

Port choice: A frequency-based container assignment model

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Declaration of contribution

I hereby declare that, the work presented in this thesis has been carried out by myself, with advice from Prof Michael G. H. Bell (my supervisor) and occasionally from Dr. Panagiotis Angeloudis. In it, references and citations whenever I refer to, describe or quote from the published or unpublished works of others have been proper listed.

Abstract

The process of containerization has connected the world with a cost-effective freight service, successfully forming a competitive global market. Mixed freight shipping has changed dramatically due to containerization and globalization. The port system has experienced a tough time keeping pace with globalisation in terms of its roles and functions in liner shipping. Consequently, port choice has become a challenging problem to analyse with many stakeholders and complex circumstances.

The literature formulating the basis of this maritime container assignment model can be identified as a combination of port choice modelling, a freight flow model and empty container repositioning. It is observed that the maritime container assignment problem shares a greater affinity with transit assignment than with traffic assignment conventionally applied freight in the four step approach, because containers are generally carried by shipping lines which operate services on fixed routes or port rotations. A model capable of representing full and empty container flows at a global level would be useful to almost every stakeholder in the container liner shipping industry, such as shippers, shipping lines, port authorities, terminal operating companies, regional and national planning authorities, marine insurance companies, and others.

The classic frequency-based transit assignment approach of Spiess and Florian is transferred and applied to maritime containers as the foundation for a global maritime container assignment model. The first version of this model assigned full and empty containers to routes to minimise expected travel time, which consists of sailing time between ports and

dwelling time at intermediate transshipment ports. Service frequency and port capacity influence the pattern of full and empty container flows and therefore port choice. In this thesis, the model is further developed to fit the reality of container liner shipping by minimising expected cost rather than expected travel time. The objective is now to assign container flows to routes to minimize the sailing costs and expected dwell costs at the origin port and intermediate transshipment ports. The constraints included are extended to include the maximum number of containers each route can carry.

Finally, the capabilities of the cost-based container assignment model are explored through a case study of the Europe-Far East trade lane. A range of strategy and policy options, such as a shipping line planning a new route or modifying an existing route and a port authority considering expansion, are simulated. A possible approach to model validation through independent data is proposed. Recommendations for future research are provided at the end of the thesis. Many aspects are covered in the thesis; an origin-destination matrix estimation, automated virtual (task) network construction from routes and schedules, improvements to the probability distribution used for ship arrivals, a validation procedure, and model extension from port-to-port movements to door-to-door container movements.

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Chapter 1

Introduction

A port is a geographical area providing the facility for serving ships and transferring cargo. Empirically, ports have several functions are crucial to the efficiency of the ships. First of all, the primary purpose is to provide a secure location where ships can berth. However, this is just the beginning. Improved cargo handling requires investment in shore-based facilities. If bigger ships are to be used, ports must be built with deep water in the approach channels and at the berths. Of equal importance is cargo handling, one of the key elements in system design. A versatile port must be able to handle different cargoes – bulk, containers, wheeled vehicles, general cargo and passengers all require different facilities. There is also the matter of providing storage facilities for inbound and outbound cargoes. Finally, land transport systems must be efficiently integrated into the port operations. Railway, roads and inland waterways converge on ports, and these transport links must be managed efficiently.

The status and function of the port has been changing dramatically along with the development of world trade. According to the famous Anyport model (Bird, 1980), Setting, Expansion and Specialization are the three main stages that can be identified. The previous port development processes can be described very well using those three stages, especially in large conventional ports. However, when it comes to explaining contemporary port development, it may have some disadvantages.

Following with the evolution of the port development theory, Notteboom and Rodrigue (2005) have made certain additional suggestions on these models. First of all, the recent rise of seaport terminals that mainly perform the function of transshipment hubs in extensive maritime hub-and-spoke networks has to be explained. Second, the hinterland dimension as a driving factor in port development dynamics has to be included. As a result, regionalization, which is the fourth stage, is proposed based on what they concluded from the above. The stage of port regionalization not only expands Bird's Anyport model, it also extends the existing literature on the spatial development of seaport systems in regard to maritime and hinterland networks. As introduced by Stopford (2008), there are four levels of port development which are small local port, large local port, large regional port and regional distribution centre. Port regionalization may be seen as the next phase of port development.

Logistics integration and network orientation in the port and maritime industry have redefined the functional role of ports in supply chains and have generated new patterns of freight distribution and new approaches to port hierarchy.

As certain hinterland routes develop to a greater extent than others in association with the increased importance of particular urban centres, an increasing level of port concentration is suggested in some models (Taaffe et al., 1963). Along with this, the port system is transforming itself from a pattern of scattered, poorly connected ports along the coastline to a network of corridors between gateway ports and major hinterland centres. Barke (1986) and Hayuth (1981) by contrast have introduced a process of port system deconcentration using the similar approach. More recently, some modifications to the above models have been introduced in order to reflect the specificity of some port regions (Wang, 1998). Empirical research has demonstrated that some port systems and port ranges are getting more spatially concentrated while others are evolving to a more evenly distributed system (Notteboom, 1997).

Port choice mainly performs an approach to evaluate the attractiveness for the ports sharing a common hinterland area with respect to a common set of attributes of the port system. As to port choice modelling, there exists an extensive array of published studies which attempt to explain the approaches and criteria shippers and shipping lines use to choose a port (Brooks, 1984, 1985; Slack, 1985; Bagchi, 1989; D'Este and Meyrick, 1992; Mruphy et al., 1992a; Nir et al., 2003; Tiwari, 2003; Lirn et al., 2004; Ding et al., 2005; Bruno and Guy, 2006). In addition, similar studies discuss the factors used by shippers when selecting their preferred shipping line and land transport mode. Indeed these studies use a number of approaches such as revealed preference surveys and interviews to support specific conclusive formulations and models of port choice.

However, with the progressive integration of ports in supply chains, it has become clear that shippers are no longer choosing a port per se, but rather a supply chain – a bundle of logistics services and a pathway to markets – in which a port is an important element of the system. Clearly, the shipper's influence on port choice decisions is diminishing, particularly now that a single shipping line, a third party service provider or supply chain integrator may control the freight from the origin to the destination applying various transport arrangements and multiple pathways designed to minimise the total logistics cost and maximise the profit for both the supplier and the customer. Increasing effort is being put into this new approach to port choice modelling (MDST, 2006; Magala, 2008; Joyce et al., 2008; MDST, 2008).

As a result, a model capable of interpreting container flows at a global level would gain more interests. In the context of liner shipping, container assignment in large part investigates an optimal strategy about how to assign container flows on the target network and assess the consequences of relative policy and/or tactical applications. Note that container transit is recognized as transshipment which is one of the most important functions in the extensive hub-and-spoke network. Some works have been done in this field (Newton, 2008; Perrin et al., 2008). In the meantime, a number of related international, national and regional freight flow models have been reviewed. These literature reviews regarding container flow and freight flow models help to enhance the understanding of a better maritime container flow assignment model, and also indirectly solve the port choice problem under the circumstances of logistics integration and network orientation.

1.1 Aims and objectives

Based on the above discussion, the purpose of this thesis is to develop a maritime container assignment model at the global level, with the respect of representing full and empty container flows. Flows will be assigned to the maritime network to minimize total cost, measured either in time or monetary unit, using available service and cost data. An important output of the model will be insights into port choice.

The objectives of the thesis are therefore to:

- Investigate the characteristics of the container liner shipping system including the evolution of the liner shipping business and analyse the liner shipping market and its competitive conduct.
- Determine the effects of containerisation and globalization on the liner shipping business, especially on port systems. As the liner shipping service pattern has been changing dramatically, the functions and key components of container port systems needs to be reviewed.
- Identify the key principles of the proposed frequency-based container flow assignment model. Previous studies of freight flows have usually applied the conventional four stage approach, choosing traffic assignment as the fourth stage. The model developed here is based on the observation that the maritime container assignment problem shares a greater affinity with transit assignment rather than with traffic assignment. The maritime container assignment model is extended to include empty container repositioning.
- Formulate a method which incorporates full and empty container flows simultaneously to minimise total expected cost, but in a way that is less data intensive,

more computationally efficient, and accurate enough to address various policy and strategy issues.

1.2 Thesis organisation

This thesis consists of seven chapters, structured to present the research aims and objectives outlined above.

Chapter 2 presents the background to the liner shipping business and port choice. The literature on port choice, freight flow models and empty container repositioning are reviewed in Chapter 3. Chapter 4 describes the fundamental time-based container flow assignment model. As a further development, a cost-based container flow assignment model taking into account the major cost factors in the container liner shipping market is built in Chapter 5. Numerical examples will be given for both versions of the container assignment model. In Chapter 6, the cost-based container flow assignment model is applied to a full scale network of the Europe-Far East trade lane. Analysis of results and interpretation of dual variables are presented for both numerical examples and the case study. Finally, Chapter 7 revisits the key objectives listed at the beginning of this thesis, presents conclusions and makes recommendations for future research.

Chapter 2

Background

According to Stopford (1997) liners is a recent addition to the shipping business, dating from the 1870s when improving steamship technology first made it possible to offer scheduled services. With the invention of the ISO container in about 1966, liner shipping stepped into the container era. Nowadays, most of the world's seaborne trade is carried by liner shipping with regular services carrying containerized cargo on specific routes. It only took 40 years for container liner shipping to transform the world economy. In this chapter, some key aspects of the liner shipping are presented. The roles and functions of container ports and terminals are reviewed as well.

2.1 The evolution of the liner shipping

Liner shipping is a comparatively new segment to the shipping business. From the 1870s, the improving steamship technology and the innovating commercial systems made it possible for the industry to step into the liner shipping era. And the shipping community successfully seized the opportunity. In 1869, the Suez Canal was opened due to great advantages of steamships. As a result, a booming freight market was observed in the early 1870s with a great number of orders for steamships to provide liner shipping services on the prosperous Far East route. Once set up, the network of liner shipping services expanded dramatically into the comprehensive transport system which exists today.

2.1.1 The cargo liner era

Liner companies started to offer scheduled service and ran fleets of multi-deck vessels with their own cargo handling facilities from the 1870s for a century until the 1960s, known as the cargo liner era. Shipping business had not been divided into many specialized operations in this era. As a result, the liner services had to carry a mixture of manufactures, semi-manufactures, minor bulks and passengers. The trade routes mainly sketched from North America, Europe to their colonies in Asia, Africa and South America. However, there was an imbalanced trade on many of these routes due to exporting manufactures and importing minor bulks. Therefore, the main aim of the liners was how to fill the ships on return. Under such circumstances, a flexible vessel capable of carrying all kinds of cargo became the most desirable work on the ship designer's desk. The multi-deck cargo liner being able to carry both general cargo and bulks was the preferred option.

In the meantime, great flexibility can be achieved by the cargo liners with similar size, design and speed to the tween-deckers deployed by tramp service providers. In other words, the cargo liner fleets and tramp fleets were to a large extent interchangeable, a liner could be transferred to a tramp service, and vice versa. On one hand, the liner companies are enabled to charter tramps as a part of their fleets. On the other hand, the tramp service providers are allowed to make use of the mechanism as a cushion against the bulk market cycles through ordering ships with tween-decks and comparable speeds. The similarities shared between liners and tramps made both parties benefit from efficient risk management. When it comes to the twentieth century, the system was refined and developed along with the growing trade. More advanced cargo liners with adding features such as refrigerated holds, roll on-roll off decks, extensive cargo handling facilities and much automated equipment were built by the liner companies in order to enhance productivity and widen the cargo range carried. They became increasingly complex and expensive.

The flexibility of the cargo liner was achieved at the cost of intensive labour and capital. When it comes to the 1950s, the situation changed where productivity weighed more than flexibility due to more expensive labour and changed trading pattern. The cost, complexity and poor deliver performance of the cargo liner stopped it from being a competitive segment in shipping business. Three factors contributed to this situation. First, the dramatic change in the pattern of trade is the main driver. The world economy experienced rapid growth starting from 1950s and lasting for about two decades due to prosperous trade growth between the industrial centres of North America, Europe and Japan. Fast, reliable, secure shipping services became the primary concern for the shippers in these trades. Second, the liner and bulk shipping industries grew apart. Many of the minor bulk backhaul trades transferred to bulk carriers, because they offered extremely competitive rates the liners could not possible

match. As a result, the size of the bulk carrier fleet increased dramatically. Third, the liner companies lost their privileged position in many of the core trades in which the cargo liners had been most effective as the colonies gained independence.

