suggestion. Upon answering all the above questions, we will be able to estimate the outcome of the application of RM methods in liner shipping and we will be able to compare them against each other using multi-criteria analysis.

1.4 Relevance of research

Our intention is that this research provides useful and practical information for the application of RM methods in liner shipping to maritime experts and container liner companies in the current market. We hope this dissertation will contribute to the currently limited amount of research on RM in container shipping and provide motivation to future researchers to develop the subject even further.

In the current shape of the market, fierce competition is not allowing companies to have a lot of control over the freight rates. In addition, the cost of empty container repositioning is increasing along with trade imbalances around the world, as Asia continues to increase its exporting, while Europe and America are mostly importing.

In order to understand the importance of ECR, Head of Maersk Line's Equipment Flow, the biggest container liner in the world, reported that 1 billion USD is a good estimate of the cost of shipping empty containers for Maersk (Shipping Watch, 2012). As a result, companies have difficulty generating profits and sometimes even run deficits. While there has been a lot of research and development on improving the efficiency of ECR, it was only recently that the shipping industry took steps to create a more suitable environment for segmentations based on service differentiation. A few examples are more reliable services, express services, adding fees for late arrivals which have given new options to liner companies, in terms of segmentation of their services. Based on a segmentation, it is possible to use slot allocation models and revenue management methods in order to accept or reject bookings (Talluri & Ryzin, 2004). This in turn will give carriers the opportunity to achieve better control of the market, better services and more importantly increased revenue and profits and this is exactly what we are trying to show with the results of our research.

Finally, despite their significant differences, we cannot also oversee the similarities with other industries and especially the aviation industry, in which revenue management proved very beneficial for its growth in times of fierce competition and crises, such as in container liner shipping at the current time. Thus, we firmly believe that a focus on development and application of RM methods in liner shipping could prove equally beneficial in the long run.

1.5 Structure

Having presented the main objects and the scope of our research, in the next section, Chapter 2, we will give a brief theoretical background in RM methods and strategies. In that section, we will analyze in depth how revenue management is structured and how it was applied in airline and other transportation industries. Having examined how RM methods faired in other industries, we will examine if and how they can be transferred in the liner shipping industry.

In Chapter 3, we will present past researches that focus on RM methods in liner shipping industry, as well as how research has progressed over the years. Additionally, we will analyze which criteria we will use to choose and compare the models and continue with the selection of the most representative RM models out of the pool in our literature review, in order to answer our first sub-research question.

In the next chapter, we will study in depth the selected models to see exactly how they work and examine the differences in the assumptions, parameters and outcomes. We will analyze the formulation of the selected models as well as examine the simulation results of each model. Chapter 4, along with Chapter 5, that includes the multi-criteria analysis, will help us examine the model differences and we will attempt to compare them in different situations depending on the criteria we selected earlier. That will allow us to answer our second sub-research question.

Finally, in Chapter 6 we will list the results and conclusions of our comparison and discuss which model excels in different situations and why, effectively answering our third sub-research question. That section will also include the added value of our research, paired with suggestions about further research.

2. Theoretical Background

In order to better explain RM tactics, we will decompose them in sub-problems that exist when we try to implement them. Phillips (2005), identified three interrelated sub-problems that are part of tactical RM:

- Network Management
- Capacity Allocation
- Overbooking

Network Management handles bookings for multi-resource products. It is important for industries that sell products consisting of a combination of resources, such as hotels where managing the length of stay is more important than the rate, but not as important to industries that sell single-resource products, such as passenger airliners who sell seats. In liner shipping case, network management is important because of the existence of fixed scheduled services with several ports of origin and destination where the containers booked before the start of the round trip can have different destinations and arrival times as well as the ports a service reaches can have significant imbalances concerning the supply and demand of containers.

Capacity allocation focuses on creating booking limits for single-resource products. In simple words, the question capacity allocation has to answer is how much of each product of constrained capacity, in our case container slots on a vessel, we can sell in two or more different prices.

Overbooking is important where bookings are allowed to cancel or not show without much of a penalty. In liner shipping, despite the effort of some companies such as Maersk to impose them, cancelation fees are either non-existent or insignificant for customers. On the other hand, containers can sit in container yard for weeks if incoming ships are full and shipping lines usually do not compensate their clients either.

These problems are obviously not independent. In particular for liner shipping, capacity allocation and network management are largely connected. However, it is important to separate them as they are not equally important in the different RM industries. In the sections below, we are going to analyze those problems as well as present past research that examined their implementation in transportation industries and especially in liner shipping.

2.1 Revenue Management in airliners and other transportation sectors

Revenue management allows one to control the availability or pricing of services in order to maximize revenues and it has been a topic that has been researched in depth in a lot of transportation industries. Airline Industry is the most characteristic example, where research has been ongoing for decades. A good overview is given by McGill & van Ryzin (1999) where the studies and advancements over the years are analyzed. In airliner industry, the primary problems that require RM methods are capacity allocation and overbooking. Network management is not as important for passenger airliners as seats on a plane are largely a single-resource product. In the past, overbooking was arguably the most important as tickets were sold with little to no penalty and cancellations were frequent. As a result, companies overbooked their flights meaning that a number of passengers could get denied entrance if more people than the available seats on a plane had showed up before a flight. As the regulation against overbooking by airliners has become stricter and companies are now forced to compensate passengers if they are not allowed to board a plane, airliners have significantly increased the amount of non-refundable bookings as well as the surcharges for changing a booking date (Phillips, 2005). As a result, overbooking has become somewhat less important than capacity allocation, however still being critical in revenue management of most airline companies as cancellations, even now, happen quite often. On the other hand, capacity allocation is more critical than ever in the industry. Airliners use RM software in order to set fare classes to tickets depending on criteria such as business or leisure travel, early reservation or late reservation, ability to refund ticket or not and others, while also setting the prices and the capacity limits of the different fare classes. In brief, as Phillips (2005) describes, a fare class is a combination of a price and a set of restrictions on who can purchase the product and when. The application of such methods was a resounding success, favoring the ones who had the tools to implement them and overwhelming those who did not.

Following those advancements, airliners that were also focusing on cargo transportation tried to implement RM methods to air cargo transportation. In this case, we have more multiple-resource products thus network management as well as overbooking were the most significant problems, as cargo capacity in planes is three-dimensional (weight, height, volume) and also uncertain, as it most of the times depends on the amount of capacity the passengers' luggage occupy. A more in depth analysis on air cargo RM methods is given in Houang and Chang (2010) and Zou et al. (2013). Ultimately, in both passenger and cargo airliner industry, RM methods have proven extremely profitable to the companies that applied them.

Those RM systems were so successful that after their implementation in airliner cargo and passenger industry, increasingly more industries were interested in applying similar strategies. This lead to RM methods spreading rapidly as specialized companies, with the experience they had in the airliner industry, started offering software and consultancy on RM in other sectors as well. Thus, despite the various differences between the transportation sectors, we saw a rapid movement towards RM tactics from rail (passenger and cargo) and trucking transportation. Some important studies looking into the advancement of RM in other transportation industries are Guerriero et al. (2012) for trucking, Ciancimino et. al (1999) and Armstrong & Meissner (2010) for railway industry, Geraghty and Johnson (1997) for car rental services and Ladany & Arbel (1991) for cruise liner services.

2.2 Revenue Management in liner shipping

While the revenue management methods are well developed in most other transportation industries, the same cannot be said about liner shipping. The reason behind that is Liner Conferences, which were present in the industry until October 2008 and set global prices so that carriers had little power to change their prices individually (Munari, 2009). In fact, Brooks (2000) finds that revenue management in liner shipping can only work in a non-conference system. Even after the eradication of liner conferences however, transferring revenue management methods directly from other industries into liner shipping could not be easily done, as liner shipping has fundamental differences with other industries. If we take as example the air cargo industry, the space allocated solely for cargo cannot be known in advance, as most of the time a plane's cargo hold is shared with passenger luggage. Another major difference is that in air cargo, as opposed to containers in liner shipping, the size of parcels is not standardized. Finally and more importantly, the network structures of other cargo transportation industries differs significantly from that of liner shipping. Therefore, it is important to have specific models and approaches solely for liner shipping. The reasons mentioned above are the primary reason that there is limited effort in the research of Revenue Management for liner shipping, which we will focus on.

Despite the differences, it would also be necessary to mention the similarities between liner shipping and other cargo transportation industries. Hellerman (2006) analyzed revenue management for air cargo industry and stated that in order to implement an RM system the following 7 characteristics are essential:

- Perishability of the product offered
- Relatively fixed capacity
- Low marginal sales cost and high marginal capacity change cost
- Ability to segment markets
- Sale/Booking in advance
- Stochastic demand
- Forecastable demand

First of all, in the case of liner shipping container slots in a vessel are perishable, as there are schedules and if a slot remains empty, the carrier makes no revenue. Secondly, capacity is fixed and cannot be increased easily unless we replace a vessel with a larger one. The third characteristic is presented with the difference between the operating costs of a ship, which are high compared to the low marginal cost of transporting an additional container. Fourth, we can split the demand of liner shipping into different segments, such as by container size, routes or service that a liner offers. The fifth characterstic is easily identified, as the slots in vessels are sold and booked in advance, which gives the carrier the option to accept/reject a booking depending on a revenue strategy he chooses. The sixth characteristic is applied by the existence of seasons and geographical differentiations that give different regions in different seasons higher or lower demand, thus deeming it stochastic. The final characteristic mentions that demand should be able to be forecasted through the use of historical data, which is clearly the case for liner shipping. Since liner shipping fits all the above characteristics, carriers could theoretically apply revenue management in their operations, in order to increase profits in times when demand exceeds the capacity provided.

Currently in liner shipping, booking agents receive booking requests and have the option to either accept or decline them on the spot. Very rarely do they use decision support tools and instead use their experience in the business to make a decision. More often than not, the strategy used by the booking agents is very similar to an FCFS strategy as their first aim is to maximize vessel utilization. In times such as this, one could argue that it is the most effective strategy, as the overcapacity presented in the current market forces carriers to focus on filling up their ships first and then worry about which cargo bookings are the most profitable. However, as we have seen many times before, cyclicality in the shipping market will sooner or later create circumstances in which vessel capacity is scarce and accepting the more profitable bookings in favor of the less profitable ones, for the available capacity, will be an important issue.

2.3 Market segmentation in liner shipping

Before we dive into the sub-problems mentioned in the above sections, it is very important to look into possible segmentations of the liner shipping market as it is a requirement for the implementation of RM methods. After all, before dividing the products in categories or classes, we need to examine the differences in products and their demands. In fact, Brooks (2000) stated that product differentiation in liner shipping is a very challenging subject, as before we perform a segmentation it is important to know what the criteria are for a customer to choose one product class over the other. At the moment there are three major market segmentation criteria in liner shipping. The first one is container type, as containers differ in sizes, the most common being 20', 40' and 40' High Cube (HC) but also in their use, as we have dry, reefer and special purpose containers that can be loaded on a vessel. Cargo that needs to be refrigerated needs to be transported in reefer containers, oversized cargo needs to go in special containers such as flat rack or open top containers and the rest of the cargo usually travels in dry containers. The second criterion is the network provided by the services of a carrier. A network can consist of one leg or multiple legs and it can also provide transshipment. We will analyze this further in the network management section. The third one is the relationship between the carrier and the shipper. A customer can either be contractual or coming from the spot market. Contractual customers usually enjoy lower, fixed rates and special service agreements.