The disadvantages of cargo liners became increasingly obvious. Shippers were complaining about the waiting time as their cargo made a slowly progression round eight or ten ports, often arriving damaged. In the meantime, ship-owners found that too much time for their expensive liners had been spent sitting in port. As to the liner companies, intensive tied up capital and limited scope for economies of scale made operating cargo liners unrewarding. Expensive liners spent up to 50% of their time in port, and doubling a liner's capacity almost doubled its port time. This fundamental problem could not simply be solved by any manager or naval architect.

By the 1960s, the cargo liners became technically undesirable due to the expense of the ships, the cargo handling problems and the isolation of their cargo from the rest of the transport system. As a result, the shipping system was completely restructured into four business segments bulk, specialized, containers and air freight.

2.1.2 The container liner era

A US businessman, Malcolm McLean, with no shipping experience was the pioneer to deploy containers on the liner shipping business. Malcolm McLean had spent his life building up McLean Trucking which owned a fleet of 1700 vehicles. In 1955, he sold it and bought the Pan Atlantic Tanker company. McLean had a tanker called Poltero Hills fitted to carry 60

35 foot containers. On 26 April 1956, the first seaborne shipment of modern containers, 58 containers was loaded in New Jersey and sailed for Houston. Those containers sailed for 3000 miles and the handling cost was 16 cents per ton. It was a great commercial success compared with 5.83 dollars per ton for break bulk cargo handling. Therefore, on 4 October, a second tanker was converted into a fully cellular vessel named Gateway City with 226 TEU. It sailed from Newark to Miami and the cargo was delivered to the consignee in Miami within 90 minutes.

By the mid-1960s, a container fleet of 54000 units was running in the deep sea. However, the established liner companies with large fleets of cargo liners remained doubtful about the new system, because initially they used it as a supplement for their existing cargo liner operations. From this perspective, the economics of the new system attracted little attention. Such a fundamental change needed a different perspective, considering dedicated container ships, terminals, truck distribution networks and a fleet of containers as a complete system. Many other less radical systems were examined such as palletization and roll on-roll off services. The economics of these systems did not work well in practice and deep sea roll on-roll off services remained a niche business.

At the same time, Malcolm McLean renamed his company Sea-Land. In April 1966, the first transatlantic container liner service, SS Fairland, sailed from New Jersey to Rotterdam. The cargo arrived four weeks ahead of a conventional cargo liner service. By this time, the major European liner shipping companies had just started to build up their own container liner services. Consortia were established because of the intensive investment in container ships, container terminals and the boxes. For example, in 1965, Ocean Transport and Trading,

British and Commonwealth, P&O and Furness Withy formed a joint venture Overseas Containers Limited. And on 6 March 1969, the first container liner service of Overseas Containers Limited was launched. Over the next thirty years, a series of corporate changes accompanied the growing container liner business. During the 1980s, P&O gradually increased its share and merged with Nedlloyd N.V. to establish P&O Containers Ltd. In 2005, it was sold to the A.P. Moller-Maersk Group and incorporated into Maersk Line.

The solution to unitize general cargo using containers salvaged the cargo liner business. It allowed liner companies to standardize the cargo unit and deploy automated systems and equipment in the transport process. As a result, productivity improved dramatically. To conclude, there were three components constituting the new system; the standardized containers, an integrated transport system, and high speed cargo handling facilities.

First, the standardized units used to carry general cargo should be handled across each stage in the transport chain. Although other systems, such as palletization and barges, were considered, containers were the preferred option by all the major liner companies. Second, an integrated transport system was built to handle the containers. On the sea leg, the investment was in purpose-built cellular container ships while road and rail vehicles capable of carrying containers efficiently were required on the land legs. Last but not the least, high speed cargo handling facilities facilitate loading and unloading the containers between one leg of the transport system and another. Container terminals, inland distribution depots and container packing facilities where part loads could be stuffed into containers all played a part in this procedure.

2.1.3 The effects of containerisation

Building a container ship was a technical challenge due to its open hatch structure. For ship builders, container carriers posed new design challenges. An early order for six 1600 TEU Encounter Bay class ships, for example, had the cell guides fitted to the open holds, so the containers could be slotted in without being clamped. They were fitted with flush steel hatch covers which provided a platform on which containers could be stacked four high and clamped in place. The cell guides and open hold technology were new and raised various technical problems though the size of container ships was not big compared to tankers and bulk carriers. On the land leg, rapid progress could be observed on the development of container-friendly trailers. Over 300 European truckers were contracted for their service in April 1966.

The second key aspect was the size of standard containers. Initially, different sizes of container were in use due to different road regulations across the USA. Malcolm McLean chose a 35 ft box for the first container liner service because as a compromise. The initial standard containers for general cargo were 8 ft high and 8 ft wide with four optional lengths, 10 ft, 20 ft, 30 ft and 40 ft. The height of standard containers was increased by 6 inches in 1976, providing extra capacity without altering the other dimensions of the containers. Eventually, the International Organization of Standardization developed standards regarding dimensions, floor strength, corner casting strength, racking tests and the gross weight of the container. Nowadays, 20 ft and 40 ft containers have become the workhorses of the international container business. As seen in Table 2.1 of the world container stock in 2004, 75 percent were 40 ft units and 18 percent were 20 ft containers. Other sizes made up the

balance. Generally, a container can be used for 12 to 14 years. About half of the container fleet is leased in the US and Europe.

Table 2.1 – World container stock by principal type (Containerization International, 2005)

Container type/20 ft equivalent units ('000s)	2004	% in 2004
20 Standard	5,060	18%
40 Standard	21,621	75%
Integral reefer	1,111	4%
Open top	258	1%
Folding flatrack	151	1%
Ventilated	26	0%
Insulated reefer	24	0%
Other	217	1%
Total	28,486	100%

Various technical developments in the 1960s and 1970s were the third element to stimulate the growth of the service, especially in the fields of communication and data processing. These innovations improved the efficiency offered by containerization in many aspects such as service planning, the exchange of detailed cargo manifests across the world, and the execution of paper work.

Finally, the container terminal became a vital part of the system. During the cargo liner era, the liner ports had spacious wharves backing on to warehouses where liners would wait for the cargo to be handled for weeks. However, it was very different for the container terminals. Usually, a number of berths backing on to open storage were served by gantry cranes. To speed up the connection with road transport most companies would stack the containers three or four high and retrieve them from stack as required. This new system of cargo handling was

recognized to be extremely effective due to mechanized container movement within the terminal using fork lift trucks, straddle carriers and automated gantry cranes. As a result, productivity was improved dramatically. The new container terminals could handle 1 to 2 million tons of cargo a year on each berth, whereas a general cargo berth only handled 100,000 to 150, 000 tons a year. Intermodal compatibility was also greatly improved by the deployment of the standardized container. By 2007, over 75 percent of the general cargo trade was carried by containers and 4300 container ships with a capacity of 10.6 million TEU carried over 1 billion tons of cargo a year between 360 ports in the world.

The main objective of containerization was to reduce port time, which it did extremely successfully. It also changed the way liner companies operated. First of all, door-to-door service was made as an essential part of the business through unitization. Most liner companies used to focus on ships and shipping operations. The fundamental change in the system created the need for liner companies to handle both the land and sea legs of the transport, therefore the concept of logistics was introduced into the liner shipping business. Second, the new container terminals operated with fewer ships and staff than conventional cargo liner ports. Third, the accelerating progress of consolidation was observed in liner business. A great number of liner companies disappeared and liner shipping became the most concentrated segment of the shipping business. Fourth, the core business of liner companies focused on through transport where less attention had been paid on ships and ship-owning. Fifth, tramp operators turned to the bulk carrier or tanker market. Liner companies had to carry the marginal capacity they needed in their own fleets, because container ships could not switch between bulk and liner charters. As a result, the tramp market for ships capable of carrying containerized cargoes was diminishing. At last, minor bulk cargoes which had occupied the lower cargo holds, deep-well tanks and roll on-roll off decks of cargo liners

transferred to specialist vessels such as open hatch bulk carriers, parcel tankers, car carriers, heavy lift ships and multipurpose vessels.

The effects for the world economy were even more profound compared with those consequences on the shipping business. Transport between regions changed from slow, expensive and unreliable to fast, secure and incredibly cheap, therefore distance from the market and transport cost became a less important factor in the location of manufacturing industry. Along with the growth of the container network, so did globalization.

2.2 The contemporary liner shipping business

According to the annual Maritime Transport Review of the United Nations (UNCTAD, 2005), there were 32 maritime coastal regions with 1024 potential liner routes between these areas. In addition, some of the coastal regions have thousands of miles of coastline with numerous ports. Therefore, providing global liner services is a challenging business. The ultimate task for the liner industry is to establish a network which meets the changing needs of the shippers in these coastal regions cost effectively. Between 1975 and 2007, the volume of containers lifted increased from 14.1 million TEU to 466 million TEU, which constituted a much faster growth than other segments of the shipping business. Between 1983 and 2006, the average growth rate of world GDP was 4.8% per annum, whereas container cargo grew much faster, averaging 10.1% per annum for container lifts and the volume of containerized cargo grew by 10%.

Generally, three groups of trade routes can be identified which are the East-West trades, the North-South trades, and intraregional trades. First, the East-West trades include the long-distance routes with the largest container ships connecting the industrial centres of North America, Europe and Asia. Second, the North-South trades link the economies of Northern and Southern hemispheres. Third, the intraregional trades include shorter distance routes and use smaller container ships. It has relatively less container ship demand because the voyages are generally much shorter.

Anything that can physically fit into a container could be potential container cargo. Many other transport modes are competing for the same cargo, causing many difficulties when analyzing the trades. Especially, different segments of the shipping services also compete for cargoes. Cargoes with high value, such as manufactured and semi-manufactured products, consumer goods, machinery, textiles, chemicals and vehicles always travel by liner or possibly air freight, which competes for the most urgent and high value cargoes, especially on long routes. Cargoes with lower value such as forest products, refrigerated cargo and wheeled cargo are transported using specialized shipping services. On the other hand, liner shipping competes for minor bulk cargoes, such as building materials, steel products and foodstuffs, with bulk shipping. Although these cargoes do not generate much revenue, the spare capacity can be fully made use of on the routes where trade imbalance occurs. To conclude, the growth of the existing container cargo trades, especially the manufactured goods trade, stimulates the core increase in container volumes. New cargoes and cargoes from specialized and bulk segments top up the success of liner shipping.

2.2.1 Key components of current liner shipping

A liner service is a fleet of ships, with a common ownership or management, which provide a fixed service, at regular intervals, between named ports, and offer transport to any goods in the catchment area served by those ports and ready for transit by their sailing dates. What really makes the liner shipping different from the tramp service are a regular service with fixed itinerary and the duty to sail according to the published schedule no matter whether the ship has been filled or not. By the end the twentieth century, the traditional cargo liner service had been largely replaced by the container liner service. We focus on the container liner shipping market. As a result, four components the cargo, the services, the liner companies and the fleet in the container liner shipping market will be analyzed.

The basic demand for container liner services are still generated from the general cargo, the same as previously with cargo liners. However, the process of containerization had two main consequences for transport demand, one regarding economies of scale and the other product differentiation. Firstly, the deployment of much larger container ships with dramatically improved cargo handling meant that many cargoes that used to be shipped through the bulk and specialized services increasingly become targets for containerization. Secondly, containers meet various demand characteristics despite the same appearance, for example high value or urgent cargoes and low value minor bulk cargoes.

The services or the major routes can be divided into four groups, namely the transpacific trades, the Far East to Europe trades, the transatlantic trades and other trades which include the North-South trades, and large intraregional trades. These routes are the centre of the container liner system. Shippers with cargo to transport have numerous container services to choose from. Take the transpacific trades for example, where there are 76 loops served by

520 container ships transported about 17 million TEU (Clarkson Research Services Ltd, 2007). As with any other market, rates are negotiated between shippers and carriers. However, there is a long history of container liner services cooperating to fix prices or collusion by the exchange of information. It has been a hot issue for at least 150 years in terms of the regulation of their commercial behaviour.

The enormously complicated work of scheduling container ships and providing the most cost-effective liner service is executed by the liner companies. The detail of this will be discussed later. Finally, the container fleet and its charter market are dealt with. The size of the container fleet reached 4200 with another 1300 on order (Clarkson Research Services Ltd, 2007). Economies of scale are a major concern due to various ship sizes within the container fleet. When it comes to the container ship charter market, a strategic decision for a liner company is whether to build their own container ships or to charter them. In this market, container ships rather than cargo transport is dealt with. With the independent operators who own the ships on one side and the liner companies which provide services on the other, great flexibility could be achieved in terms of liner operation. Before the 1990s, most of the container fleet was owned by the liner companies. By 2007, the ownership of the container fleet had been taken over by the independent operators owning almost half the fleet.

2.2.2 Concentration, consolidation and vertical integration in liner shipping

There are many reasons for concentration in container liner shipping. One of the major objectives is to capture the economies of scale. Owing to relatively low freight rates and low rates of return on capital, individual carriers have to concentrate on reducing fixed cost. As a

result, many carriers started to pursue this objective through deploying increasingly large and more efficient vessels and in developing “hub and spoke” logistics systems to circumvent related infrastructure restrictions. Generally speaking, this is an effective approach to fill the ships on the fixed sailing schedules under the situation that there is sufficient demand. But owing to the high uncertainty of the demand, which displays highly seasonal patterns, it is also a high risk strategy to increase the degree of concentration rapidly. This almost guarantees chronic and unstable industry-wide excess capacity. Consequently, this characteristic of the liner shipping industry increases the attractiveness that individual firms face to cooperate with each other to reduce unit costs through alliances¹ or maintain stable revenues through conferences². Also, the accuracy of a traditional market structure analysis where each firm is treated as a single entity may be reduced owing to the cooperation among individual firms.

After the passage of the OSRA (Ocean Shipping Reform Act, 1998), the market power of the conferences started to fall due to the creation and enlargement of “discussion agreements” and increased reliance on vessel sharing agreements. Discussion agreements are not registered as conferences under US law and are consequently not permitted to fix prices or capacity. However, the general levels of supply, demand and the direction of freight rates are allowed to be discussed among members through regular meeting. Whether this leads to illegal price fixing is an open question and not easy to answer, because the pricing data is limited. The global alliances are formed as an important strategy in part to cope with industry excess capacity. Although collective price setting among groups are forbidden under ORSA,

¹ A set of agreements integrated the operational aspects of each participant’s services, whilst leaving the commercial activities in the hands of the individual companies. The alliances typically cover operating joint services on the major liner routes, chartering in vessels, slot sharing, shared terminals, pooled containers, coordinated feeder and inland services where permitted, and information sharing.

² An affiliation of ship-owners operating over the same routes who agree to charge uniform rates and other terms of carriage.

sharing capacity, terminals and equipment, joint-scheduling, slot-chartering and marketing functions make them appear to behave as a single entity.

Concentration is lower in the post-OSRA period because the increasing equipment or vessel sharing agreements among carriers have reduced barriers to mobility (PIERS On Board Review, 2004). Vessel sharing, which is a prevalent means of entry without the requirement of deploying physical assets, evolved into the larger global alliances today. It helps to reduce the risks associated with full-scale market entry by permitting carriers to ‘test the water’ before making large capital commitments.

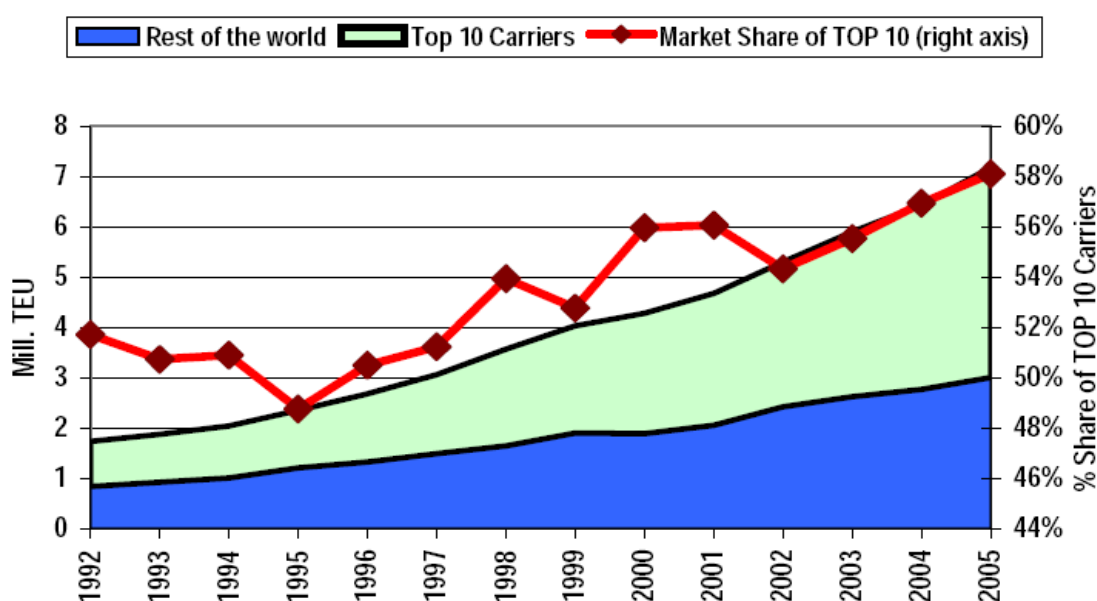


Figure 2.1 – Capacity and market share of Top 10 Carriers 1992-2005 (ISL, 2005)

The process of consolidation and vertical integration is also an important part of the analysis of the liner shipping market. As said above, the carriers have approximately tripled their capacity during the past decade in order to cope with the growing demand. This distribution of the additional capacity has also been mirrored by the significant consolidation in the liner industry as a result of company growth and mergers and acquisitions. The top 10 carriers

currently have a market share of approximately 58% (2005) compared with 50% (1995) ten years ago (Figure 2.1). Consolidation within the liner shipping industry is also demonstrated in Table 2.2, which highlights the number of carriers, ranked by market share, that are needed to sum up to a joint market share of 50%.

Table 2.2 – Carriers making up 50% of Total Existing Capacity (Global Insight, 2005)

1995	2000	2005
1. Maersk – Sealand	1. Maersk – Sealand	1. Maersk Line*
2. Evergreen	2. Evergreen	2. MSC
3. Cosco	3. P&O Nedlloyd	3. Evergreen
4. Sea – Land	4. Hanjin	4. CMA CGM
5. NYK	5. MSC	5. Hapag – Lloyd**
6. P&O Nedlloyd	6. COSCO	6. NOL/APL
7. Hanjin	7. NOL/APL	7. COSCO
8. P&O Containers	8. NYK	
9. Mitsui OSK	9. CP Ships	
10. K – Line		
11. Zim		
12. Hapag – Lloyd		
13. NOL/APL		
14. DSR Senator		
15. MSC		
16. Yangming		

Note: *After merger with P&O Nedlloyd; **After merger with CP Ships

Consolidation also takes place on the shippers' side. Owing to the trend toward integrated logistics solutions, freight forwarders and in particular the big 3PL (Third Party Logistics) providers increasingly combine shipping freight activities with their other services in order to offer door-to-door solutions for all logistics needs. This is fostering a concentration trend on

the shippers' side as well. Freight forwarders usually negotiate with several shipping carriers to carry out their customers' orders.

Concentration does not only take place on horizontal level. Carriers also participate in vertical integration covering almost the whole transport chain. The main carriers' service strategy relies on the supply of global logistics solutions. To offer door-to-door services, carriers operate companies for hinterland transport, port terminals and in-house agencies. Furthermore, some of the large liner shipping companies, like Maersk, focused on own or quasi-own terminals recently. In that case, faster and more efficient port operations are allowed through direct access to handling capacities. Besides this, a strong revenue stream based on volume throughput and relatively high terminal handling charges levied by the industry can be rationalized.

Vertically integrated carriers' ownership or control over port terminal space and berthing could eventually become an effective means of exclusion of rival firms and could deter entry or the threat of entry that would otherwise discipline the pricing behaviour of incumbent carriers, especially in highly concentrated markets.

2.3 Container ports and port choice

Previously, cargo liners were operated on a port-to-port mechanism with lengthy itineraries. Also, equal rates were charged for all ports on the itinerary. Because each port had its own catchment area, shippers had a motivation to hire a liner service which called at their local

port. Liner services had to include that port on their itinerary in order to win a share of this cargo.

Containerization changed the way the liner business scheduled its port itineraries. The control of the land transport was taken by the liner company, and they could plan and adopt the itinerary which achieved the lowest overall unit cost. As a result, the trade was managed through fewer ports with dramatically enlarged catchment areas. In the meantime, competition between the ports to attract liner services was getting fiercer. Because there is a trade off between the cost of the port call and the revenue generated from providing a direct service to and from the port. Then there is the possibility of establishing intermediate distribution centres to cover a third area. As a matter of fact, the hub-and-spoke system, which evolved recently includes, two levels of service which are hub ports and feeder ports. A regular service with frequent loading and unloading of cargoes is scheduled on the hub ports. And the service is offered to the shipper at a fixed tariff whether they are served directly or not. In the meantime, feeder ports are not covered in the normal service, because they do not handle sufficient cargo to make this cost-effective. Therefore, cargoes at feeder ports have to be served by a feeder service with an extra cost.

There are currently about 400 ports which have a significant throughput of containers. However, 98 percent of the total throughput is handled by the top 60. Many countries have only one or two hub container ports serving the deep sea trades, supplemented by a range of smaller ports handling short sea and distribution trades. When it comes to the practice, making a decision on port choice within such an extensive hub-and-spoke global container network is a complex and challenging business.

2.3.1 Parties involved in port choice

Fundamentally, shippers, shipping lines and third party service providers are the main parties who are considered to be involved in the port choice procedure. However, the bargain power of these parties is transferring from shippers to other parties under diversified circumstances. Therefore, one of the key points in analyzing and explaining the port choice problem is to identify the principal decision-making party or parties in each specific case. In order to gain a better understanding of this, the following explores the question “who are the controlling parties involved in port choice”.

Many researchers (D’Este and Meyrick, 1992b; Fleming and Baird, 1999; Wang and Cullinane, 2006) posed the similar question “who actually chooses a port” on different occasions. A universal answer has not been found yet, partly because the answer is complicated and limited attention has been paid to this issue. However, it has important implications for policy formulation and investment decisions.

First of all, which parties are involved in regular port choice should be discussed. From the shippers’ perspective, previous studies show that they can be grouped into three types as shown in Figure 2.2: Those who are independent shippers, those who use third party service providers and those who have long-term contracts with shipping lines. The second group of shippers delegate the responsibility for port selection to third party service providers while the third category of shippers are committed to a particular carrier for a number of years and are therefore relying on the shipping lines’ chosen port of call. Thus, only the independent

shippers and the third party service providers are engaged directly or indirectly in regular port selection.

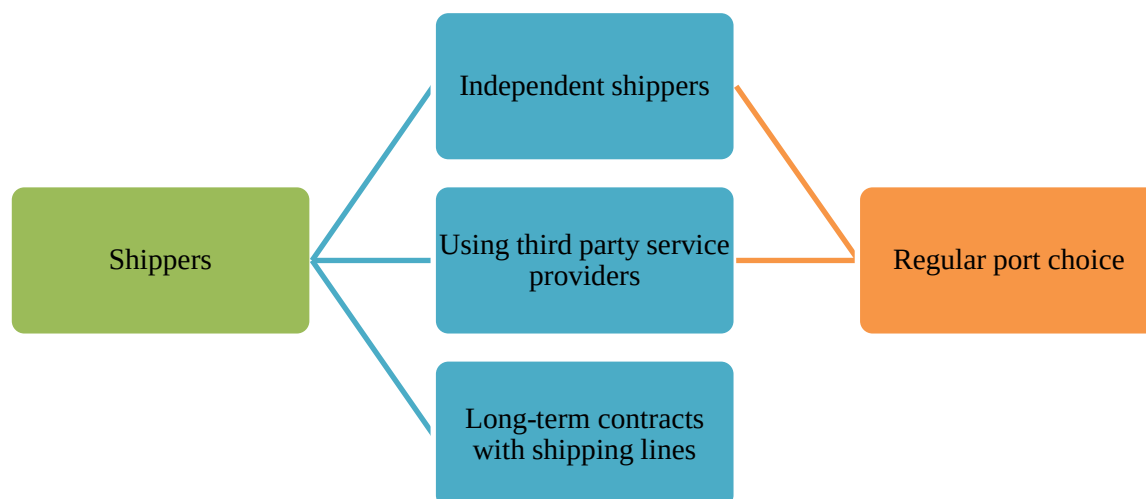


Figure 2.2 – Shippers classification

Liner choice of port raises similar questions about which party is the decision-maker. Ocean carriers conduct the following prior research in order to target their sales activity. Basically, there are two parts covering the vertical integration of freight services are distilled by the ocean carriers to market their services which are the transactional elements of the terms of international sale/purchase of cargoes and the involvement of third party service providers such as freight forwarders, customs agents, consolidators, multi-modal service suppliers. In practice, this has been proven to be the simplest and most efficient approach to strategic commercial activity. However, the “terms of sale” do not always dictate the party controlling the choice of carrier. As a result, the ocean carriers may make a mistake and have to re-investigate who controls the cargo routing.