At the same time, research has been ongoing about additional market segmentation in liner shipping. Collison (1984) performed a market segment analysis on shipping and identified the timeliness of a service as the most significant aspect for segmentation. Additionally, Lu (2007) emphasizes on reliability and the competence of a carrier as competitive advantages and suggests segments that offer valuable services to shippers. In his book, Stopford (2009) attempts to separate the customer preferences depending on their cargo. In fact, he states that delivery, speed and reliability are especially important for those that own high value commodities. Segmentation on delivery speed and urgency is also suggested by Alvarez (2008) and Pompeo and Sapountzis (2002). Similar ideas on segmentation are also presented by Acciaro (2011) in a study in which came up with a model based on advance booking, in order to optimize the trip of a carrier operating one vessel with fixed capacity, from one port to another. The reasoning behind that segmentation is that a client with urgent cargo is willing to pay more to guarantee that his cargo will be loaded on a certain ship that will arrive at an arranged date. On the other hand, a customer that does not care about urgency will not mind waiting for the next available ship if that translates into a lower freight rate for him. The idea emerged from Lufthansa Cargo who introduced a 'time definite' segmentation in 1998 which was soon implemented by other air cargo companies as well (Hellerman, 2006). From the research, we can conclude that there is room for such a segmentation in the liner shipping industry. In fact, Maersk (2010, 2011) publicly announced their effort to segment their services and provide service differentiation for their customers based on delivery reliability and urgency. Firstly in 2010, they started offering priority bookings for higher cost, which meant that if a customer pays a premium, his cargo is guaranteed to be loaded onto the next ship available. This made a difference from a normal booking because if a ship was overbooked, the customer who had cargo booked would have to wait until the next service. With that strategy, a customer can have better control of his cargo depending on if his cargo is urgent or not, as well as Maersk gain additional revenue from the higher charge per container. Another service differentiation policy was announced by Maersk in 2011, called the "Daily Maersk", where they would guarantee transportation time punctuality from each origin port to each destination port for every day of the week, in the Europe-Asia trade route. With this service, a customer can again have the choice between urgency and cost, while the carrier is able to estimate the time ranges of transportation and be more flexible in allocating cargo to the various vessels operating in the Asia-Europe trade route.

Another step towards market segmentation, this time also aiming at improving customer reliability was introduced again by Maersk. In an article in popular maritime news website "JOC.com", Leach (2011) reports that Maersk introduces a "load protection fee" and can develop new booking classes with flexible rebooking costs, in order to enforce reliability from its shippers. This was caused due to the no-show rate of approximately 30% from shippers, as the industry either enforces low fees or not at all for no-shows (Leach, 2011). This RM method is very similar to those the airliners use to tackle the problem of overbooking, as we explained in the sections above.

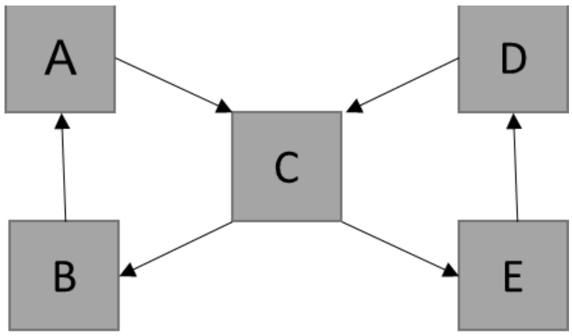
As for the current market situation, Alvarez (2008) reported that, to his knowledge, at least one major liner is following a revenue management strategy. In fact, liner shipping companies have revenue management departments, but little is known about which tactics they are using. The shipping market has been struggling the last few years since the big shipping crisis in 2008 and combined with the current overcapacity from the introduction of constantly larger vessels, pricing strategies are affected by the fierce competition in the market. Fierce competition in turn forces liner shipping companies to be less transparent, as they do not want to share any vital information with their competitors. However, based on the research provided above, we can conclude that the current trend in the industry is segmenting the market by offering differentiated services.

2.4 Network Management in liner shipping

In liner shipping, a carrier offers different services to his customers in order to meet the demand. A single service usually consists of a number of port calls that can be in same or different regions. In most cases, especially in deep-sea shipping, services connect ports in different continents. A carrier can offer single-leg or multi-leg services. A leg is the direct connection between two ports and as such, one service can have multiple legs connecting consecutive ports. In most cases, carriers create services that loop after reaching the final port of call in order to visit each port frequently (Stopford, 2009).

For better interpretation, we will present an example of two services (A-C-B and C-E-D) in Figure 1 below. There are three ports and three legs in each service connecting consecutive ports. As with the majority of services, vessels loop and perform round trips calling the ports. Once a ship has visited all three ports of a service we refer to it as a cycle. The starting point of the first service is port A and of the second service port B. We will assume we can operate multiple vessels in each service and schedule a weekly port call for each port in both services.

Figure 1: Two Service Network Example



Source: Author

It is obvious that we can connect the two services via transshipment. For example, if a customer wants to transport a container from A to D, the carrier will have to load in the vessel performing the first service and do transshipment at port E in order to load the container to the vessel operating the second service. Each booking belongs to a cycle and one booking cycle includes all the bookings that can start on one ship cycle. On the other hand, we can also have a booking that belong to two cycles, such as a booking from port B to port C. In that case, the leg from port A to C will belong in another ship cycle compared to the leg from B to A, as a new cycle starts at A. Thus, we can safely conclude booking cycles and ship cycles are not identical, as they can sometimes overlap.

In the past, researchers focused on studying RM in single-leg networks. Problems with a service between two ports, or multiple ports that are directly connected by one service per pair, represent the majority of past studies. As globalization became a trend and shipping lines tried calling more ports per service in order to cope with increasing supply and demand, we can find quite a few papers that look into multi-leg network problems. Furthermore, the existence of numerous small ports in areas where the liner services only call a few major ports has also led researches to look into the problem of transshipment. Nowadays, there are services that call even more than ten ports in one cycle and this is the reason we will mostly consider this network structure in our models.

2.5 Capacity allocation in liner shipping

Capacity allocation for bookings received is a crucial factor for revenue generation in liner shipping. The FCFS strategy that the majority of liners use at the moment is not always beneficial for profit maximization, as it would be wiser to reject a booking in the present, for a future one that could generate more profit. Models to overcome that issue are presented in other industries such as airlines, hotels and rental cars (Talluri & Ryzin, 2004), however implementing them into liner shipping is not easy and requires multiple adjustments. The most important factor we have to take into account are the capacity restrictions. While liner shipping is generally considered to offer a homogenized service, there are a number of different ship sizes with different capacities and slots as well as several different container types to fit those slots. On top of that, every ship has a deadweight capacity (dwt) which is not only related to the number of containers it can take, but also their weight. Moreover, the number of special container slots varies from one vessel to another. That can mean the number reefer plugs, high cube containers or special container slots (flat racks, open top containers etc.). Furthermore, we also have to consider that all those limitations differ depending on the origin and destination of the vessel, as the contractual customers' capacity changes depending on the port a vessel calls. Finally, an issue that needs to be taken into account is empty container repositioning. Trade imbalances in regions around the world such as between Europe and Asia are causing vessels to travel to one region loaded with a lot more empty containers than on the return leg. Thus, empty containers need to be transported between regions in order to balance the container flow worldwide. Based on the above, it is easy to conclude that the capacity allocation in liner shipping differs significantly from that of other industries, such as for example the one-dimensional capacity allocation of seats in airliner industry.

In a liner shipping network, carriers are trying to allocate the limited capacity they have on their vessels by accepting the bookings that promise the largest potential profit. In order to achieve that, they use booking acceptance strategies, which aided by the segmentation we analyzed earlier, can increase a carrier's profit generation. There is a plethora of booking acceptance strategies already applied in RM of other industries and especially that of airliner industry, but due to the multiple differences, are not always applicable in liner shipping. The three most common strategies we can find in past researches of RM in liner shipping are Booking Limits (BL), Nested Booking Limits (NBL) and Bid Prices (BP) and we are going to analyze them in depth in the following sub-sections.

2.5.1 Booking Limits

Bookings limits are the most simple booking acceptance strategy in RM. A booking limit represents the maximum capacity that can be allocated to a class, after segmentation. Usually in liner shipping, classes consist of a network path, a type of container and a service segment, as explained in previous sections. Through the use of a slot allocation model that determines booking limits, a sales agent can receive decision support when a customer asks for a booking. If the bookings belongs in a class that has already exceeded the maximum capacity set by the model's booking limit, the booking will get rejected. While the approach is easy to understand, it also has a major drawback; bookings limits are fixed. In fact, if a carrier is in a situation where his highest profit class capacity is already booked and he receives another booking, BL strategy will suggest to reject it. Obviously, a carrier rejecting the highest potential profit booking is not a good decision. For that reason, RM companies "nest" their inventory in order to protect the most profitable bookings, as explained below.

2.5.2 Nested Booking Limits

Nested booking limits were developed to avoid the situation in which high-fare bookings were rejected in favor of low-fare bookings. According to Phillips (2005), the concept of NBL is that if one fare class is open for booking then all higher fare classes should be open. It works similarly to BL; again we have slot allocation models that create booking limits for each class fare except in this case, the higher fare classes bookings can be transferred in lower fare classes slots. This means that in a situation where a higher class fare booking is made but the capacity of the said class fare is fully booked, this booking will be accepted and instead take a slot in one of the lower class fare inventory. In that way, potential bookings that generate more profit to a carrier are always preferred against less profitable ones.

2.5.3 Bid Pricing

Bid pricing strategy has a slightly different concept than the other two bid acceptance methods. However, it is by far the easiest method to implement and it also delivers a good revenue performance (Talluri & Ryzin, 2004). The major difference bid pricing has with other strategies is that it is revenue based instead of class based when it comes to controlling prices. Its principle is based on the function of NBL, which suggests the following rule: "A*ccept a single-seat booking request if its associated fare is greater than or equal to the fare in the lowest open class. Otherwise reject it."* (Phillips, 2005, p.164) Therefore, for any booking there can be a minimum acceptance fare, called the bid price. In this strategy, a slot allocation model sets the bid price for a product and a booking is accepted only if the fare exceeds the bid price. BP has the advantage of giving the carrier the choice to use bid price as a measure to control his sales in order to increase his profit, depending on the given demand. As such, in times of scarce capacity a carrier can increase the bid price, in order to have a higher average price and in times where the demand is low he can reduce it to accept more bookings and ensure his vessels are fully loaded. In fact, if bid price is updated optimally depending on the booking requests, any booking accepted should reflect the exact opportunity cost of the customer. However, that is infeasible as bid prices should be recalculated every time a new booking or cancellation occurs, especially if we consider the volume of transactions. Despite that, BP strategy still represents a pretty good estimate of the opportunity cost of the customer and that is what makes it such an important concept.

2.6 Overbooking in liner shipping

Overbooking is the practice of a seller who sells more units than the constrained capacity he has available. The reason this strategy was introduced first in airliner industry, was because of the amount of cancellations and no-shows from the customers. In fact, Smith et al. (1992) present a report for American Airlines in which they state that around 50% of the reservations resulted in either a cancellation or a no-show. That situation is very similar in liner shipping, where cancellations and no shows are subject to insignificant fees or even none at all. It is easily understandable that, unless overbooking is applied, a no-show would equal an empty container slot on a vessels, while other customers wanting to book that slot would be left waiting. Thus, overbooking is a significant strategy for carriers to remain financially viable.

Phillips (2005) states that overbooking is applicable in industries that have the following characteristics:

- Capacity is constrained and perishable and bookings are accepted for future use
- Customers are allowed to cancel or not show
- The cost of denying service to a customer is relatively low

While the first two characteristics are obviously applicable in liner shipping, the third one could be debatable, as the cost can be different for different customers. In airliners, a passenger denied service translated into him having a booking for the next available flight which, in most cases, took off in a few hours. In liner shipping, denying a customer service could mean that his cargo would have to be transported days or even weeks later. In particular, denying service to a shipper with urgent cargo, such as hi-tech products or perishable products could have a much higher cost than denying service to a customer with non-urgent cargo. This is the reason carriers need to develop individual policies depending on the risk they are willing to take denying customers service and the service level they wish to uphold.