The above port choice argument provides a multi dimensional perspective on how port choice is arrived at and who are the controlling or influencing parties. The problem is that the influencing parties and stakeholders in the supply chain weigh the same attributes differently in each case. The main parties in the circle of events surrounding the supply chain are the supplier, the purchaser and the service providers, including shipping lines and third party service providers. Port selection would share a similar set of criteria as ocean carriers consider in their sales focus. However, it is more complicated as we can see from the examples listed and again when reviewing current cases of main and minor port selection.

When it comes to the third party service providers (3PLs), they intervene in delivering a consignment to the final customer, a seller is rarely the manufacturer of cargoes and a buyer is rarely the final customer. Efficiency and added-value are created by the third party service providers through integrating a supply chain by importing or exporting a large variety of items on behalf of shippers and purchasers. Such services allow shippers to outsource logistics functions and concentrate on their core business.

In the context of a port as an element of the supply chain, it is reasonable to argue that all the major players in the chain, the shippers, shipping lines, third party service providers and/or chain integrators make decisions on port choice but in different ways and for different purposes in a port oriented supply chain. Most probably they attach different relative importance to the port. As noted by Hayuth (1987), intermodalism provides choices of route, ports of call and modes of transport increasing the power of intermodal operators, freight forwarders or large shipping lines and dramatically reducing the shipper's influence over choice of routes/logistics pathways and modes. Nevertheless, the choices they make are

related. For example, shippers choose a port as part of the overall package of logistics solutions being offered mostly by the third party service providers. Shipping lines too, choose a port as part of their network with a view to offering competitive services to shippers and their other customers. Third party service providers also choose ports but as part of their effort to offer packages of competitive logistics services to the shippers, shipping lines and to a lesser extent consignees.

Under these circumstances, the relevant research question should be how shippers, shipping lines and third party service providers choose a port as part of the overall supply chain selection procedure. As we know, logistics service suppliers are the parties who provide value to the end customer and capture value for themselves through offering competitive supply chain solutions. In this case, it is supposed that shippers, shipping lines and third party service providers are all suppliers. A subsequent issue is the relative importance that each major party in the chain attaches to the port and the criteria they value most to arrive at a final selection of a supply chain in which the port is a part. More importantly, the issue about the power that the key parties have in the choice of a port as a pathway or supply chain element is worth investigating.

There is some anecdotal evidence that the shipping lines hold the final word on port selection. However, this lacks of empirical evidence. Moreover, the example throws some doubt on this. In Australia, a firm based in Darwin exports iron ore to Shanghai through a trader based in Melbourne. The truth is that the iron ore is not delivered on the direct shipping service from Darwin to Shanghai at comparable freight rates to other ports. Instead, it is routed to Fremantle and transhipped on a coastal carrier, loaded and delivered to Shanghai (travelling

over 3500 nm more than the direct service). The reason is that the trader uses a domestic freight firm that provides warehouse and storage at a cost associated with volume throughput. As a result, the trader must satisfy the minimum volume in order to achieve the favourable warehouse and storage rates. In turn, the trader offsets this against the higher ocean freight rate.

In this seemingly casual assessment, the controlling party is identified as a combination of influences and decisions including third parties rather than a single party. Generally, the global freight consolidator offers linked services to importers and exporters which in turn negate the supposed influence the terms of commercial (sale/purchase) transaction may have. The explanation is that each importer has assigned the carrier selection to the global forwarder under the terms of their consolidation agreement. In turn the global consolidator selects the carrier using his combined ocean freight volumes to achieve the lowest possible unit (TEU/FEU) freight rate and best terms. The port selection in this case is the result of an indirect agreement between global consolidator using economies of scale and ocean carrier willingness to offer long-term contract conditions to lock in the cargo volume.

As we can see from the East-West trade route, various ocean carriers serving on this trade route from Far East to West Coast USA call at different ports but major shippers and consolidators switch carrier without much interest in the port of call. We can also observe the same pattern in the world's busiest container ports in the Greater Pearl River Delta, including the Yantian Port in Shenzhen, the Huangpu Port and Nansha Port of Guangzhou and the Kwai Chung Container Terminals in Hong Kong. Port charges in these locations are recognized as being some of the most competitive in the world, but hold little relevance to

port selection without taking into consideration the bundled events surrounding the complete supply chain.

Another reason why we need to re-evaluate the past theories of port choice modelling is the emergence of Inland Container Terminals and Depots (ICT/D). The ICT/D as one common user inland terminal can connect road, rail and freight consolidation networks to many competing seaports. These facilities are becoming more commonplace around the globe due to the diminishing availability of cost effective port land for handling the ever increasing container volumes. The ownership of these inland terminals is mainly split into two types. One is the proprietary service centre operated by the seaport, while the other is owned and operated by third party commercial property developers. These third party inland terminals are offered as common facilities open to all service providers and incorporate “freight villages” whereby consolidators, forwarders, road and rail freight operators can all take leased space and operate as an integrated intermodal group.

Either type of ICT/D ownership adds a new dimension to port choice. This gives reason to explore the future dynamics and relationships between seaports and inland ports and who may hold greater influence in the overall supply chain event.

A simple conclusion is that all major players in the supply chain make port selection decisions but with different foci and relative importance attributed to the port. Moreover, they take a holistic view and choose a port as an element of a supply chain.

2.3.2 Key factors influencing port choice

As a result of operational innovations, such as intermodalism, some new factors may have to be taken into account. In the meantime, some existing factors may lose their weight or be ignored under the new circumstance. The key factors influencing port choice are fundamental to investigating the technical approaches to port choice modelling. Better understanding of the key influencing factors will contribute to the improvement of port choice modelling.

Existing literature has applied a wide range of approaches and key determinants to measuring port performance and efficiency, attempting to analyze the fierce competition for market share among ports located within the same region and serving approximately the same hinterland. According to Fleming and Hayuth (1994), geographical location is essential to explaining a port's competitive advantage. Baird (1996) has argued that faster turnaround time within the port is a significant factor in port advancement. Tabernacle (1995) has described the importance of crane productivity in improving port performance. Fung (2001) has tried to measure the competition between the Port of Singapore (PSA) and the Hong Kong Port by looking at factors like the volume of trade passing through these two terminals, especially to countries like China and the rest of the Asia. However, these studies are focusing on partial productivity factors which might not be helpful to the port authorities for policy making in the long term. Besides that, most shipping lines are concerned with the overall productivity of the port rather than partial productivity.

Referring to the determinants of the overall port productivity and performance, Tongzon (1995) has been looking at such factors as location, frequency of ship calls, economic activity within the sector, labour and capital productivity and work practices within a port. Besides that, there is an extensive literature on freight transport choice of shippers focusing on modal choice and carrier selection (e.g. Jerman et al., 1978; Marr, 1980; McGinnis, 1980; Gray, 1982; Meyrick and D'este, 1989). There are mainly three factors identified in these articles which are route factors, cost factors and service factors. Route factors are indicators such as capacity, frequency, transit time and convenience; cost factors include freight rates and service factors include reliability, delays, avoidance of damage, loss and theft. However, investigation of port choice on behalf of the shipping lines is quite limited (Tongzon and Sawant, 2007). Moreover, research by Brooks (1985) based on carrier choice has found that shippers' actual behaviour may not comply with their stated preferences. Limited attempts have so far been made to assess whether there is consistency between the stated preference and the revealed preference of shipping lines (Tongzon and Sawant, 2007).

There are few studies of the port choice determinant. Slack (1985) presented interesting information on port choice. He surveyed port end users and freight forwarders engaged in transatlantic container trade between the American Midwest and Europe to identify port selection criteria. Similarly, Branch (1986) produced a general list of factors relating to shippers' choice of port. Other studies (Willingale, 1984; Murphy et al., 1991, 1992) attempt to identify and explain the various factors in port choice.

In the meantime, there are numerous studies on freight transport choice by shippers, but they have centred on modal choice and carrier selection, rather than addressing the more specific

question of choice between competing ports (Saleh and Lalonde, 1972; Bardi, 1973; Gilmour, 1976; McGinnis, 1979; Ogden and Rattray, 1982; Brooks, 1984, 1985; Wilson et al., 1986 and D'Este and Meyrick, 1992). However, modal choice and port choice can be reasonably assumed ultimately related so the results from modal choice studies can provide some basis for formulating certain hypotheses about port choice factors.

Generally, the potential determinants of port choice identified in these studies can be grouped into two categories which are qualitative factors and quantitative factors. Qualitative factors contain subjective influences such as flexibility and ease to use, the port's marketing efforts, tradition, personal contacts and the level of cooperation that may have developed between the shipper and the port. Quantitative factors are those that can be potentially measured and compared in an objective way. These factors can be further grouped into three broad categories: route factors, cost factors and service factors (D'Este and Meyrick, 1992). In practice, the distinction between qualitative and quantitative factors is blurred because the perception of the shipper about the port performance level may not be a fair reflection of the actual performance. In many cases, perception can take precedence over actual performances (D'Este and Meyrick, 1992). And also, it is shown that a perception gap exists between the port users and port operators.

Although the perception gap exists between stated performance and actual performance, some key factors can still be identified and listed as follow. The shippers can be attracted due to high levels of port efficiency. Port efficiency can be reflected in the freight rates charged by shipping lines taking into account the turnaround time of ships and cargo dwelling time. The longer a ship stays at berth, the higher is the cost that a ship will have to pay. This higher

cost can be passed to shippers in terms of higher freight charges and longer cargo dwelling time. The ability of shipping lines to pass on the costs to shippers depends on the elasticity of demand and the proportion of total costs attributable to these costs.

Geographical location has been treated as one of the main determinants of a port's attractiveness through conventional notions of port choice. The choice of a port is not merely a function of proximate convenience but derives as well from the overall costs of cargo trafficking. For example, the distance between the port and the shipper's factory has a major impact on inland transportation costs. Willingale (1984) and Murphy et al. (1991) found that the location factor had a relatively low ranking in their respective surveys, yet they cited other studies which have demonstrated that this is in fact a primary factor. One explanation given was that significant improvements in domestic transportation system appeared to have lessened the importance of close geographical proximity between ports and their customers in port choice decisions.

Frequency of ship calls is also a significant factor for shippers in port choice. Greater frequency of ship calls represents more choices for shippers in scheduling their shipments and selecting a shipping service for the transportation of their cargo, and hence resulting in more competitive carrier costs. Further, greater frequency of ship calls allows for greater flexibility and lower transit time. Thus, the more ship calls a port has, the more attractive it is to shippers.

Several indicators of port efficiency have been identified by Tongzon and Ganesalingam (1994). These indicators can be categorized into two broad groups which are operational efficiency measures and customer-oriented measures. The first set of measures deal with capital and labour productivity as well as asset utilization rates. The second set includes direct charges, ship waiting time, reliability and minimization of delays in inland transport.

Another factor is adequate infrastructure. Infrastructure refers not simply to the number of container berths, cranes, tugs and terminal area, but also to the quality of cranes, quality and effectiveness of information systems, availability of intermodal transport, the approach channel provided and the preparedness or otherwise of the port management (Tongzon and Ganesalingam, 1994). If the volumes handled far exceed a port's cargo-handling capacity, this will result in port congestion and inefficiency, and thus can reduce the number of port users. Furthermore, limited access to current information about shipment arrivals due to lack of adequate information system will slow the documentation process and thus the smooth functioning of a port. Without adequate intermodal links, shippers cannot easily move cargo to and from the port, which could lead to congestion, delays and higher costs.

Port charges are another important factor related to port choice. There are different types of port charges, which vary between ports in terms of levels and structures depending on the nature and functions of ports. Except for landlord ports, which derive their revenues from rents, port charges are generally levied on the basis of port visits and/or cargoes. Examples of ship-based types include port navigation fees, berthage, berth hire, harbour dues and tonnage while cargo-based types include wharfage and demurrage. Berth hire and berthage are usually levied either on the basis of net registered tonnes (NRT) or against gross registered tonnes

(GRT). Stevedoring and terminal handling charges are levied on cargoes with different rates for different cargoes. Direct port charges may eventually be reflected in the freight rates shippers have to pay. Other types of costs which shipper eventually pay include ancillary charges such as the costs of pilotage, towage, lines, mooring/unmooring, electricity, water and garbage disposal. Previous studies produced varied findings on the relative significance of port charges as a determinant of port choice. Foster (1978) has found that port charges are the principle factor driving port choice, but its importance must be seen in the context of overall costs. Shippers are more concerned with indirect costs associated with delays, loss of markets/market share, loss of customer confidence and opportunities foregone due to inefficient service, than with port charges (Tongzon, 1995). Murphy et al. (1991, 1992) have shown that some users are actually willing to accept higher port costs in return for superior and more efficient service.