For overbooking, booking limits are set for each product before any bookings arrive and serve as a maximum acceptance level of bookings. Once the booking limit is reached, no more bookings are made. A carrier wishing to uphold a high service level will choose a lower booking limit but in the case of no-shows might have unused vessel capacity. On the other hand, a carrier wishing to use a risk-based policy will choose a booking limit much higher than the available capacity and might run into the problem of overcompensating those denied service or losing customer trust. The goal of a carrier's policy is to set the optimal booking limit in order to maximize revenues by correctly predicting the amount of shows and no-shows. While overbooking is not directly related to price, it is an important part of revenue management because it is intertwined with capacity allocation, as overbooking limits give the amount of capacity a carrier makes available for booking.

3. Criteria and selection of models from past research on revenue management in liner shipping

Having analyzed RM methods background in other industries as well as how they function, in this section we will look into findings from previous studies done on the implementation of RM in liner shipping and define the criteria with which we will select the models to conduct our research as well as analyze why we believe the models we select are the most representative in the literature. As mentioned above, Revenue Management in liner shipping has not been given as much attention as other transportation industries. We can only find a few publications that study Revenue or Yield Management in liner shipping and most of them focus on developing a slot allocation model in order to create optimal booking limits for a liner carrier. Segmentation of the container market is usually done by container type, origin/destination route and regarding the customer services offered.

3.1 Literature review on revenue management in liner shipping

The first contribution to the subject can be found as early as 1994, by Maragos, where he studies dynamic capacity allocation and pricing models for the liner shipping industry (Maragos, 1994). Kadar and Proost (1997) also tried to introduce RM methods in the liner shipping industry in order to tackle the fierce competitiveness of the carriers. Finally, Brooks (2000) researched on Revenue Management methods with and without Conference System in liner shipping. It was in that publication that she came to the conclusion that Revenue Management cannot be applied in liner Shipping unless the Conference System is removed, and this is also one of the reasons that there are few publications on the subject prior to the talks for abolishing Conference System which started in 2006 and lasted until the complete removal of the system in 2008.

The last few years, RM has become an upcoming research topic in liner shipping industry and as a result, a number of quantitative models for its application have been developed. Ting and Tzeng (2004) developed an arc flow model for container slot allocation in order to determine the optimal number of containers a carrier must accept between two ports and between the most common container types (20',40',Reefer 20',Reefer 40'). In order to formulate the LSRM model (Liner Shipping Revenue Management), they estimate the average freight and variable cost of each port pair, the minimum and maximum demand of both empty and loaded containers of each port pair but not the inter-port cargo demand. The optimal number of containers, obviously, is subject to the vessels operational capacity. Finally, the model is applied to a case study of a liner carrier in Taiwan, and it achieves excellent results compared to the past strategies. Demirag and Swann (2007) also attempted to find optimal capacity limits for carrier's sale agents, in order to form a capacity allocation model, in a decentralized logistics network. At around the same time, it was Lee et al (2007, 2009) that first tried to formulate a stochastic dynamic programming model so as to solve a single-leg revenue management problem. They separate contractual and spot orders and in their approach, a liner is able to differentiate the contractual container slots in two ways; urgent cargo and cargo that can be delayed. The results they achieve in their two different studies are impressive compared to strategies used at that time, improving the outcome by up to 199%. Similarly, Bingzhou (2008) developed a stochastic model for dynamic capacity allocation on one leg, taking into account multiple container types in order to find the revenue maximizing strategy for a carrier. Acciaro (2011) looked into ways to introduce price differentiation in container liner industry and came up with a model based on advance booking, in order to optimize the trip of a carrier operating one vessel with fixed capacity, from one port to another.

The first multi-leg slot allocation model is presented by Xiangzhi et. al. (2007), where they took empty container reposition into account as well as demand uncertainty and proposed a novel capacity allocation optimization method. Through the use of case studies, it is shown that their method is able to generate better revenue income than deterministic linear programming. Feng and Chang (2008, 2009) focus on short-haul transportation and in particular intra-Asia, and they formulate an RM slot allocation model for multiple ports where the capacity is restricted at the loading port. They take into consideration the dimensions of the containers as well as the demand and capacity of the ports of call and they separate the containers in three types depending on which port they are loaded and which port they are destined to be unloaded at. Lu et. al. (2010) also focus on short-haul trip and construct a path flow model in order to maximize potential profit per round trip voyage with multiple ports for a liner company. They take into account demand, slot, deadweight and reefer capacities as well as empty container repositioning restrictions and they come up with a very interesting result, that 40 feet containers and reefers have higher contribution than other types of containers. Løfstedt et. al. (2008) compare a path flow and an arc flow model in revenue management for a liner shipping company, while taking empty container repositioning into account. The significant difference with previous researches, is that their model also takes the time factor into account, creating a time-space network for a liner company. Since the model takes into account multiple commodities, demand is estimated for each commodity defined by the origin, destination and demand per unit. The results of the algorithm help them conclude that the path flow model, with a column generation algorithm, outperforms the arc flow model in all instances.

While the above researches look into designing slot allocation models, most of them do not go deeper into the bid acceptance methods. To our knowledge, the only study that looks into the different bidding acceptance strategies, is that of Zurheide and Fischer (2011, 2012, and 2015). They design a network slot allocation problem for a liner shipping company that considers different path, transshipment and service segmentation. The segmentation of the network is created in their initial paper in 2011 by separating different kind of container types but also urgent and non-urgent containers, which the customer can choose to book depending on the cargo he wants to transport. Their additional publications in 2012, present network allocation models that determine booking limits (2012b) and nested booking limits (2012a), strategies that are very popular in Revenue Management theory. Their last paper in 2015 also introduces a bid price strategy, and then compares the three strategies to determine the one that is the best performing in different scenarios through the use of simulation. The simulation comes up with a variety of results, depending on the criteria and scenarios, however the bid price strategy appears to have the highest performance in most realistic scenarios.

3.2 Criteria for the selection of revenue management methods

Having presented the existing literature on RM in liner shipping, a very important question that has to be answered is defining the criteria with which we select the models for comparison. While comparing all the studies conducted on the subject would be the best solution, it would not be optimal in terms of time and feasibility. Therefore, in order to categorize the models and select the most representative of the pool, we have to define the criteria that lead us to choose certain models over others. In general, the criteria for a revenue management method to be valuable is to be maximizing profits in a realistic situation while at the same time avoid being over complex, in order to have the smallest solving time possible. More specific, the criteria can be further analyzed depending on the network structure, formulation of the slot allocation model and service segmentation, as explained below.

Firstly, criteria for the categorization of the models can be derived from the network structure, as depending on that there can be significant differences between the models. As analyzed in the literature review, there are existing models that focus on single-leg or multi-leg networks. There are compelling structural differences between those models, as a single-leg model optimizes the capacity allocation for containers in a single trip with set origin and destination ports, while multi-leg optimizes a liner's network of services with multiple origin and destination ports. Another important criterion for separating the models is their formulation. We can find both arc and path flow models in existing literature and this is closely related to the network management criterion. In particular, Løfstedt, et al. (2008) found that path flow formulation outperforms arc flow formulation in optimization problems of today's international liner shipping networks. It is easily understandable, that depending on the network size and complexity the formulation of a model can be different which can also effect the time required to achieve results from it. Finally, the creation of a short-sea network or a deep-sea network is another criterion by which we can separate and compare the models. Short-haul services tend to have less travel time, lower capacity and as a result more loops between port pairs in a network.

Market segmentation of the respective models can also provide different criteria for their comparison. Each container type taken into account makes a model more complex but also closer to reality in liner shipping. For example, the existence of reefer containers with reefer plugs or open top containers could be ignored in a model for reasons of simplicity, but then the model would not provide results that would be easily applicable in a realistic situation. Similarly, further service segmentations adds complexity but also are capable of providing extra revenue generation for a carrier. As explained in the chapters above, segmenting the services of a liner shipping network, such as for example for urgent and non-urgent cargo, can increase profitability and market share for a carrier. Furthermore, assumptions made for ports' demand and supply as well as fixed capacity slots on ports and vessels, such as that for contractual customers, can serve as criteria for the differentiation of the models. Finally, empty container repositioning plays a major role in container slot allocation, as empty containers often take up a significant amount of slots on vessels, thus limiting the capacity. In fact, estimating trade imbalances between ports is very significant for the formulation of a revenue management method and can also be taken into account when comparing different models.

3.3 Selection of the models

Having analyzed the criteria for the comparison of different models, the models chosen must best represent the existing literature presented above. We have selected the following models; the liner shipping revenue management model (LSRM) of Ting and Tzeng (2004), the short-sea slot allocation model of Lu et al. (2010) and the four level network slot allocation model of Zurheide and Fischer (2015) that also considers bidding acceptance strategies.

The reason we believe those models best represent the revenue management method pool is that they combine the majority of the criteria we mentioned in the section above. The LSRM by Ting and Tzeng (2004) is a single-leg arc flow model that takes into account empty container repositioning and segments the container types into 20', 40', Reefer 20'and Reefer 40', ignoring special type containers as well as high cubes while also not taking into account contractual customers and not looking into service segmentation. They estimate the freight rates, variable costs, minimum and maximum cargo demand between each origin-destination port pair but do not take inter-port cargo demand. On the other hand, the path flow multi-leg model of Lu et. al (2010) focuses on short-haul transportation, while also taking into account empty container repositioning. They split the container types into every possible segmentation, namely 20',40', Reefer 20', Reefer 40', High cubes and special purpose containers (open top, flat rack) but do not take into account contractual customers and do not look into possible service segmentations. They estimate the average contribution and cost per container type and the upper and lower bounds of allocated slots in each port-pair. Finally, the path flow four-level network slot allocation model of Zurheide and Fischer (2015) also takes into account empty container repositioning, except in some parts of their simulation, and segments the containers into any possible type by using a parameter for their dimension. In their model, they assume contractual customers' capacity as fixed, due to the lack of access to information and also perform service segmentation by separating ship cycles from booking cycles so as to offer differentiated services. The estimate the average price and cost of transporting a container but also empty repositioning costs and storing or leasing containers as, in their model, containers in a port have been stored there from a previous time or are leased when the vessel arrives. Another major difference from the other models is that time is taken into consideration, in order to calculate trade imbalances between port-pairs as a round trip is being performed. In this case, demand is forecasted for each different service segment. At the end, they also look into bidding acceptance strategies by modifying their slot allocation model for BL, NBL and BP in order to test their performance.

We believe the diversity of the models we chose represents the variety of the models presented in our literature review well enough in order to examine each different criterion we set in the above section. In the next sections, we will present the models further in order to analyze them in depth and finally we will perform a multi-criteria analysis comparison to find out which one is more beneficial.

4. Revenue management models

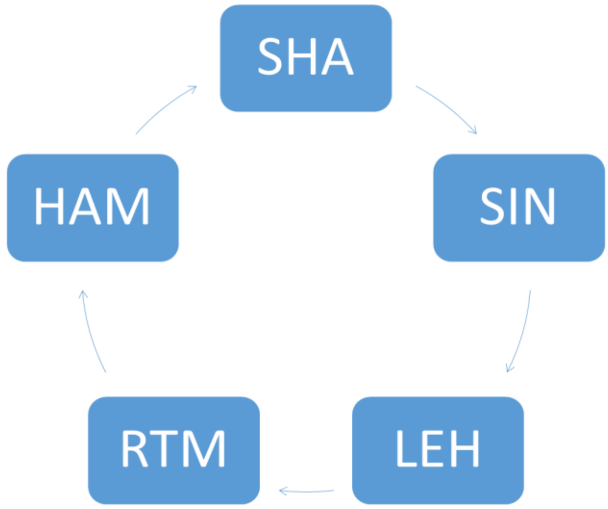
4.1 Ting and Tzeng (2004)

4.1.1 Network and slot allocation model

In this section, we will present the quantitative slot allocation model formulated by Ting and Tzeng (2004). A single voyage trip is represented and there are four container types taken into account (20’, 40’, 20’ Reefer and 40’ Reefer). Service segmentation is not considered and empty container repositioning is also included in the formulation. An example of the network is shown in Figure 2 below. It shows a simple Asia-Europe route calling at Shanghai (SHA), Singapore (SIN), Le Havre (LEH), Rotterdam (RTM) and Hamburg (HAM) before returning to Shanghai and starting over. The authors formulated a model that allocates vessel capacity (slots) to every origin to destination port pair efficiently in order to maximize marginal contribution. Their model focuses on the slot allocation problem voyage by voyage.

Average freight rates and variable costs have to be estimated for each port pair but the inter-port cargo demand is not taken into consideration. Finally, highest and lowest demand of each container type and empty container imbalances have to be forecasted based on historical data. Following, having explained the network, we will explain the decision variables, indexes and parameters of the slot allocation model.

Figure 2: Service Network



Source: Author

- The following indices are presented in the model:

  $i = Index\ of\ loading\ port, i = 1,2, \ldots, m$

  $j = Index\ of\ discharging\ port, j = 1,2, \ldots, n$

  $k = Index\ of container\ type\ where\ k = 1\ for\ 20', k = 2\ for\ 20' Reefer,\ \ k = 3\ for\ 40', k = 4\ for\ 40' Reefer$

  $f = Index\ of\ slots\ for\ loaded\ containers$

  $e = Index\ of\ slots\ for\ empty\ containers$

- The following decision variables are presented in the model:

x_{ijk}^{f}: Number of loaded containers of type k shipped from port i to port j.

x_{ijk}^{e}: Number of empty containers of type k shipped from port i to port j.

- The following parameters are presented in the model:

MC_{ijk}: Marginal contribution of each container of type k delivered from port i to port j.

$$MC_{ijk} = FR_{ijk} - VC_{ijk}\ (\mathbf{1})$$

FR_{ijk}: Freight revenue of each container type k delivered from port i to port j.

VC_{ijk}: Variable costs of each container type k delivered from port i to port j. Those include truck, feeder, railway, handling, terminal, stowage, commission, tally and cargo claim costs.

EC_{ijk}: Repositioning costs of each container type k delivered from port i to port j. Those include inland transport, feeder, handling and holding costs.

IF_{ijk}: Imbalance factors of type-k container flow from port i to port j.

$$IF_{ijk} = \begin{cases} (F_{ijk} - F_{jik})/F_{ijk} & if\ F_{ijk} > F_{jik} \\ 0 & if\ F_{ijk} \leq F_{jik} \end{cases} \quad (\mathbf{2})$$

F_{ijk}: The type-k container flow from port i to port j during a period of time.

CP: The operational capacity of the vessel in TEU.

DW: Deadweight tonnage of the vessel in tons.

W_{ijk}^{f}: The average total weight in tons of each loaded container of type k delivered from port i to port j.

W_{k}^{e}: The tare weight of each empty container of type k.

RF: The maximum amount of reefer plugs in a vessel.

FE: The maximum amount of 40' containers able to be loaded in a vessel.

D_{ijk}^{L}: The minimum contracted k-type container slot number from the agent at port I to port j.

D_{ijk}^{U}: The maximum contracted k-type container slot number from the agent at port I to port j.

CI_{jk}: The repositioning demand of containers of type k to be supplied to port j.

Having analyzed all the indices, parameters and decision variables below we will present the slot allocation model, whose purpose is to maximize the freight contribution of the whole voyage.

$$MaxZ = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{4}(MC_{ijk} - IF_{ijk}EC_{ijk})x_{ijk}^{f} - EC_{ijk}x_{ijk}^{e} \quad (\mathbf{3})$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{4}(x_{ijk}^{f} + x_{ijk}^{e}) + 2 * \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=3}^{4}(x_{ijk}^{f} + x_{ijk}^{e}) \leq CP \ (\mathbf{4})$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{4}(W_{ijk}^{f}x_{ijk}^{f} + W_{k}^{e}x_{ijk}^{e}) \leq DW \ (\mathbf{5})$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=2,4} x_{ijk}^{f} \leq RF \ (\mathbf{6})$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=3,4}(x_{ijk}^{f}+x_{ijk}^{e})\leq FE\ (\mathbf{7})$$

$$x_{ijk}^{f}\geq D_{ijk}^{L}\ \forall i,j,k(\mathbf{8})$$

$$x_{ijk}^{f}\leq D_{ijk}^{U}\ \forall i,j,k\ (\mathbf{9})$$

$$\sum_{i=1}^{m}x_{ijk}^{f}\geq CI_{jk}\ \forall i,j,k\ (\mathbf{10})$$

$$x_{ijk}^{f}\geq 0\ (\mathbf{11})$$

$$x_{ijk}^{e}\geq 0\ (\mathbf{12})$$

With the objective function (3) the freight contribution is maximized by subtracting the repositioning cost of loaded and empty containers from the total marginal contribution of all container types. Constraints (4) and (5) are the capacity restrictions. Constraint (4) explains that the slots for both empty and loaded containers cannot exceed the operational capacity of the vessel and constraint (5) that the weight of both empty and loaded containers cannot exceed the deadweight capacity of the vessel.

Constraints (6) and (7) are vessel specification constraints, the first restricting more reefer containers than there are reefer slots available on a vessel and the second restricting empty and loaded 40' or 40' reefer containers exceeding the maximum designed capacity for 40' containers on a vessel.

Equations (8), (9) and (10) are demand constraints. Constraint (8) and (9) set the slots allocated to each origin-destination leg between the interval of lower and upper bound of demand for those ports. Represented as equation (10), the total slots for empty containers cannot exceed the repositioning demand of containers of type k that must be supplied to port j.

Finally, constraints (11) and (12) are the integrality restriction on the decision variables. Obviously, the amount of empty and loaded containers cannot be negative.

4.1.2 Simulation results

In order to examine how their model fares against the booking strategies at the time, the authors perform a case study based on a liner company in Taiwan that operates eight vessel on a service route calling eleven ports so as to be able to offer weekly service for each one of those ports. They assume vessels of identical capacity of 3,350 TEU, 36,510 dwt that are equipped with 200 reefer plugs and 1,135 40' maximum container slots. The average variable costs, the average freight costs as well as container and repositioning demand are imported from databases and the results of the model are extracted using optimization software. Furthermore, to make things simpler for container liner agents and operators, they simplify the model into a Microsoft Excel file so it can be easily utilized.

Despite most RM models aiming for maximization of revenue, in this case the authors also focus on marginal contribution because of the high variable costs of liner shipping. For the comparison of the results, past lifting and revenue data are used and they find that the average revenue and marginal contribution generated by the model is significantly greater than the past average revenue and contribution. Moreover, results show that even with the higher contribution, the load factor remains at approximately 93%, simply because the deadweight utilization is almost 100%. In fact, it is suggested that the operators who choose to use this model should continuously monitor space usage and adjust allocation accordingly, as the parameter of weight of loaded containers appears to be very sensitive when the deadweight limit of a vessel is not enough to load all containers, thus allocating less slots to load heavy containers to fulfill the demand. It is for that reason that the authors conclude that the marketing strategy of a carrier should revolve around attracting lower weight cargo demand as that will assist the goal of fully utilizing capacity and having high contribution at the same time.

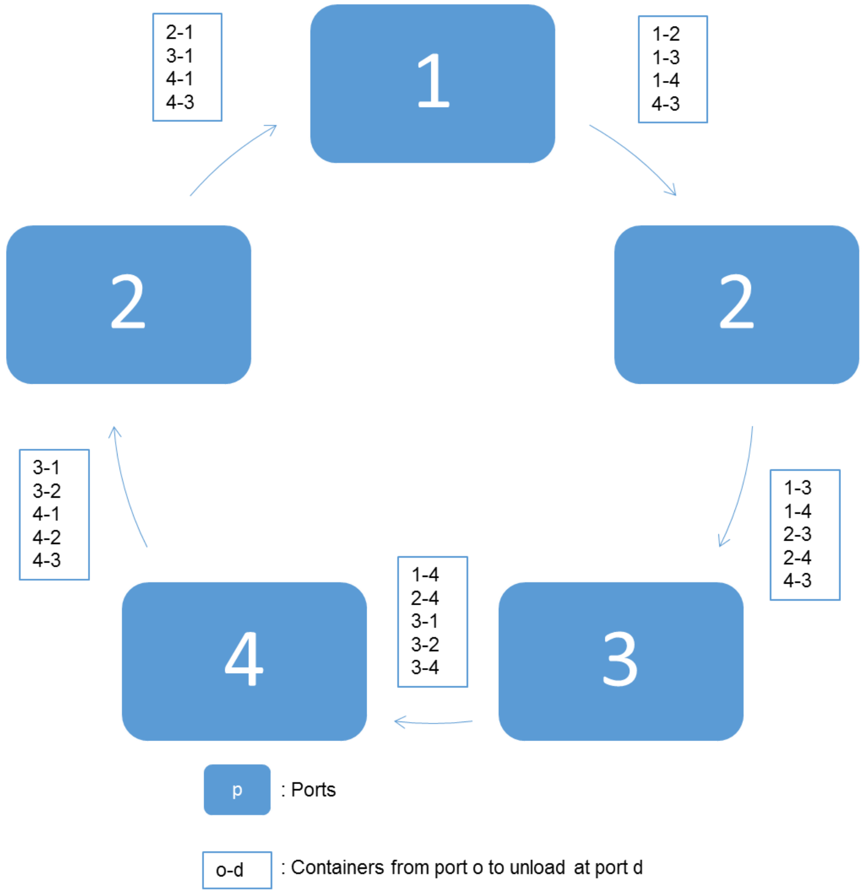
4.2 Lu et. al (2010)

4.2.1 Network and slot allocation model

In this section, a model by Lu et. al (2010) is presented. In their model containers of all types and dimensions are taken into account as well as empty container repositioning. The path-flow model is formulated in a multi-leg network with rotated services on a fixed, circular port rotation. As the primary focus is short-haul transportation within a region, a shipping company prefers to arrange the path with the shortest travel time and this means that containers of multiple categories that are on board of the vessel may come from various port pairs and the slot allocation must maintain the relationships between sailing legs and port pairs, as the sailing legs have fixed capacity. An example network is shown in Figure 3 below, where a round trip voyage of five calls with 4 ports is demonstrated as well as the relationship between sailing legs that are demonstrated by the arrows, and the port pairs. In the network, twelve port pairs are included as well as five sailing legs and the rotation is 1-2-3-4-2-1.

The average price/contribution and variable cost per container have to be estimated as well as lower and upper demand of containers between each port pair. While there is empty container repositioning in the model, there is no forecasting or estimation of trade imbalance between the areas, which means that the model assumes there is empty containers constantly available in all ports of the network. Following, the indexes, decision variables and parameters of the model will be explained.

Figure 5: Example short-sea network with sailing legs and port pairs



Source: Author

- The following indices are presented in the model:

$E: Set\ of\ category\ indices\ for\ empty\ containers.$

$H: Set\ of\ category\ indices\ for\ laden\ containers.$

$R: Set\ of\ category\ indices\ for\ laden\ reefer\ containers.$

$A_k: Set\ of\ ports\ of\ origin\ for\ empty\ containers\ of\ category\ k, k \in E$

$L_k: Set\ of\ ports\ of\ destination\ for\ empty\ containers\ of\ category\ k, k \in E$

- The following decision variables are presented in the model:

x_{od}^{k}: Number of allocated slots for k-type containers delivered from port o to port d.