Low level of cargo damage is another key determinant of port choice. Perception of cargo safety can be more powerful and important than the actual safety. If a port has a reputation that the handling of cargoes is unsafe, this could drive away potential clients and discourage existing clients. Thus, marketing and promotional efforts by port authorities to highlight the port's positive characteristics and accomplishments could improve the port's reputation. A record of accomplishments and achievements gives assurance to customers in terms of quality and reliability. The latter is important for influencing carrier's choice of port as it is often the relative perception of customers that supersedes the actual port performance.

Ports are also expected to respond quickly to port users' needs. This means that ports would have to constantly monitor and understand the needs of port users in order to devise the

quickest way to respond to them. Regular dialogues and social interactions between the port's public relations staff and port users are quite useful in this regard.

2.4 Summary

As we can conclude from the review of the evolution of liner shipping, two aspects, the development of liner shipping industry and the effects of containerization, are presented and discussed. During the cargo liner era, liner services carry general cargo and operate in a market where all the competitive edge of the bulk shipping segment could be achieved. However, the market and competition are altered by two major differences. One is that the requirement to operate a regular service makes liner capacity inflexible. The other one is the more restricted price negotiation with so many shippers. As a result, the free market mechanism which regulates the bulk shipping market takes on a different character with these restrictions in the liner shipping industry. When it comes to the container liner era, dramatic changes brought to the liner shipping business are described along with the progress of containerization.

The review of contemporary liner shipping business demonstrated key components and competitive conduct of current liner shipping market. The East-West trades operating between the industrial centres of North America, Europe and Asia are the major container liner routes. These are supplemented by a complicate array of North-South trades covering the various developing countries. The intraregional trades are provided to meet particular local needs. The container service network is constantly changing in order to meet the needs of trade. Starting with a brief analysis of the global liner shipping market, a framework of the

world container business with four components, the cargo, the service, the liner companies and the fleet, is well established. In addition, the competitive conduct in the liner shipping industry mainly regarding concentration, consolidation and vertical integration are presented. A highly flexible supply system involving alliances, capacity chartering arrangements and a container ship charter market has built up to serve these trades mentioned above. One of the major purposes is to capture the different economies of scale of stakeholders, such as liner companies and shippers.

As to the port system, containerization changed the way the liner business scheduled its services. A much more competitive network type, the hub-and-spoke network, has been established and used in pursuing the lowest overall unit cost. However, making a decision on port choice within such an extensive hub-and-spoke global container network is still a complex and challenging business. Much research has been done in this field. With a comprehensive understanding of the parties involved in port choice, a number of key factors that can be identified are geographical location, frequency of ship calls, port efficiency, adequate infrastructure, port charges, reputation for cargo damage and quick response to port users' needs. A simple conclusion is that all major players in the supply chain make port selection decisions but with different foci and relative importance attributed to the port. Moreover, they take a holistic view and choose a port as an element of a supply chain.

Finally, the lessons learned from the above can be concluded as follows. First, the process of containerization has connected the whole world with a competitive market successfully providing the most cost effective service. Second, the service pattern and competitive conduct has been changed dramatically due to containerization and globalization. A much more

extensive hub-and-spoke global container network is operating at the centre of the liner business. Third, the port system has experienced a tough time in order to keep pace with the trend in terms of its roles and functions in liner shipping. Therefore, to understand the port choice problem is challenging and the circumstances are complex, given the many stakeholders involved.

Chapter

3

Literature review

The literature formulating the basis of this maritime container flow assignment model can be identified as a combination of port choice modelling, freight flow models and empty container repositioning. Previous works within the field of port choice posed technical approaches applied from the perspectives of various stakeholders. Moreover, better understanding of the port system and new approaches to analyzing the port choice problem could be thereby achieved.

In the following section, the literature on freight flow model covering basic and most related innovations contributing to establishing the model are presented. Finally, in terms of empty container repositioning, this chapter mainly focuses on three issues. First, how empty container repositioning demand is induced? Second, what techniques have been applied? Third, why this problem could be better solved by combining it with full containers?

3.1 Port choice modelling

Basically, literature that contributes to port choice modelling comes from two primary directions. First is qualitative analysis regarding empirical surveys of carriers and shippers. Second is economic modelling, in particular that applied to maritime transportation. This modelling includes primarily linear programming, cost modelling and choice modelling.

3.1.1 Qualitative analysis

For the qualitative analysis, surveys of industry participants have addressed two major issues which are who selects the port for each shipment and what factors influence the selection of port. Neither question has generated consistent results. With regard to the first question, most authors have suggested that the carrier selects the port for each shipment. In analyzing the results of surveys, Slack (1985) wrote that carriers play the key role in the port selection process; D'Este et al. (1992a; 1992b) found that in most cases the port is just another factor the shipper evaluates in the carrier selection. They suggested that as carriers increased their scale of operations and shippers began soliciting prices for door-to-door service rather than individual segments, the port selection shifted from the shipper to the carrier. With

deregulation of the maritime industry, rates were no longer so closely related to distance. Carrier could offer less direct routes that were cost effective for the shippers as well as themselves. As shippers adjusted to the deregulated environment, carriers began to select the route for shipments. In selecting the route, carriers would consider the shippers' interests to capture their business.

In the port selection, decision makers seem to value service characteristics more highly than price characteristics. In an early survey, Bardi (1973) found that transit time, reliability, capability, availability, and security were the most important characteristics. Two surveys conducted for Distribution Worldwide (Foster, 1978b; Foster, 1979) had conflicting results. However, according to the first survey, shippers valued service more than cost. With the second survey, the author found that transport costs and port charges were most important criteria. Qualitative choice analysis can produce this inconsistency, since it focuses on stated preference rather than actual preference. Foster also remarked that only 30% of respondents cared if the port they chose is the last port of call for the vessel carrying the goods, suggesting that more should. In analyzing these surveys, Slack (1985) found that the number of voyages and inland freight rates were most important. Significant port characteristics included the port's connection to inland transport services and the available container facilities. Slack concluded that the choice of port depended more on the price and quality of service offered by land and ocean carriers than on the attributes of ports themselves.

From semi-structured interviews of industry participants, Hanelt et al. (1987) concluded that each participant valued characteristics differently. They argued that many important factors are beyond a port's control. Port managers can't influence the two most important factors, the

size of the local market and domestic transportation costs. However, they can indirectly influence port labour productivity, rail transit times, port access, total transit time and ocean carrier intermodal networks. Besides these, they can also directly influence terminal gate capacity, channel and berth depth, indirect port charges, port charges on cargo or carriers, and cargo handling equipment. Brooks (1984, 1985) present one disadvantage of stated preference analysis when finding similar results from her survey. She remarked that importance does not necessarily represent salience for a factor; the inconsistency of surveys noted earlier reflects this. A characteristic could be considered important yet not influence the decision process if the characteristic did not vary among alternatives. Within quantitative research based on revealed preference, values can be assigned to each factor's importance to measure its true salience.

3.1.2 Economic models

When it comes to the economic models, three types of economic models have been developed: linear programming models that assign fleets in simplified situations, economic models that represent the costs of carriers or ports and economic models that represent carriers' decisions.

A simple method to minimize vessel operating costs for a given load and a pre-specified fleet was first proposed by Benford (1981). He assumed that carrier revenues were fixed so the objective was cost minimization. If average costs increased with the volume transported by a vessel, the optimal solution could be yielded that each group of vessels would operate at a speed that produced equal average costs between groups. Perakis (1985) corrected Benford's

results with the Lagrangean method and showed that Benford's results were not always optimal. Lane et al. (1987) represented different aspects with cost components, e.g. late loading costs, idle time costs and utilization costs. Perakis et al. (1991) extended the optimization model further by including all operation costs. In each model, however, the flows were pre-specified. More importantly, customer costs such as inventory costs were virtually ignored. Cho et al. (1996) attempted to incorporate demand forecasts with multiple ports, but demand was again pre-specified and did not vary with service levels. In reality, shippers would often pay more to have shipments delivered faster, more frequently, or more reliably.

Cost models influence each carrier's port and ship size selection, and numerous authors have modelled cost for the maritime industry. Waters (1997) summarized options for estimating cost functions which are engineering, econometrics and statistical regression. Tolofari et al. (1987a, 1987b) estimated cost models for bulk shipping and tanker industries. Each model suggested scale economics in vessel size, but the authors emphasized that carriers could exploit these economies only at the expense of port operators or shippers. Port operators would incur additional dredging costs, and shippers might face higher inventory costs from reduced frequencies. Garrod et al. (1985) and Jansson et al. (1985) showed the importance of shippers' inventory costs when minimizing carrier costs. Jansson et al. (1978), Talley (1990) and Lim (1998) found similar characteristics for general cargo and container ships.

From another perspective, many authors have explored the optimization of port performance. The authors emphasize the measures gathered, and the objectives pursued, by port operators. Griffiths (1976a, 1976b) first modelled the optimal handling capacity at a berth. He assumed

that vessels carrying a fixed load arrive either as a Poisson process or at a uniform rate and that the time to service each vessel is distributed as a negative exponential variable. He then predicted the delay for each vessel as a function of the port's handling rate. Griffiths used shippers' delay costs and port operators' service provision costs to estimate an optimal level of service. Wanhill (1976) and Chappell (1979) added minor elements to the model, such as the time required for vessels to access berthing facilities and the possible nonlinearity of port costs. Laing et al. (1989) showed that the congestion necessary to justify a new berth decreased with the number of available berths. With more berths, the reduction in delay from a new berth is smaller but can be spread over additional vessels.

Through focusing on quay length and the number of cranes, De Neufville et al. (1981) confirmed that scale economies exist at container ports. He argued that the other two resources, land and manpower, could be represented by the first two as proxies. At six eastern U.S. ports, De Neufville found that productivity increased with port size. He argued that investing at major ports would be advantageous to investing elsewhere. Bendall et al. (1987, 1988) measured port productivity as a function of labour, capital and time for different ship types. They found vessel age and vessel size to be important and that congestion was greater in certain years due to specific events. They also found that, to increase efficiency, port could customize facilities for different ship-types. Talley (1988a, 1988b) argued that an incentive existed for smaller, neighbouring ports to consolidate and for ports to invest efficiently as a group. He suggested that larger volumes could produce lower rail costs and that smaller ports might need to subsidize rail services to compete. He also suggested that ports compare actual throughput with maximum throughput only for a captive hinterland. In a competitive environment, unit cost minimization or zero deficit throughput maximization may be preferred.

Talley (1994a) later showed how a port could maximize efficiency with Lagrangean modelling, since the shadow cost represents the cost needed to handle an additional container. Minimizing the shadow price for a given volume would be equivalent to maximizing a port's operational efficiency. Tongzon (1995) argued that a port's throughput efficiency affects its overall throughput since it influences the port's attractiveness to shippers. With a Cobb-Douglas function, he showed that throughput efficiency is affected by container mix (20 ft. versus 40 ft.), work practices, crane efficiency, vessel size and cargo exchange. He argued also that port charges are important, but also so are service factors.

Riendeau (1977) presented an early model of the shipper-port-carrier transportation system to describe the selection of ports. He discussed many of the elements that influence the route and thus the port chosen for each shipment. He merged the decision patterns of each party to establish a final route. He expected behaviour to change at certain thresholds i.e. the boundary of a port's hinterland, but his assumptions were simple. He gave little attention to carriers' scale economies. In addition, the present system is much less regulated. The routes available to carriers and the rates available to shippers are more flexible, making Riendeau's work less applicable to today's environment.

Numerous reports have also examined the economic impact of port charges. Authors (Gentle, 1989; Tongzon, 1989; Goss, 1990) have argued that these fees do not affect carriers' port selection. In a quantitative analysis, Tongzon examined the elasticity of the number of shipments with regard to wharfage in Australia. Due to relatively low elasticity, he predicted

no significant increase in port traffic or port revenues would result from reduced wharfage. Thus, though port charges played a significant role in the generation of revenues by a port authority, they did not heavily influence port selection. In addition, the structure of port charges is not consistent across ports (Foster, 1978a).

Using microeconomic modelling, Allen (1977) and Daughety (1979) each defined a decision maker with an objective of profit maximization. They represented profits as the difference between revenues and production costs, and they represented revenues as the difference between the product's final price and its transportation costs. With this equation they could determine the optimal level of inputs, including transportation services. Alternatively, they could generate a cost function to represent the desired output with the required amount of transportation. They proposed the inclusion of service characteristics, such as scheduling delay or shipment damage, if converted to lost revenues or added costs.

Discrete choice modelling, however, focuses on a measure that does not require the formulation of profits or costs (Winston, 1983). Researchers do not need to convert each factor to a monetary value. For an aggregate model, the basic unit of observation is a freight mode's aggregate share. For a disaggregate model, the basic unit is the decision made for an individual shipment. Aggregate and disaggregate models have been applied to freight transportation, most commonly for the study of mode selection or demand estimation for a new mode. Boyer (1977) and Oum (1979) discussed shortcomings of the linear logit model used for aggregate analysis, particularly with the elasticity of substitution between alternatives. Disaggregate models were applied by Winston (1981a, 1981b) and Nam (1997). Initial application of a disaggregate model toward the selection of port was presented by

Malchow et al. (2000). With a disaggregate model, we could represent more richly the situation faced by the decision maker. A disaggregate model however requires more precise data, data often considered proprietary by shippers.

Two different modelling approaches dominate the study of choices individuals make (Hensher and Johnson, 1981; Ben-Akiva and Lerman, 1991). The first uses discrete choice models based upon revealed choice data. Revealed choice data provides information about past decisions individuals made on the subject of interest. The second approach uses choice models derived from stated choice experiment data and it is very useful for situations where the subject of interest is behaviour in new situations. A key assumption is that decision makers behave rationally and will always choose those alternatives that yield maximum utility or satisfaction.

Generally speaking, stated choice models are based on information integration theory in psychology (Anderson, 1981), random utility theory in economics, and econometric specifications of discrete choice models (Hensher and Johnson, 1981). The presumption is that shippers arrive at a choice by cognitively integrating the utilities attached to the attributes that characterise the choice, according to a simple algebraic rule and by implementing a utility maximising rule to convert their preferences into a choice. The main difference between revealed choice models and stated choice models is that revealed preferences of the decision makers are based on their actual choices. Both models refer to the key factors observed to be influencing port.

In order to estimate the assumed utility function and to test the underlying choice model, shippers in a sample are typically presented with choice sets that may vary in size and composition and are asked to select from each choice set the alternative they like best. The choice possibilities or alternatives may be examples from the real world, but more typically they represent profiles of hypothetical supply chains. Choices are aggregated across individual shippers for each choice set and analysed by means of a choice model, usually a multinomial logit model (Hensher and Johnson, 1981; Louviere et al., 2000; Kuhfeld, 2003). Once a specific model is assumed, the aggregated choice frequencies may be decomposed to determine the contribution of each factor or attribute.

3.1.3 New approaches to port choice

Ports have always been part of the maritime transport chain but their full integration in supply chains is a recent phenomenon. Earlier chains were highly fragmented, uncoordinated and inefficient. Ports were important but weak links in the chain. Individual firms in the chain including ports were internally rather than market driven; their focus was on maximising their own profit by being managed as stand-alone entities. Shippers were more concerned with minimising transport cost to remain competitive. For most shippers, the choice of a port, shipping lines and land transport was a major logistics consideration because these elements of the transport chain were perceived as significantly eroding value created and delivered to end customers. Competition was driven by cost; the value of the service provided was a secondary consideration.

In such circumstance, it was an important issue not only for shippers but also for port managers, shipping lines and policy makers who chooses a port and how. It is then not surprising that research was conducted to shed light on the issue. In response, a number of studies on port choice were undertaken using a number of methodologies, depending on the interests and knowledge of the researchers involved (Slack, 1985; Bagchi, 1989; Murphy et al., 1992). Most of the studies provided useful insights into the determinants of port choice in different contexts with significant implications for policy and practice. Nevertheless, none of the studies has examined port choice in a situation where a port is considered as an element of a supply chain (Magala, 2004). Robinson (2002) articulated the view of a port as an element in value driven chains and called for a paradigm change. The significance of this shift in thinking was recognised as a major breakthrough by Panayides in 2006 in a special edition of the *Maritime Economics and Logistics* and noted later by other authors in a number of subsequent academic papers. Yet, its full acceptance has not been seen.

In the highly competitive and rapidly globalising economy of today, the integration of supply chains is taking place and ports are increasingly competing not as individual entities but within supply chains. Better integrated supply chains, rather than individual firms or highly fragmented chains now compete with each other (Robinson, 2002, 2003, 2006; Lam, 2006). Integration has been driven mostly by third party service providers not simply seeking to extract costs and efficiency advantages but in so doing to deliver competitive advantage to the end customer with a view to extracting value and competitive advantage for themselves.

Clearly ports can no longer be expected to attract cargo simply because they are natural gateways to rich hinterlands. Major port clients are now likely to choose ports not simply on

their efficiency and location but rather on the quality and reliability of the entire supply chain. The successful functioning of ports is indistinguishable from the successful functioning of the entire supply chain. For shippers, port choice becomes more a function of overall network performance and ports are chosen on the basis of faster, better and more cost-effective access to the markets in which shippers compete. Shippers see as the greatest value of competing as part of an integrated supply chain the opportunity to reduce vulnerability to competition by providing the port with complementary resources and capabilities needed to compete effectively in the marketplace. In essence, supply chain integration may allow some firms to compete effectively in the marketplace without first owning all the critical resources needed to do so.

Under the new circumstances it is apparent that shippers are being offered for the most part logistics packages of varying composition and prices, which include among other things, port services. Third party services providers or/and supply chain integrators have assumed the role of packaging and marketing logistics services to shippers. This means that shippers can now focus on their core business and intervene only when a selection/choice of a supply chain solution that suits their tests and objectives is required. Therefore, the choice of a supply chain solution rather than the choice of a port per se becomes the focal point of shipper decision making.

The primary concern of a shipper is to move freight from market A to market B or more specifically from a point of production to a point of consumption or further processing in the most cost effective way. In consigning cargo to an end market the shipper chooses a logistics pathway which the freight follows. The notion of a logistics pathway connotes a sequential

set of logistics operations, warehousing, depot operations, port operations, trucking freight forwarding, that deal with the end-to-end movement of freight. A logistics pathway connects one supplier in a supply chain with one consumer. Figure 3.1 is a simple high level description of logistics pathways. From the figure it can be recognised that a shipper has a number of choices to make to reach the end market in which it competes with other shippers for value. The shipper has to choose routes, modes, carriers and ports. These choices are rarely made independently; they are interdependent and often internalised in the overall choice of the supply pathway. In this conceptualisation a port is just an element – an important one – of the supply chain system.

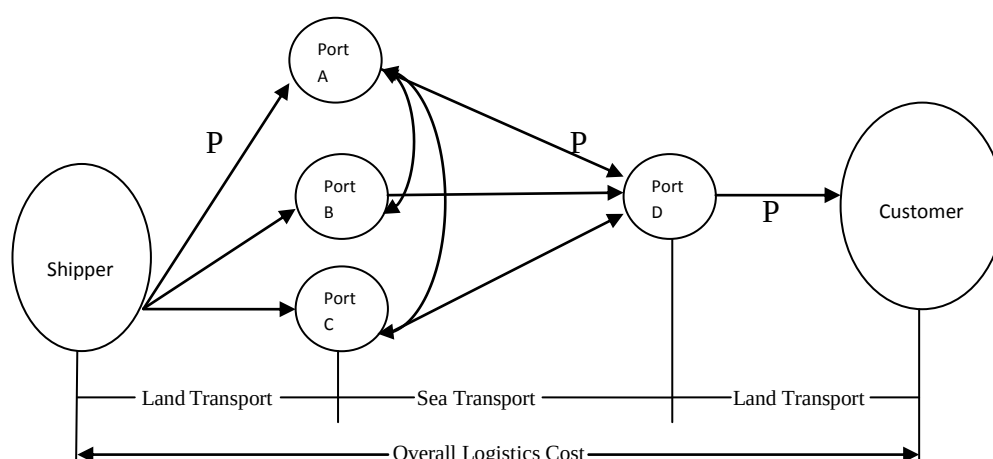


Figure 3.1 – Logistics pathways in a port oriented supply chain

The availability and suitability of a particular pathway is governed by a number of spatiotemporal and logistical factors including the availability of a shipping line, land transport, accessibility, connectivity and alignment with shipper needs and strategy. It follows then that when choosing a pathway a shipper will consider not only the possible combinations of ports of origin and destination, but also the availability of shipping lines, routes, land transport and a host of other logistics factors. Since all these elements are part of the pathway,

it can be argued with some degree of confidence that the choice of a port is the by-product of a choice of a logistics pathway in which the total logistics cost is a major supply chain consideration.

Logistics pathways are being offered to shippers at a price by the third party service providers who intervene in firm-to-firm transactions to effect the freight movement and by so doing capture value for themselves (Robinson, 2002). The 3PLs offer packages that include not only transport, cargo handling and storage of goods, but also full responsibility including risk over the cargo from origin to destination on the basis of a single contract and bill that reflects the total logistics cost and not the cost of separate functions carried out by individual firms in the chain. They do so because, in the eyes of the customers, no longer is it satisfactory to supply one part of the solution; a total logistics solution has become a threshold requirement to compete.

The choice of a port's relevancies is difficult to explain if it is not placed in the context of supply chain selection. Shippers choose ports not simply on their efficiency and location but on the extent they exist as elements in the supply chain that provide low cost transport pathways to markets. Ports not only must themselves be efficient, they must exist within efficient pathways where the total cost is lower than the cost of competing pathways for a comparable level of service. Quality and reliability of the entire supply chain is a major consideration. For shippers, ports are chosen on the basis of how well they are integrated in the supply chains.

There are two well developed theories which offer exceptional insights on how to approach the modelling of port choice from a perspective of a port as an element of a supply chain. The first is based on systems theory and the second on the economic and marketing theory of bundling. The theories share a number of similarities but the way then explain how things work is different though not contradictory (Robinson, 2002).

The systems theory emerged as a reaction to analytical or classical natural science approach which is based on the assumption that the parts make up the whole and as long as the parts are describes well enough the individual merely has to put them together to get the whole picture (Churchman, 1981; Capra, 1997). The behaviour of the whole is assumed to be understood entirely from the properties of the parts. On the contrary, the systems theory states that the various parts of the system are linked together and can only be understood by a holistic approach. Put in the context of port choice, this means that the choice of a port can be fully understood if we examine the overall choice of supply chain pathways. Under a systems approach, instead of breaking the supply chain or pathway into its component parts, i.e. ports, shipping lines, land transport, the parts are integrated into pathways to more fully understand and model port choice. Someone still needs to put the elements together in the first place. In the maritime business this is being done currently by 3PLs and chain integrators.

The way shippers go about constructing and evaluating a set of shipment options is of considerable interest in particular when consumer behaviour theories based upon single-item choice fail to predict behaviour adequately in a situation involving multiple choices. In such circumstances bundling appears to offer an adequate. Bundling is concerned with the joint offering of two or more non-substitutable items together at a single, combined price (Yadav,

1994). In the case of a shipping industry, for example, a shipper selects a number of logistics services all of which are necessary for a shipper to be able to move the goods from one end of the market to the other. The key feature of bundling is the treatment of the choices as interrelated.

Under bundling it is predicted that the consumer will choose the bundle with maximum utility; this is a bundle that will maximize customer satisfaction for a given service requirement. Bundling is an integrating approach for offering shippers a greater choice of cost control, flexibility, competition, reliability, risk management and a one-stop service that is more cost effective than the alternative options. It offers the shipper the opportunity to select combinations of logistics packages that offer the level of efficiencies and costs that is more aligned with customer's expectations.

The usefulness of bundling for the new approach to port choice modelling is that it provides a framework within which we can explore how a supply chain is formed, priced and evaluated by the shipper to arrive at final choice decisions. According to Russell et al. (1997) bundles are formed through a selection process in which items with different features are combined to compose the set. These items in the set are not substitutes and must complement each other to fit the purpose. The relative importance of each item may be different but the items must be interrelated.

The economic rationale for bundling (Guiltinan, 1987) is based on the reality that the cost structure of most service business is characterised by high ratio of fixed to variable costs and

by a high degree of shared costs; and the services offered by most service businesses are generally interdependent in terms of demand. The effectiveness of price bundling then appears to be function of the degree to which it stimulates demand in a way that achieves cost economies.