- The following parameters are presented in the model:

p_{od}^{k}: Estimated average price or contribution per container of type k delivered from port o to port d.

c_{od}^{k}: Estimated average variable cost per container of type k delivered from port o to port d.

a_{od}^{s}: A parameter that to represent if the container delivery passage of port pair (o,d) passes leg s. 1 if that is true, 0 otherwise.

t^{k}: Capacities occupied in TEU per container of category k.

w_{od}^{k}: Average weight in tons per container of type k delivered from port o to port d.

l_{od}^{k}: Lower bound of carried containers of type k delivered from port o to port d.

u_{od}^{k}: Upper bound of carried containers of type k delivered from port o to port d.

n_{o}^{k}: Maximum number of empty containers of type k that can be repositioned from port o.

m_{d}^{k}: Maximum number of empty containers of type k that can be repositioned to port d.

U: Capacity of the vessels in TEU.

Z: Number of reefer plugs on board of the vessel.

DWT_{s}: Deadweight capacity in tons on leg s. It may be decreased depending on draft limitations in different ports.

Having analyzed all the indices, parameters and decision variables below we will present the slot allocation model, whose purpose is to maximize profits per round trip voyage.

$$Max \sum_{k} \sum_{(o,d)} (p_{od}^{k} - c_{od}^{k}) x_{od}^{k} \quad \mathbf{(1)}$$

$$\sum_{k \in H} \sum_{(o,d)} a_{od}^{s} t^{k} x_{od}^{k} \leq U \quad \forall s \quad \mathbf{(2)}$$

$$\sum_{k \in H} \sum_{(o,d)} a_{od}^{s} w_{od}^{k} x_{od}^{k} \leq DWT_{s} \quad \forall s \quad \mathbf{(3)}$$

$$\sum_{k \in R} \sum_{(o,d)} a_{od}^{s} x_{od}^{k} \leq Z \quad \forall s \quad \mathbf{(4)}$$

$$l_{od}^{k} \leq x_{od}^{k} \leq u_{od}^{k} \;\; \forall (o,d), k \in H \;\mathbf{(5)}$$

$$\sum_{d \in L_{k}} x_{od}^{k} \leq n_{o}^{k} \quad \forall k \in E, o \in A_{k} \mathbf{(6)}$$

$$\sum_{o \in A_k} x_{od}^k \leq m_d^k \; \forall k \in E, o \in L_k \; (\mathbf{7})$$

$$x_{od}^k \geq 0 \;\; and \; integer \; \forall (o,d), k \; (\mathbf{8})$$

With the objective function (1) the profit is maximized by subtracting the variable costs of transporting both empty and loaded containers from the average price/contribution per unit of all types of containers. Constraints (2) and (3) are the capacity constraints, (2) limiting the amount of loaded containers of all type to the maximum TEU capacity of the vessels and (3) limiting the weight of the containers to the maximum deadweight capacity of the vessel on each sailing leg. Similarly, equation (4) is a constraint for the reefer containers, making sure that the amount of reefers do not exceed the number of plugs available on board.

Constraint (5) indicates that the loaded containers have to be between the lower and upper bounds of allocated slots for laden containers. Equations (6) and (7) deal with empty containers. Constraint (6) indicates that empty containers transported out of port o cannot exceed the maximum amount that can be repositioned from it while constraint (7) ensures empty containers transported in port d cannot exceed the maximum amount that can be repositioned to it. Finally, constraint (8) ensures nonnegative and integer variables.

4.2.2 Simulation results

For the examination of the model in realistic situation they study its application on a short sea service of JTC that serves 12 ports, namely Tokyo, Yokohama, Nagoya, Osaka, Kobe, Oita, Keelung, Kaohsiung, Hong Kong, Laem Chabang, Bangkok, and Taichung. Between those ports exist 16 sailing legs and the service is performed in a loop. They assume four vessels of identical size and capacity of 1100 TEU, 15400 tons deadweight capacity and 100 reefer plugs. Because of the existence of a plethora of special container types along with the usual sizes, they obtain the weight of each category of containers from the liner company. Furthermore, as prices and costs are confidential, they are estimated using older public data. In fact, assumptions are also made for the cost contents, based on suggestions of JTC, such as 50% less cost for empty container compared to loaded and empty reefer containers costing the same amount as empty dry containers. Finally, demand per port pair is estimated based on the predictions of the carrier.

In order to see how their slot allocation fares, they test it against the original slot allocation plan of the shipping company. As the price is confidential, they are not able to extract any profit differences from the company's plan, but it is noted that higher utilization rate and more detailed allocation is achieved. Specifically, they find that categories such as reefer (20' and 40') containers and 40' containers reach very close to their upper bounds of demand while others, such as 20' dry containers do not. Primarily, this happens because of the higher unit profit of those categories that lead to the model to try to achieve maximum allocation for those types of containers. To prove that point, an increase in 20’ dry container price is tested and the results show that in that case, the allocated slots for that type of container will greatly increase. Besides unit profit contribution, another factor that influences how the different categories of containers are allocated are the operational constraints from the different rotated services. Finally, the authors find that contribution of empty containers is a lot less significant than that of laden containers, but not so much that it can be neglected entirely.

4.3 Zurheide and Fischer (2015)

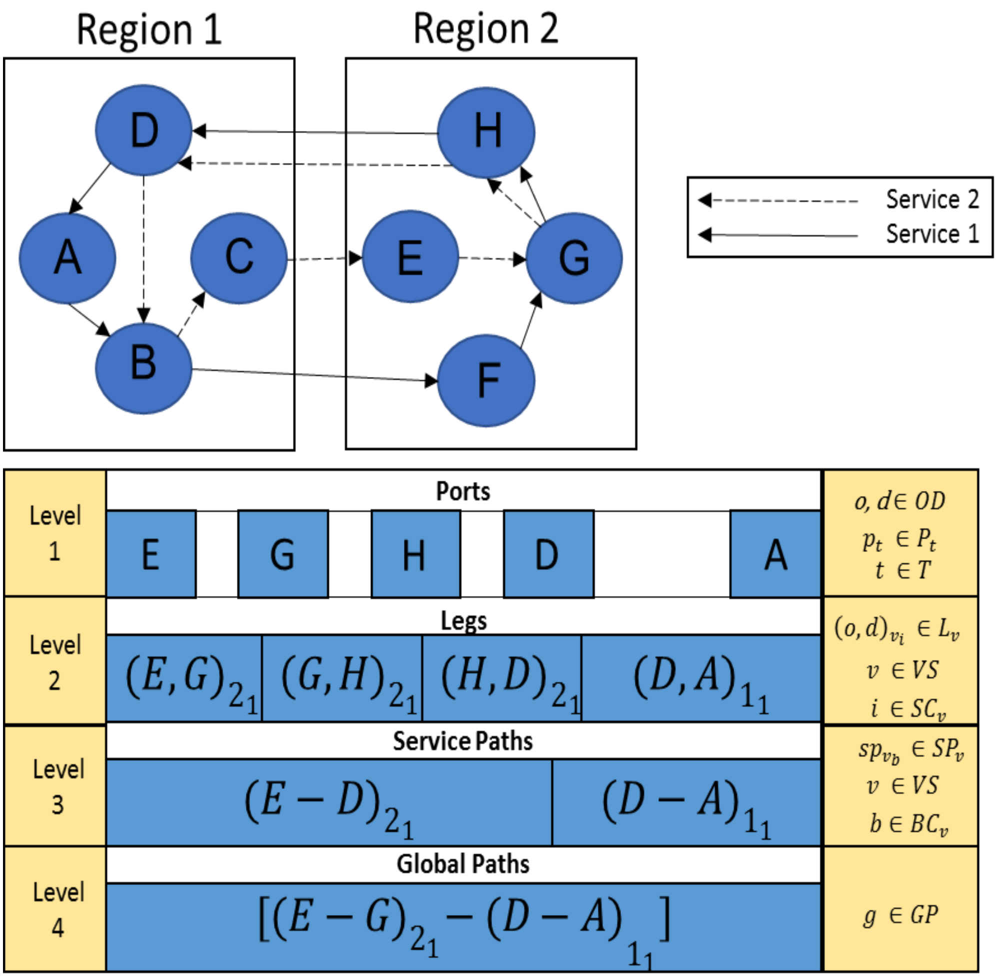
4.3.1 Network and slot allocation model

The quantitative model we present is a modified version of that presented in Zurheide and Fischer (2015) and it takes into account container type and priority service segmentation while the network is structured in such a way to allow transshipment as well as the existence of ship and booking cycles. Different services are included along with the vessels deployed on them and the legs’ capacity restriction are taken into account for each ship cycle. Depending on the booking cycles, there are different service paths and series of those service paths create global paths in the liner shipping network. Finally, ports are considered in different time seasons, presenting different supply and demand in order to deal with empty container repositioning.

Three different modification of the model are presented after the slot allocation model, representing the three bidding acceptance strategies we are comparing, namely BL, NBL and BP. The model represents a liner shipping company’s network and its goal is to provide booking limits, nested booking limits and the minimum bid price respectively for each container type and service segmentation on the global paths, depending on the strategy we want to apply. It is very important to note, that the authors consider contractual customers a fixed capacity constraint and thus, only spot market customers are considered variable.

It is a path flow formulation model, as in a similar situation, Løfstedt et. al. (2008) found that it outperforms the arc flow formulation model, and create a network structure that consists of four levels. On the first level, we have the different origin and destination ports $o, d \in OD$, where OD is the total set of ports. A port is also defined $p_t \in P_t$ where it is time indexed by $t \in T$, where T is the set of all the time seasons. The ports are specified by a time index in order to be able to examine the supply and demand of empty containers at different seasons. The legs, which consist of an origin (o) and destination (d) port are defined in the second level. For each leg, there is a combination of a vessel and a service $v \in VS$, where VS are all the vessel/service combinations available. In addition, each leg is also indexed by a cycle $i \in SC_v$, where SC_v are the available sets of ship cycles of a certain vessel/service combination v. In the third level, the service paths $sp \in SP_v$ are defined, where SP_v includes all the service paths for the combination of a vessel service v. A service path is created by sequencing the legs of a service and in addition to v, it is also specified by a booking cycle $b \in BC_v$, BC_v being all the sets of booking cycles of the vessel/service combination v. As we analyzed above, a booking cycle consists of all the bookings on the service path that can start on a specific ship cycle. Finally, at the fourth level global paths $g \in GP$ are introduced, where GP is the set of all possible global paths, as well as two indices; service segment $s \in SS$, SS being all the possible service segments and container type $c \in CT$, with CT being the set of different available

Figure 6: Four Level Network Example



Source: Author

container types. We further analyze the structure of the four level network in Figure 2 above, displaying an example network. After explaining the network, in the following, we will define the decision variables and the parameters in order to present the model. The goal of the model is to determine how many containers slots on each segment and each service should be provided so as a carrier can maximize profit and it is based on a demand forecast. For the demand forecast and for variables such as freight rates and container weights average values are used based on historical data.

- The following decision variables are presented in the slot allocation model:

x_{gsc}^{F} : Number of slots for full (F) containers on a global path (g) in a certain service segment (s) for a container type (c).

x_{gc}^{E} : Number of slots for empty (E) containers on a global path (g) for a container type (c).

$x_{scsp_{v_b}}^{F}$: Number of slots for full (F) containers of a container type (c) in a service segment (s) on a certain service path (sp_{v_b}).

$x_{csp_{v_b}}^{E}$: Number of slots for empty (E) containers of a container type (c) on a certain service path (sp_{v_b}).