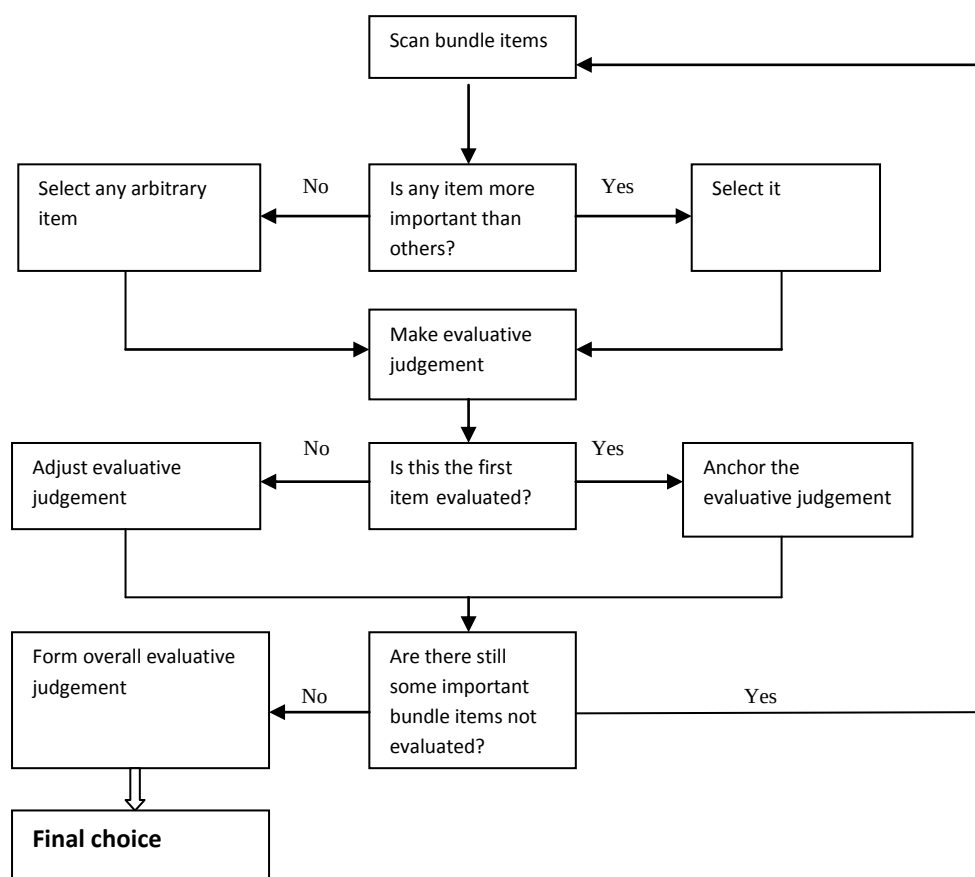


Figure 3.2 – Bundle evaluation process (Yadav, 1994)

The issue of bundle evaluation is central to the approach we propose. Yadav (1994) developed and tested a model of how buyers evaluate product bundles. The model was adapted from the strategy proposed in Lopes (1982) which suggested that in the presence of a substantial amount of information buyers anchored their evaluation on the item perceived as most important and then made adjustments on the basis of their evaluation of the remaining bundle of items. Yadav (1994) suggests that buyers tend to examine bundle items in a

decreasing order of perceived importance and make adjustments to form their overall preference of the bundle. This bundle evaluation process is depicted in Figure 3.2 and can be viewed as an extension of the Anderson (1981) information integration theory. It also offers a richer perspective for understanding how shippers may evaluate and choose a port within the paradigm of a port as an element of a supply chain.

Systems theory and bundling are useful in helping us to understand why it is more appropriate to model a port as an element of a supply chain. The main thrust of the theories is that modelling a system provides a better understanding of the choice of individual elements that compose the system. Trying to study a system by focusing on its individual parts has weaknesses in that it omits the key interdependences. Shippers choose a system to profit from synergies that a well functioning system provides.

To model complex decision problems with a large number of intervening factors, Louviere (1984) developed a hierarchical information integration approach illustrated in Figure 3.3, which is an extension of information integration theory (Anderson, 1981). Basically, the approach (1) categorises attributes into several non-overlapping sets based on theory, logic or empirical evidence, such that the sets represent particular factors including port, shipping line, land transport or the like; (2) designs and administers separate experiments to define each factor in terms of the attributes that categorise it; and (3) develops an overall or bridging design based on the factors that allow one to concatenate the results of the separate designs and overall design into one fully specified utility model.

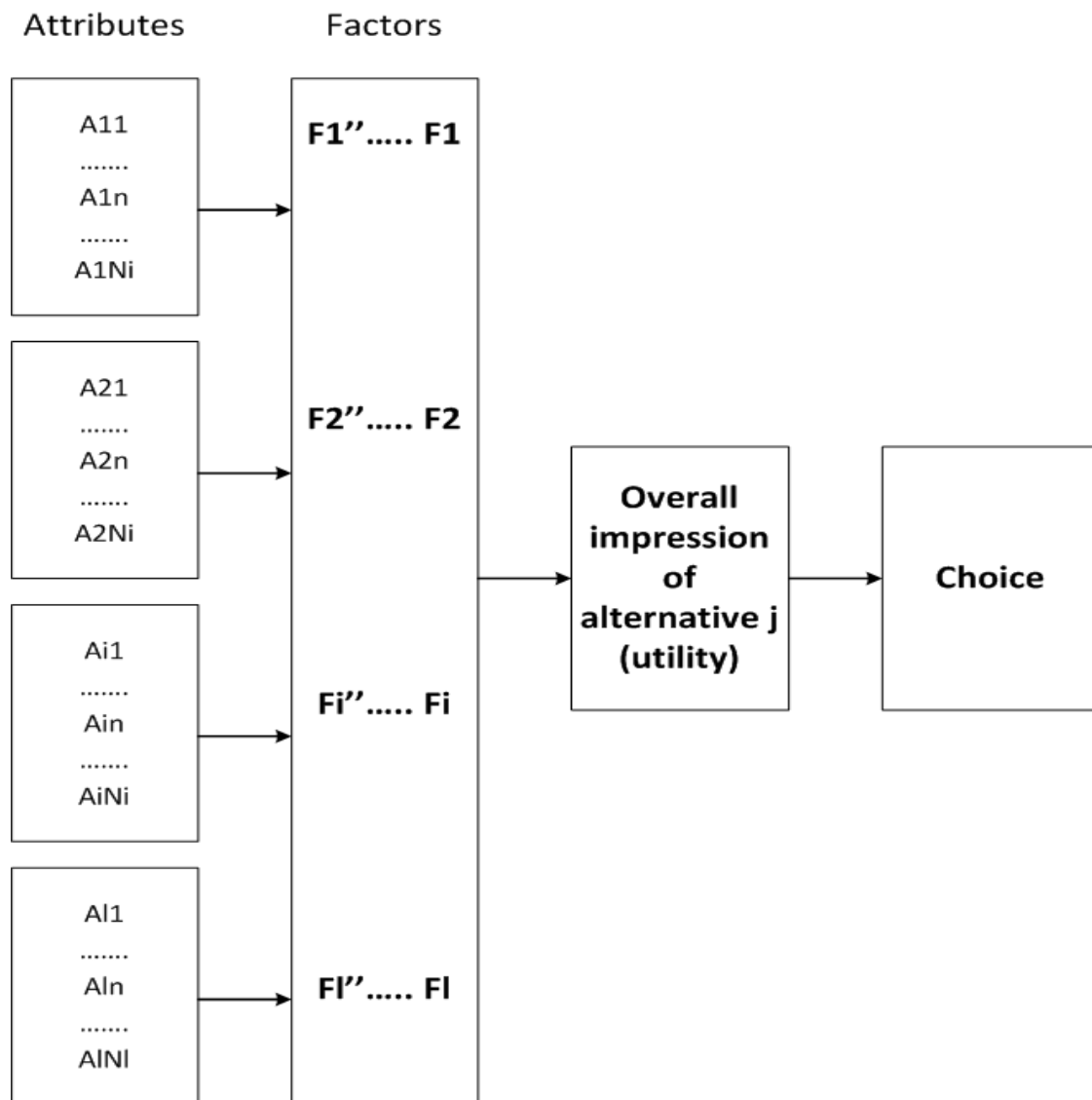


Figure 3.3 – Overview of the hierarchical information integration approach

(Magala&Sammons, 2008)

Essentially, the attributes A , in Figure 3.3, can be combined into constructs or factors to represent the choice process. This process is repeated in Figure 3.4 with a more specific example of choice of a port as an element embedded in a supply chain.

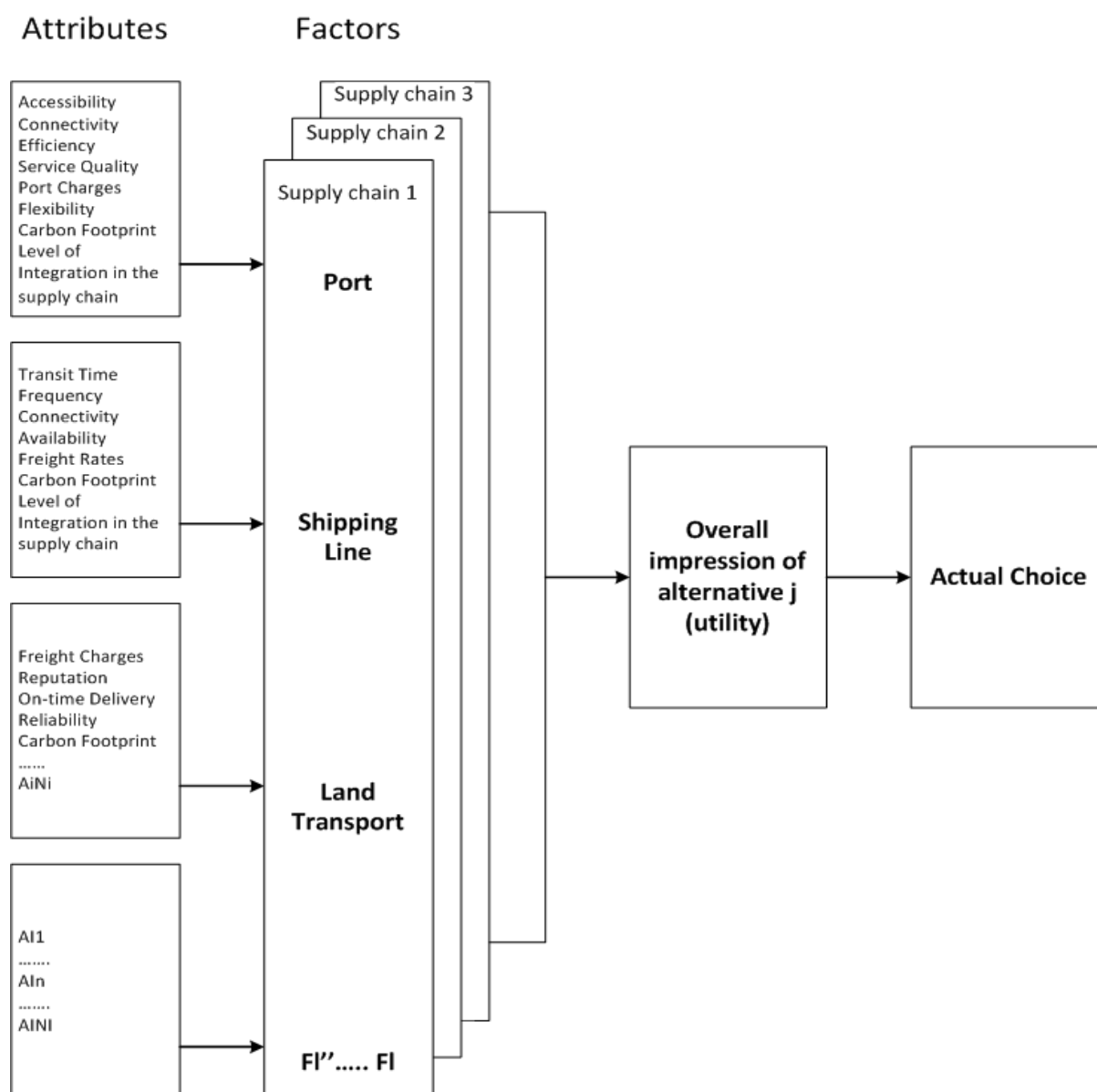


Figure 3.4 – Port choice procedures (Magala&Sammons, 2008)

Figure 3.4 identifies two possibilities to model choice using the systems approach. At one level, it is possible to model supply chain choice in the presence of a number of competing supply chain alternatives. At another level, it is possible to use the same model specification to understand the determinants of port choice, shipping line, land transport and other elements that compose the supply chain.