$x_{cp_t}^{L}$: Number of leased containers (L) of a container type (c) in a port (p) at a particular time (t)

$x_{cp_t}^{S}$: Number of stored containers (S) of a container type (c) in a port (p) at a particular time (t)

- The following parameters are presented in the slot allocation model:

$CAP_{(o,d)_{v_i}}$: Available capacity of the leg $(o,d)_{v_i}$ in TEU.

$DW_{(o,d)_{v_i}}$: Deadweight of the leg $(o,d)_{v_i}$ in tons.

$RP_{(o,d)_{v_i}}$: Number of reefer plugs available in the leg $(o,d)_{v_i}$.

$W_{csp_{v_b}}^{F}$: Average weight of a full container (F) of a type (c) on a certain service path (sp_{v_b})

W_{c}^{E}: Average weight of an empty container (E) of type c.

D_c: Dimension of a container of type c.

U_{scg}: Forecasted demand in service segment s of container type c on global path g.

P_{scg}: Average price for a container type c in service segment s on global path g.

C_{cg}^{F}: Average cost of transporting a full container (F) of type c on global path g.

C_{cg}^{E}: Average cost of transporting an empty container (E) of type c on global path g.

C_{cp}^{S}: Average cost of storing a container type c in port p.

C_{cp}^{L}: Average cost of leasing a container type c in port p.

$M_{so_{v_i}}$: Maximum number of containers in a service segment s that can be loaded at port o ∈ OD.

ST_{cp_0}: Stored containers of type t in the first period in port q.

$$Y_{(o,d)_{v_i}sp_{v_b}}^{B} \begin{cases} 1 \; if \; leg \; (o,d)_{v_i} \in L_v \; is \; used \; by \; service \; path \; sp_{v_b} \in SP \\ 0 \; otherwise \end{cases}$$

$$Y^{BSt}_{(o,d)_{v_i} sp_{v_b}} \begin{cases} 1\ if\ leg\ (o,d)_{v_i} \in L_v\ is\ the\ start\ of\ the\ service\ path\ sp_{v_b} \in SP \\ 0\ otherwise \end{cases}$$

$$Y^{QSt}_{p_t sp_{v_b}} \begin{cases} 1\ if\ port\ p_t \in P_t\ is\ the\ start\ port\ of\ the\ service\ path\ sp_{v_b} \in SP \\ 0\ otherwise \end{cases}$$

$$Y^{QEn}_{p_t sp_{v_b}} \begin{cases} 1\ if\ port\ p_t \in P_t\ is\ the\ end\ port\ of\ the\ service\ path\ sp_{v_b} \in SP \\ 0\ otherwise \end{cases}$$

$$Y^{G}_{sp_{v_b} g} \begin{cases} 1\ if\ service\ path\ sp_{v_b} \in SP\ is\ part\ of\ the\ global\ path\ g\ \in GP \\ 0\ otherwise \end{cases}$$

The purpose of the slot allocation model we present below is to find the slots that should be allocated to different container types on different service segments. The initial model determines the booking limits and afterwards we also present modifications of the model in order to give nested booking limits and the bid price.

$$max \sum_{s \in SS} \sum_{c \in CT} \sum_{g \in GP} (P_{scg} - C^F_{cg})\, x^F_{gsc} - \sum_{c \in CT} \sum_{g \in GP} C^E_{cg}\, x^E_{gc} - \sum_{c \in CT} \sum_{p_t \in P_t} C^L_{cp}\, x^L_{cp_t} - \sum_{c \in CT} \sum_{p_t \in P_t} C^S_{cp}\, x^S_{cp_t} \quad \mathbf{(1)}$$

$$\sum_{c \in CT} D_c \sum_{sp_{v_b} \in SP_v} Y^B_{(o,d)_{v_i} sp_{v_b}} \Big(\sum_{s \in SS} x^F_{scsp_{v_b}} + x^E_{csp_{v_b}}\Big) \le CAP_{(o,d)_{v_i}} \ \mathbf{(2)}$$

$$\forall (o,d)_{v_i} \in L_v\ with\ v \in VS\ and\ i \in SC_v$$

$$\sum_{c \in CT} \sum_{sp_{v_b} \in SP_v} Y^B_{(o,d)_{v_i} sp_{v_b}} \Big(W^F_{csp_{v_b}} \sum_{s \in SS} x^F_{scsp_{v_b}} + W^E_c x^E_{csp_{v_b}}\Big) \le DW_{(o,d)_{v_i}} \ \mathbf{(3)}$$

$$\forall (o,d)_{v_i} \in L_v\ with\ v \in VS\ and\ i \in SC_v$$

$$\sum_{c \in CT_R} \sum_{sp_{v_b} \in SP_v} Y^B_{(o,d)_{v_i} sp_{v_b}} \sum_{s \in SS} x^F_{scsp_{v_b}} \le\ RP_{(o,d)_{v_i}} \ \mathbf{(4)}$$

$$\forall (o,d)_{v_i} \in L_v\ with\ v \in VS\ and\ i \in SC_v$$

$$\sum_{c \in CT} \sum_{sp_{v_b} \in SP_v} Y^{BSt}_{(o,d)_{v_i} sp_{v_b}} x^F_{scsp_{v_b}} \le M_{so_{v_i}} \ \mathbf{(5)}$$

$$\forall s \in SS, \forall (o,d)_{v_i} \in L_v \ with\ v \in VS\ and\ i \in SC_v$$

$$\sum_{sp_{v_b} \in SP_v} Y^{QEn}_{p_t sp_{v_b}} (x^E_{csp_{v_b}} + \sum_{s \in SS} x^F_{scsp_{v_b}}) + x^L_{cp_t} + x^S_{cp_{t-1}} = \sum_{sp_{v_b} \in SP_v} Y^{QSt}_{(o,d)_{v_i} sp_{v_b}} (x^E_{csp_{v_b}} + \sum_{s \in SS} x^F_{scsp_{v_b}}) + x^S_{cp_t}\ \mathbf{(6)}$$

$$\forall c \in CT, \forall \mathrm{p_t} \in \mathrm{P_t}\ with\ t \in T$$

$$x^S_{cp_0} = ST_{cp_0}\ \forall c \in CT, \forall \mathrm{p_0} \in \mathrm{P_0}\ (\mathbf{7})$$

$$x^F_{gsc} \leq U_{scg}\ \forall s \in SS, \forall c \in CT, \forall g \in GP\ (\mathbf{8})$$

$$\sum_{g \in GP} Y^G_{sp_{v_b} g} x^F_{gsc} = x^F_{scsp_{v_b}}\ \forall s \in SS, \forall c \in CT, \forall g \in GP, \forall sp_{v_b} \in SP_v\ with\ v \in VS\ and\ b \in BC_v\ (\mathbf{9})$$

$$\sum_{g \in GP} Y^G_{sp_{v_b} g} x^E_{gc} = x^E_{csp_{v_b}}\ \forall c \in CT, \forall g \in GP, \forall sp_{v_b} \in SP_v\ with\ v \in VS\ and\ b \in BC_v\ \ (\mathbf{10})$$

$$x^F_{gsc} \geq 0\ \forall s \in SS, \forall c \in CT, \forall g \in GP\ (\mathbf{11})$$

$$x^E_{gc} \geq 0\ \forall c \in CT, \forall g \in GP\ (\mathbf{12})$$

$$x^F_{scsp_{v_b}} \geq 0\ \ \forall s \in SS, \forall c \in CT, \forall sp_{v_b} \in SP_v\ with\ v \in VS\ and\ b \in BC_v\ (\mathbf{13})$$

$$x^E_{csp_{v_b}} \geq 0\ \forall c \in CT, \forall sp_{v_b} \in SP_v\ with\ v \in VS\ and\ b \in BC_v\ (\mathbf{14})$$

$$x^L_{cp_t} \geq 0\ \forall c \in CT, \forall \mathrm{p_t} \in \mathrm{P_t}\ with\ t \in T\ (\mathbf{15})$$

$$x^S_{cp_t} \geq 0\ \forall c \in CT, \forall \mathrm{p_t} \in \mathrm{P_t}\ with\ t \in T\ (\mathbf{16})$$

With the objective function (1), the average profit is maximized by multiplying the number of containers with the average price per container and subtracting the cost of their transportation as well as subtracting the cost of empty containers transportation and leasing or storing containers in a global path. Constraints (2) and (3) are capacity constraints that make sure the amount of containers does not exceed the available capacity of a leg and the total weight of containers does not exceed the deadweight of a leg, respectively. For (2) the parameter D_c is used for the container dimensions, as different container types have different sizes. Similarly, for (3) the parameters $W^F_{csp_{v_b}}$ and W^E_c are used to determine the weight of full and empty container correspondingly. Constraint (4) is also a capacity constraint and it verifies that the reefer containers in leg do not exceed the available reefer plugs. It is assumed that all reefer container types (CT_R) use 1 reefer plug. Moreover, constraint (5) ensures the maximum number of containers in each service segment at the port of departure is not exceeded. That way, if for example a carrier has arranged for a number of priority containers to be loaded at a certain port, that number could alter the limit of containers able to be loaded in that port.

Equations (6) and (7) perform empty container repositioning for our slot allocation model by establishing equal input and output from each port. As containers can be transported either as empty or full, constraint (6) ensures that containers that can either be stored from a previous time in a port or be leased are equal to the number of containers that can be transported to another port as empty or full or be stored until the next time period. Constraint (7) makes sure containers stored at each port in the first time period have a certain set value.

Constraints (8), (9) and (10) connect service paths with global paths. Firstly, constraint (8) ensures the upper limit of the forecasted demand is not exceeded by the total number of slots in a global path. Equations (9) and (10) secure that the slots allocated in a certain service segment on a global path has to be exactly equal to the slots available in that path, for full and empty containers respectively.

Finally, constraints (11) to (16) represent non-negativity constraints. Obviously, the amount of slots available in global paths or service paths for both full and empty containers and the amount of leased or stored containers in ports must be equal or greater than zero and can never be negative.

4.3.2 Booking limit strategy slot allocation

As explained earlier, for the booking limits strategy each class has to have fixed limit on capacity allocation. Thus, every type of container or service segment has fixed capacity that cannot be accessed by others. Of course, this poses the disadvantage of missing on potentially more profitable bookings, despite there being available capacity on other classes. However, it is still a strategy of significant importance to RM (Talluri & Ryzin, 2004).

BL strategy can be easily applied with this model as the results of the decision variable that are provided from the model can directly be used for that purpose. Thus, by solving the model we can come with a profit maximizing number for containers of different types and in different service segments that we can use as booking limits for each class. Those booking limits need to be updated constantly, depending on changes in the availability of capacity as bookings are accepted and also depending on demand changes after large periods of time. In order to achieve that, the model has to be solved repeatedly. The results of the strategy will be shown in the sections below where they will also be compared to the results of other booking acceptance strategies.

4.3.3 Nested booking limit strategy slot allocation

For the modification of this model to achieve nested booking limit strategy, more valuable booking classes must be able to access the capacity of less valuable ones. In order to achieve that, the classes have to be brought into order based on the average profit they provide to the carrier. This is not easy to do in liner shipping, as the amount of possible combination of the different classes (service segments, container types and sizes) makes bringing them into order challenging. Therefore, a special nested booking limit algorithm has to be developed to determine the possible slot allocations for the different booking classes within a global path.

The authors analyze the formulation of the algorithm in depth in Zurheide and Fischer (2012a). In brief, the legs affected are checked to find out if there is available capacity. Obviously, if there is none, the booking is rejected. If there is capacity available, the algorithm first checks for the specific booking class available capacity and if there is space, the booking is accepted. If there is no availability on the specific class, the algorithm checks for other possible allocations and lists them. Booking classes that have less potential profit from a slot than the booking under consideration and have available space, are added to that list. Then, the algorithm creates a second list to find leftover capacity from previous bookings due to size differences of containers. Of course, the capacity available in those lists has to be larger than the capacity required for the booking under consideration in order for it to be accepted. Once the booking is accepted, the algorithm proceeds to check first the remaining capacity in the specific booking class, then the leftover capacity from previous allocations and finally selects the most profitable of the possible allocations to other classes. Similarly to BL, NBL algorithm also needs to be updated constantly depending on changes in the availability of capacity as bookings are made. Again, this can be achieved by solving the model repeatedly.

4.3.4 Bid-pricing strategy slot allocation

For the BP strategy, the model needs to deliver a minimum bid-price which will serve as the lowest acceptance fare for capacity slot. In fact, Talluri and Ryzin (2004) state that BP can be interpreted as marginal cost for the next unit of capacity. In a linear model, in order to determine BPs, the shadow prices of the capacity restrictions can be used. Particularly for a network, Bertsimas and Popescu (2003) report that the BP can be estimated by summing the individual BPs for the required capacity. In our case, this means that there is a BP for each leg-based capacity and that for global paths, the BP is the sum of all BPs for the legs in that particular global path.

Therefore, based on the model we presented, the BP can be estimated based on the shadow prices of each capacity type. Since there are three possible capacity dimensions (slots, weight and reefer plug for reefer containers), the shadow prices (SP) of all legs (y) in the booking's global path (GL) for all capacity restrictions must be used to calculate the booking's BP (BP). Furthermore, since a booking can include several containers of a certain type, the number of containers (N), the dimension (DI) of the container type and the weight of the booking (W) have to be taken into account. Thus, BPs can be defined as follows:

$$BP^{Dry} = \sum_{y \in GL} SP_y^{sl} * N * DI + \sum_{y \in GL} SP_y^{we} * W \ (\mathbf{17})$$

$$BP^{Ree} = \sum_{y \in GL} SP_y^{sl} * N * DI + \sum_{y \in GL} SP_y^{we} * W + \sum_{y \in GL} SP_y^{re} * N \ (\mathbf{18})$$

These equations show how BPs for dry and reefer containers are calculated. Using the bid price, a booking can be accepted if its expected profit exceeds the bid price and denied otherwise. Ideally, BPs should be recalculated after each booking made, but the size of a large network model would require excessive time thus making it infeasible. Therefore, BPs are updated after a predefined number of bookings or period of time and this is achieved by repeatedly solving the model.

4.3.5 Simulation results

In order to compare the results of each of those modifications of the model, as well as how they compare against the FCFS strategy that is mostly used by container liners, the authors conduct a simulation. They use a case study of 3 services and 19 ports that reflects a realistic service operated by Hapag-Lloyd on the Asia-Europe trade route. Even though the capacity of each leg in the network can be set individually, a capacity of 2,500 TEU is assumed for each leg with 35,000 dwt and 250 reefer plugs, for reasons of simplicity. They consider most container types and segment the services into three; “standard” which is the normal container service, “flex” which has a possibility of flexible rebooking with an extra charge of 100$ and “express” which includes priority loading on the next ship available for an extra cost of 250$.

Four different forecasting methods are used, namely historical average, moving average, exponential smoothing and “perfect” forecast, and tested with and without empty container repositioning to examine their differences. In fact, the authors decide not to take empty container repositioning into account for the main parts of their simulation, mainly because the BP strategy seems to underperform in that situation. The main reason for that is that the BPs model optimizes booking acceptance decisions and empty container decisions separately and thus an additional mixed integer programming model would be required to be solved in order to optimize empty container repositioning. In those simulations, BP strategy appears to outperform all other strategies in both utilization rate and profit, even when set in different case studies such as a Maersk network and a network from CKYH Lines and Evergreen Lines. NBL strategy is the second best performer, while the FCFS seems to outperform BL strategy in most scenarios and settings. Therefore, the authors conclude that when the demand is high NBL and BP strategies should be a preferred alternative to the FCFS strategy currently being used by liners and that a good forecasting quality is crucial for the application of RM strategies.

5. Multi-criteria analysis

In this chapter, the comparison of the RM models analyzed above will be presented. Such a task is not a straightforward, as there is no single output to base the comparison on. According to the simulation results, all three RM models analyzed earlier seem to achieve higher profits than slot allocation strategies that were used at the time each research was conducted. While all of those models focus on maximizing profit and contribution, each one is formulated through the use of different sets of parameters and assumptions, thus the results of a simple comparison of the models' outcomes, such as profit, would be trivial. In order to overcome that difficulty, a technique that can provide much more valuable results is multi-criteria analysis, as it will allow us to analyze in depth which one of those models is more beneficial in different situations, based on the criteria we presented in the above chapters.

Multi-criteria analysis describes a structured approach that helps find solutions to complex problems featuring high uncertainty, conflicting objectives as well as different sets of data, parameters and information (Cristóbal & Ramón, 2012). It is best applicable in cases when a single criterion approach, such as cost-benefit analysis, falls short. Having defined the criteria in section 3.2, it is also required to define their importance in a comparison. In multi-criteria analysis, this can be achieved by ranking them depending on the effect they have. However, in order to avoid using arbitrary weights on the numerous criteria, it would require the use of approaches that are beyond the scope of this research, such as interviews with experts or models that measure the relevant metrics of the criteria. As a result, we will assume that all the criteria analyzed above have identical weight and are therefore equally important for a revenue management model to be beneficial.

5.1 Network structure

The first criteria we noted in section 3.2, is the use of multi-leg or single-leg networks. The model of Ting and Tzeng (2004) uses a single-leg network while in the other two models, multi-leg networks are used. While optimizing slot allocation on a single origin and destination port of a network is useful, as the single-leg network does, it is much more valuable to perform the same action on the total network as the total network's demand and supply is what drives the cargo volumes and not the relationship between two individual ports in the chain. For example, the cargo demand of a port in a shipping network can be significantly affected by its position, depending on which ports are called before or after it. At the same time, separating the optimization problem into smaller ones, by optimizing each leg by itself, could be useful in some cases, such as hub and feeder networks used in shipping, where many ports are connected with only one or a few voyage legs (Mulder & Dekker, 2016). In brief, slot optimizing for a single-leg network is simpler and can provide useful results in certain cases but in reality where shipping liners build global networks with multiple legs and services, slot allocation on a multi-leg network can produce more valuable results. Furthermore, the complexity of a shipping network is very important for the formulation of the model as well. In the literature review, we presented a number of models using arc-flow formulation in most of the single-leg network optimization problems, such as that of Ting and Tzeng (2004). In the case of a multi-leg network structure however, not only is path flow formulation outperforming arc flow formulation but Løfstedt, et al. (2008) state that the current network sizes of international liner shipping companies means that path flow appears to be the only solution, within reasonable time. Thus, while arc flow formulation might be a consideration for single-leg network models, path flow formulation appears to outperform it in the case of multi-leg network both in terms of solving time and validity of outcomes. On the other hand, a very important note to take into consideration is how the network structure is translated into the complexity of the model. In fact, even if path flow formulation seems to be the best option in terms of solving time, the model of Zurheide and Fischer (2015) also uses a four-level network which deems it complicated by nature, as it requires almost double the amount of decision variables, parameters and constraints of other models. If we add to that the existence of practically three different slot allocation models in their research, the particular RM model becomes harder to use for those responsible to apply it in a shipping company but also increase the solving time, despite the little amount of information given by the authors on time required. As a matter of fact, the authors in one of their papers (2012b), when analyzing the model's formulation argue that removing the service path level, effectively reducing the levels of the network, would reduce decision variables and constraints but would make the existing ones more complicated. At the same time, the model of Ting and Tzeng (2004) can be simplified enough to fit into an excel file, making its use very simple for shipping companies. Finally, the last criterion in terms of network structure is its purpose, meaning if it is created for short-haul or deep-sea transportation. The model of Lu et. al (2010) mostly focuses on short-haul, as they assume smaller vessels, small travel times and continuous circular flows. As expected, this is more beneficial for feeder companies but not of much use to shipping companies that focus on global networks and services.

Summarizing, as far as network structure is considered, the model of Ting and Tzeng (2004) appears to be the simplest and easiest model to use, however it falls short in its realistic application in a global network. The model of Lu et al. (2010) appears to represent a realistic network, however it is mostly focused on short-haul transportation which makes it useful in certain situations and not so useful in others. Finally, Zurheide and Fischer (2015) appear to formulate a very accurate and realistic global network, but the model's and simulation's complexity could possibly be problematic for its application.

5.2 Market segmentation

More criteria for the comparison of the models can be found if we consider how each model segments the container liner market. Again, this is a matter of model simplicity against how easily a model can be applied in reality. In addition, segmenting the market further can also provide additional revenue generating services. Firstly, the slot allocation model of Ting and Tzeng (2004) only takes the four most common container types into account, namely 20 and 40 foot dry and reefer container types. While this gives the authors the ability to add a simple index k = 1,2,3,4 that defines the container type, making the simulation very efficient, there are many more container types in the shipping market that they do not take into account and thus the model cannot allocate the capacity properly in a realistic situation. There are numerous examples of types of containers such as High-cube, hard-top, open-top, flatracks or even tank containers that the model fails to take into consideration if there is demand by the shippers. On the other hand, the other two models chosen, take into account all container types by adding parameters for the different container types. Lu et. al (2010) place a capacity parameter t^k that sets the capacity of each container type in TEU and Zurheide and Fischer (2015) place a dimension parameter D_c that sets dimensions of each container type. This approach reflects reality better, however, despite most container types being almost standardized, there are still a lot of types that can come in different dimensions and sizes, thus making their models more complex and harder to use. At the same time, adding more segmentation both in terms of available capacity for special container types but more importantly segmenting your services such as in the model of Zurheide and Fischer (2015) by adding urgent and non-urgent services, creates more revenue generation capabilities by being able to capture more market demand. The other two models that do not take service segmentation into account seem to be lacking in that regard. In this case also, the matter of simplicity in the application of a model has to be taken into consideration. Another criterion for the comparison of the models is the assumptions taken by the authors. While the first two models do not take contractual customers into consideration, Zurheide and Fischer (2015) do, considering a fixed amount of capacity already booked and thus not available for the spot market. This assumption creates a better representation of the market, as in fact contractual customers usually take up significant capacity on board of vessels. Estimating or assuming higher and lower demand scenarios between services and ports as well as prices and costs of container types is also an important factor in the comparison of the models. In Ting and Tzeng (2004), demand and prices as well as costs are estimated based on historical data, but inter-port cargo demand is not taken into consideration. Lu et. al (2010) take suggestions from the company that they study in their case study in order to find costs of each container type, however since prices and contribution are confidential, they had to assume them based on older data publicly available. It is for that reason that they provide no results in their simulation in terms of profit, but only in terms of utilization and allocation rate. Zurheide and Fischer (2015) on the other hand, study demand forecasting in depth and they come up with different results based on different forecasting methods. Prices and costs are also estimated based on historical data. Finally, the last important criterion to consider is empty container repositioning. While all three models seem to be taking it into consideration, different methods are used. The first two models estimate the empty container repositioning demand between ports, however they both do not take into consideration the availability of empty containers in ports, as they do not estimate the intra-port demand. Zurheide and Fischer (2015) assume in their model that containers used in transportation can either be stored from a previous time or leased the moment they are needed for transportation. However, while their approach seems to be the most promising, they do not take empty container repositioning into consideration in the simulation because one of the bidding acceptance strategies they chose is not modeled to solve empty container repositioning efficiently.

Summarizing, considering market segmentation and assumptions taken, Lu et. al (2010) and Ting and Tzeng (2004) seem to be lacking compared to Zurheide and Fischer (2015). The latter model includes all container types and presents service segmentations, takes into consideration contractual customers and studies results with different demand forecasting methods to examine the model's performance in each of them. The downsides are that while it presents empty container repositioning, it is not taken into account in the simulation and also the complexity of the model which includes a lot more constraints and variables as every parameter has been studied in depth.

6. Results and conclusions

In this work, revenue management models are presented, analyzed and compared. Most of the models in the literature attempt to deal with optimizing slot allocation and they all appear to have a significant impact on revenue generation and utilization rate compared to the current strategies liner companies employ. To the author's knowledge, there has not been any research that focuses on comparing the different RM methods in liner shipping over the years. The goal of this paper is to compare revenue management models by examining how easily they can be applied in real world liner shipping and which ones perform better than others in particular situations.

For the comparison of the models, we set a number of criteria that allow us to select the three most representative models out of the current available literature, and compare them using multi-criteria analysis. Besides the outcomes of the models, that can be hard to compare due to the difference in parameters and assumptions, in general, we compare the models based on the level of difficulty they pose for those that are responsible for using them, their complexity but also on how accurately they represent a realistic liner shipping market.

The results of the multi-criteria analysis differ per criterion set, but all models appear to be useful for specific situations. The model of Ting and Tzeng (2004) is definitely the simplest and easiest to use model out of the three, this being particularly evident as it can be modified to fit in an excel worksheet. However, focusing on a single-leg voyage trips in a liner shipping network and ignoring all but four container types as well as service segmentation, represents a situation that cannot be easily found in modern liner shipping. While examining slot allocation separately in each leg of a multi-leg voyage could be useful in certain situations, in most cases there is significant interrelation in slot allocation between the various voyage legs on a liner shipping network and a multi-leg approach would be preferred. Lu et al. (2010) construct a multi-leg slot allocation model that is not very complicated in its formulation and appears to represent a realistic situation in short-haul shipping where circular flows are constant and travel times are small. However, they also do not take into consideration service segmentation and their empty container repositioning seems to be lacking, as they consider constant availability of empty containers when required. Furthermore, their lack of data in terms of pricing and costs cause their simulation to present no results in term of revenue generation but only in utilization rate. Finally, Zurheide and Fischer (2015) construct arguably the most accurate multi-leg model in terms of representing reality. All container types are included, contractual customers are taken into account, service segmentation provides extra revenue generation, empty container repositioning is formulated with the assumption that empty container can be stored in a port from before or leased at the time they are needed, demand forecasting is examined thoroughly and they even examine three different bidding acceptance strategies. On the other hand, the four-level network creates a problem of model complexity, as is evident by the presence of practically twice as many decision variables and parameters as other models. Finally, in the simulation they do not use empty container repositioning as the bidding acceptance strategy of bid-pricing does not allocate slots efficiently with slot allocation.

Having briefly explained how the models fare against each other, it would be useful to see where each one of those would be best applicable. The model of Ting and Tzeng (2004) would be best fitting for a liner shipping company offering single voyage trips or servicing multiple ports with one few voyage legs, such as in a hub and feeder network and the model application would be easy enough to accomplish even for the smallest companies in such a market. As Lu et al. (2010) focus on short-haul transportation, the model would be best fitting for feedering or short-sea services within a country or continent, where there are no significant trade imbalances between the ports of call so empty container repositioning does not become a problem. Finally, the model of Zurheide and Fischer (2015) should be used by the companies that employ the largest deep-sea networks, calling multiple ports in different countries and continents and offering a variety of services and voyages while the specific revenue management departments of those companies should be able to handle its complexity and application into their pricing strategies.

In future research, more sophisticated comparison methods for revenue management models should be investigated. Developing metric systems or conducting field expert interviews in order to find the weight of criteria to be compared could provide much more specific results in terms of the utility of the revenue management currently developed. Finally, simulation comparison could also be accomplished by homogenizing the different assumptions and parameters of the models in the literature in order to come up with quantitative outcomes so as to show which model performs the best.

Bibliography

Acciaro, M., 2011. Service differentiation in liner shipping: advance booking and express services. *International Journal of Shipping and Transport Logistics,* 3(4), pp. 365-383.

Alvarez, J., 2008. *Optimization algorithms for maritime terminal and fleet management,* Barcelona: Universitat Pompeu Fabra.

Armstrong, A. & Meissner, J., 2010. *Railway Revenue Management: Overview and Models,* Lancaster: Lancaster University Management School.

Bertsimas, D. & Popescu, I., 2003. Revenue management in a dynamic network environment. *Transportation Science,* 37(3), pp. 257-277.

Bingzhou, L., 2008. *A stochastic model for dynamic capacity allocation of container shipping two-dimensional revenue management.* Melbourne, IEEE, pp. 1-7.

Brooks, M. R., 2000. *Sea Change in Liner Shipping.* 1st ed. s.l.:Emerald Group Publishing Limited.

Ciancimino, A., Inzerillo, G., Lucidi, S. & Palagi, L., 1999. A Mathematical Programming Approach for the Solution of the Railway. *Transportation Science,* 33(2), pp. 168-181.

Collison, F. M., 1984. Market Segments for Marine Liner Service. *Transportation Journal,* 24(2), pp. 40-54.

Cristóbal, S. & Ramón, J., 2012. *Multi Criteria Analysis in the Renewable Energy Industry.* 1 ed. s.l.:Springer-Verlag London.

Demirag, O. C. & Swann, J. L., 2007. Capacity allocation to sales agents in a decentralized logistics network. *Naval Research Logistics,* 54(7), pp. 796-810.

Drewry, 2015. *Container Shipping Will be Lucky to Break Even in 2015.* [Online]
Available at: http://www.drewry.co.uk/news.php?id=379
[Accessed 06 07 2016].

European Commission , 2006. *www.europa.eu.* [Online]
Available at: http://europa.eu/rapid/press-release_IP-06-1249_en.htm?locale=en
[Accessed 17 June 2016].

Feng, C.-M. & Chang, C.-H., 2008. Optimal Slot Allocation in Intra-Asia Service for Liner Shipping Companies. *Maritime Economics & Logistics,* 10(3), pp. 295-309.

Geraghty, M. K. & Johnson, E., 1997. Revenue Management Saves National Car Rental. *Interfaces,* 27(1), pp. 107-127.

Guerriero, F., Miglionico, G. & Olivito, F., 2012. Revenue management policies for the truck rental industry. *Transportation Research Part E: Logistics and Transportation Review,* 48(1), pp. 202-214.

Hellerman, R., 2006. *Capacity Options for Revenue Management.* 1 ed. s.l.:Springer-Verlag Berlin Heidelberg.

Huang, K. & Chang, K.-c., 2010. An approximate algorithm for the two-dimensional air cargo revenue management problem. *Transportation Research Part E: Logistics and Transportation Review,* 46(3), pp. 426-435.

Kadar, M. H. & De Proost, D., 1997. Supply and demand in liner shipping. *Containerisation International*, June, pp. 61-65.

Ladany, S. P. & Arbel, A., 1991. Optimal cruise-liner passenger cabin pricing policy. *European Journal of Operational Research,* 55(2), pp. 136-147.

Leach, P. T., 2011. *JOC.com.* [Online]
Available at: http://www.joc.com/maritime-news/international-freight-shipping/maersk-charge-fees-no-show-containers_20110623.html
[Accessed 12 07 2016].

Lee, L. H., Chew, E. P. & Sim, M. S., 2007. A heuristic to solve a sea cargo revenue management problem. *OR Spectrum,* 29(1), pp. 123-136.

Lee, L. H., Chew, E. P. & Sim, M. S., 2009. A revenue management model for sea cargo. *International Journal of Operational Research,* 6(2), pp. 195-222.

Løfstedt, B., Pisinger, D. & Spoorendonk, S., 2008. *Liner Shipping Revenue Management with Repositioning of Empty Containers,* Copenhagen: University of Copenhagen.

Lu, C., 2007. Evaluating Key Resources and Capabilities for Liner Shipping Services. *Transport Reviews,* 27(3), pp. 285-310.

Lu, H.-A., Chu, C.-W. & Che, P.-Y., 2010. Seasonal slot allocation planning for a container liner shipping service. *Journal of Marine Science and Technology,* 18(1), pp. 84-92.

Maersk Line, 2010. It's in your hands.... *Weekly Highlights*, Tuesday January, pp. 3-5.

Maersk Line, 2011. *maersk.com.* [Online]
Available at:
http://preview.thenewsmarket.com/Previews/MAER/DocumentAssets/213546.pdf
[Accessed 19 06 2016].

Maragos, P., 1994. *Yield management for maritime industry,* s.l.: Massachusetts Institute of Technology.

Marlow, P. & Nair, R., 2008. Service contracts—an instrument of international logistics supply chain: under United States and European Union regulatory frameworks. *Marine Policy,* 32(3), pp. 489-496.

McGill, J. I. & van Ryzin, G. J., 1999. Revenue Management: Research Overview and Prospects. *Transportation Science,* 33(2), pp. 233-256.

McKinsey, 2014. *McKinsey.com.* [Online]
Available at:
http://www.mckinsey.com/insights/corporate_finance/the_hidden_opportunity_in_co

ntainer_shipping
[Accessed 06 07 2016].

Mulder, J. & Dekker, R., 2016. *Optimization in container liner shipping,* Rotterdam: Econometric Institute, Erasmus University.

Munari, F., 2009. Liner Shipping, Antitrust and the Repeal of Regulation 4056/86 : a New Era of Global Maritime Confrontation?. In: A. Antapassi, L. I. Athanassiou & E. Røsæg, eds. *Competition and Regulation in Shipping Related Industries.* Leiden: Nijhoff, pp. 7-25.

Phillips, R. L., 2005. *Pricing and Revenue Optimization.* Stanford: Stanford University Press.

Pompeo, L. & Sapountzis, T., 2002. Freight Expectations. *The McKinsey Quarterly 2*, pp. 90-99.

Shipping Watch, 2012. *http://shippingwatch.com/.* [Online]
Available at: http://shippingwatch.com/articles/article4891909.ece
[Accessed 07 07 2016].

Smith, B. C., Leimkuhler, J. F. & Darrow, R. M., 1992. *Yield Management at American Airlines,* s.l.: American Airlines.

Stopford, M., 2009. *Maritime Economics.* New York: Routledge.

Talluri, K. T. & Ryzin, G. J. V., 2004. *The Theory and Practice of Revenue Management.* 68 ed. s.l.:Springer US.

Ting, S.-C. & Tzeng, G.-H., 2007. An optimal containership slot allocation for liner shipping revenue management. *Maritime Policy & Management: The flagship journal of international shipping and port research,* 31(3), pp. 199-211.

Williams, G., 1994. *The airline industry and the impact of deregulation.* Revised ed. s.l.:Ashgate Publishing Company.

Xiangzhi, B., Rongqiu, C. & Li, L., 2007. *Container slot allocation model with liner shipping revenue management.* Wuhan, 6th International Conference on Management (ICM 2007).

Zou, L., Yu, C. & Dresner, M., 2013. The application of inventory transshipment modeling to air cargo revenue management. *Transportation Research Part E: Logistics and Transportation Review,* Volume 57, pp. 27-44.

Zurheide, S. & Fischer, K., 2011. A revenue management slot allocation model with prioritization for the liner shipping industry. In: B. Hu, K. Morasch, S. Pickl & M. Siegle, eds. *Operations Research Proceedings 2010.* s.l.:Springer-Verlag Berlin Heidelberg, pp. 143-148.

Zurheide, S. & Fischer, K., 2012a. *A nested booking limit algorithm for liner shipping slot allocation.* s.l., International Conference on Applied Mathematical Optimization and Modelling.

Zurheide, S. & Fischer, K., 2012b. A revenue management slot allocation model for liner shipping networks. *Maritime Economics & Logistics,* 14(3), pp. 334-361.

Zurheide, S. & Fischer, K., 2015. Revenue management methods for the liner shipping industry. *Flexible Services and Manufacturing Journal,* 27(2), pp. 200-223.