Within this view, it is suggested that discrete choice modelling provides the right modelling framework to handle both the system and the port choice. Particular specification of a model will be context dependent but the universal paradigm is that a port is chosen not in isolation but rather as an element of a pathway.

For the purpose of choice modelling a supply chain and a port can be described as a combination of factors and attributes at different levels. The key factors or variables relevant to the modelling are those known to influence shipper behaviour and subsequent choices of a port and supply chain. Some variables are qualitative such as the quality of a service or reputation of a port; others such as freight rates, transit time, etc. are quantitative.

The literature provides a rich set of factors that bear significance in port choice modelling (Brooks, 1984, 1985; Slack, 1985; D'Este and Meyrick, 1992; Tiwari et al., 2003; Bruno and Guy, 2006). However, with the notable exception of Tiwari et al. (2003) and D'Este and Meyrick (1992) most factors were derived neither taking into account other elements of the supply chain nor a holistic view of a supply chain. This limits the usefulness of such models in explaining the determinants of port choice particularly in a new competitive environment in which a port is chosen as an element of a system or supply chain.

Therefore, other factors are suggested such as accessibility to markets, connectivity, level of integration in the supply chain, overall port efficiency, efficiency of supply chain interfaces and links, supply chain total cost, level of supply chain coordination, type of service should

be incorporated in port choice modelling. The relationship of these factors with port choice has been established in a number of studies (Slack, 1985; Magala, 2004; Wang and Cullinane, 2006) and if included in the model design they are likely to provide us with quality information on the port choice process and its determinants in the context of supply chains competition.

3.2 Freight flow models

Freight is goods or product transported, generally for commercial gain, by train, truck, ship and aircraft. In modern time, containers are used in most long-haul freight transport. The freight flow problem, in most cases, presents, assesses and forecasts cargo movements and relative consequences of schemes at regional, national and international levels. Since container is the main carrier in freight especially at international level. Therefore, port choice contributes heavily to the sea leg of freight flow problem. The research field of freight flow modelling is relatively new compared to some other segment of transport modelling for example the passenger transport modelling. Previously, numerous works have been done on freight modelling at regional and national levels. Since the focus is on the international freight models, only a selection of key literatures are reviewed in terms of regional and national level freight models. More attention is paid on international freight flow modelling, specifically in this study the container flows models.

3.2.1 Freight flow models in the past

Tavasszy (2006) identified three decades of freight flow model development. In the early 1970s, Chisholm and O'Sullivan (1973) applied the gravity model to freight distribution in

what is believed to be the first attempt in Europe to model freight flows. Subsequently Land Use-Transport Interaction (LUTI) and Input-Output (I/O) models were supplemented to explain the generation and the distribution of freight flows. In the meantime, the first mode choice models for freight were introduced as behavioural modelling gained popularity for passenger transport. When it comes to the 1980s, there was increased interest in explaining the generation, distribution, mode split and assignment of freight flows simultaneously by applying general equilibrium principles to freight networks (Harker and Friesz, 1986a, b). In the 1990s, these models were further developed by incorporating commodity differentiation, improved probabilistic choice models and inventory considerations.

Most freight flow models continue to be based on the conventional four stage approach – generation, distribution, modal split and assignment. Usually all stages are specified at the aggregate (zonal) level. First, the production-consumption matrices are produced through applying multi-regional or regionalised national Input-Output models (Marzano and Papola, 2008). Then, value-to-weight transformations and vehicle load factors allow production-consumption matrices to be assigned to transport networks. De Jong and Ben Akiva (2007) described two freight models NEMO (Norway) and SAMGODS (Sweden) which are typical of this approach. Useful reviews of such models are provided by WSP (2002a, b). Later, an equivalent model for the UK EUNET2.0 is described in WSP (2005).

De Jong et al. (2004) reviewed a number of regional, national and international freight flow models. Different types of models within each stage of four stage approach that had been applied since the 1990s for forecasting, policy simulation and project evaluation were included. It was found that freight flow models at national and international levels, where the

focus was on retrieving matrices from various data sources and the link to economic processes was normally neglected, were much better developed than the models at urban and regional levels. The details of types of models for each of the four stages are outlined in Tables 3.1, 3.2, 3.3 and 3.4.

Table 3.1 – Types of freight transport generation models (De Jong, 2004)

Type	Advantages	Disadvantages	References
Input – output	Link to the economy Land use interaction Policy effects(elastic coefficients)	Input-output table needed (preferably multiregional) Conversion from values to tonnes needed Identify import and export trade flows needed Restrictive assumptions under fixed coefficients	TEM – II (Tavasszy, 1994) SMILE (Tavasszy et al., 1998) NEMO (EXPEDITE, 2000) WFTM (Geerts and Jourquin, 2000) SCENES (SCENES consortium, 2001)
Trip rates	Limited data requirements (zonal level)	Limited scope for policy effects and little insight into causality	Statewide Travel Forecasting (FHWA, 1999)
Time series	Limited data requirement (for many years)	Limited scope for policy effects and little insight into causality	(Garrido, 2000)
System dynamics	Limited data requirements Land – use interactions External and policy effects variables can be incorporated	No statistical tests on parameter values	Assessment of Transport Strategies (ASTRA, 2000)

Table 3.2 – Types of freight transport distribution models (De Jong, 2004)

Type	Advantages	Disadvantages	References
Input – output	Link to the economy Land – use interaction Policy effects (elastic coefficients)	Input – output table needed (preferably multiregional) Conversion from values to tonnes needed Identify import and export trade flows needed Restrictive assumptions under fixed coefficients	Fehmarn Belt freight transport model (Fehmarn Belt Traffic Consortium, 1998) NEAC (Chen and Tardieu, 2000) SCENES (SCENES consortium, 2001)
Gravity	Limited data requirements Some policy effects through transport cost function	Limited number of calibration parameters Limited scope for including explanatory factors and policy effects	TEM – II (Tavasszy, 1994) Great Belt traffic model (Fosgerau, 1996) SMILE (Tavasszy et al., 1998)

Table 3.3 – Types of freight transport modal split models (De Jong, 2004)

Type	Advantages	Disadvantages	References
Multimodal network	Limited data requirements Theoretical basis Elastic demand and policies affecting generalized transport cost can be incorporated	Mostly done with fixed demand Little insight into causality	FNEM (Friesz, 1985) STAN (Crainic et al., 1990) SMILE (Tavasszy et al., 1998) SCENES (SCENES consortium, 2001) GBFM (Newton, 2001)
Microsimulation approach	Many behavioural choices Included links to theory	Either many assumptions on distributions or large data requirements	(Neffendorf et al., 2001)
Disaggregate mode split	Many causal variables and policy measures to be potentially incorporated Theoretical basis	Need disaggregate data (shipper or commodity survey)	(Nuzzolo and Russo, 1995) (Fosgerau, 1996) FTC (1998) (Jiang et al., 1999) EUFRANET (Reynaud and Jiang, 2000) (De Jong et al., 2001) (Blauwens et al., 2001)
Direct demand	Limited data requirements	Difficult to integrate in four steps model	(Quandt and Baumol, 1966)
Neoclassical	Limited data requirements Theoretical basis	Difficult to integrate in four steps model	(Friedlaender and Spady, 1980) (Oum, 1989)
Aggregate mode split	Limited data requirements	Weak theoretical basis Little insight into causality Limited scope for policy effects	(Blauwens and van de Voorde, 1988) (Beuthe et al., 2001)
Elasticity based	Extremely limited data requirements Fast in application	Only impact of single measures, no synergies Elasticity may not be transferable	PACE – FORWARD (Carrillo, 1996) EXPEDITE (EXPEDITE, 2002)

Table 3.4 – Types of freight transport assignment models (De Jong, 2004)

Type	Advantages	Disadvantages	References
Multimodal network	Chains with different modes on a route can be handled Substitution takes place between mode-route combinations	Little scope for controlling the optimization process	FNEM (Friesz, 1985) SMILE (Tavasszy et al., 1998) NEMO (EXPEDITE, 2000) WFTM (Geerts and Jourquin, 2000) SCENES (SCENES consortium, 2001) GBFM (Newton, 2001)
Separate assignment stage	Interaction with passenger trips is allowed (passenger and freight trips are assigned together) Mode choice model can be	Transport chains are difficult, but not impossible, to incorporate Absence of interaction between demand and assignment can be	TEM – II (Tavasszy, 1994) Italian National Model system

disaggregate

unrealistic; it can only be done
iteratively

For generation, input-output and related approaches were applied in several national and European models such as TEM-II (Tavasszy, 1994), SMILE (Tavasszy et al., 1998), NEMO (EXPEDITE, 2000), WFTM (Geerts and Jourquin, 2000) and SCENES (SCENES Consortium, 2001). Distribution in those models was also based on the input-output or gravity methods. As to modal split and assignment, despite a number of different approaches observed in practice, most of the larger model systems applied multimodal network assignment in which mode choice and assignment are handled simultaneously.

Previous work reviewed above concentrated generally on freight rather than container flows. In addition, the current decade has seen interest in agent-based simulation and the application of game theory. It was noted by De Jong and Ben Akiva (2007) that four step models lack important logistical elements, like the determination of shipment size or the use of consolidation and distribution centres (although transshipments between modes may be included indirectly by the use of a multi-modal network). Consequently they specify a logistics model that takes as inputs commodity flows from production to consumption zones generated by a conventional four stage approach. The logistics model then disaggregates these flows to firm-to-firm flows. After this disaggregation, the logistics decisions (shipment size, use of consolidation and distribution centres, mode and vehicle/vessel type, and loading unit) are simulated.

3.2.2 Container flow models

A number of studies have investigated the routing problem of seaborne freight. Veldman et al. (2003) proposed a model in order to tackle the container hub ports competition problem in the Western Europe. A port is treated as a nodal point in a network of container routings. Then, a logit model is applied to quantify the route choice through taking transport cost, transit time, service frequency and indicators of quality of service into account. Therefore, the market share of the port's routings for each of the traffic zones that comprise a port's potential hinterland is explained. A mixed integer programming model was presented by Aversa et al. (2005) to explore the location of a hub port in the east coast of South America. The objective function, which represents total system costs including both port costs and shipping costs, is minimized subject to a huge number of constraints. As a result, a hub status assessment tool is delivered to all ports within the region. Leachman (2006) suggested an economic model to optimise the seaborne containerized imports from Asia to the US. The total transport and inventory costs for each shipper are minimized through optimal allocation of imports to alternative ports and logistics channels.

Some works focus on tackling network design and container routing at the same time. Agarwal, R. and Ergun, O. (2008) proposed an integrated model, a mixed-integer linear program, to solve the ship-scheduling and the cargo-routing problems simultaneously. Many relative constraints are incorporated such as the weekly frequency constraint on the operated route, and emerging trends, such as the transshipment of cargo between two or more service routes. The results suggest that higher percentage utilization of ships' capacities and a significant number of transshipments can be achieved. The network flow techniques were employed by Yan, S., Chen, C.Y. and Lin, S.C. (2009) to optimize short-term ship scheduling and container shipment planning in Taiwan. A solution algorithm, based on Lagrangian relaxation, a subgradient method, and a heuristic for the upper-bound solution, is developed

to solve the model. The results suggest that this model could be useful references for ship scheduling and container shipment planning. Alvarez, J.F. (2009) presented a model and an algorithm to address a complex problem in determining the optimal routing and deployment of a fleet of container vessels. It allows for the representation of vessel types, transshipment hubs, port delays, regional trade imbalances and the possibility of rejecting transportation demand selectively. Good solutions could be achieved very quickly according to the benchmark tests. However, none of these incorporate a comprehensive view on global networks and flows.

Song, D.P. et al. (2005) presents a simple formulation in the form of a pipe network for modelling the global container shipping network. The cost-efficiency and movement-patterns of the container shipping network have been investigated using heuristic methods. The overall incomes, costs and container movement patterns for the industry as well as for the individual shipping lines and ports could be reproduced. Wang, S. and Meng, Q. (2011) investigated the medium term (3 to 6 months) schedule design problem and the operational level container routing problem simultaneously in order to achieve shorter net transit time. It is formulated by minimization of the sum of the total transshipment cost and penalty cost associated with longer transit time than the market level transit time, minus the bonus for shorter transit time. Though it has been applied to optimize the Asia-Europe services of a global liner company, the interpretation of the results is not clear. Song, D.P. and Dong, J.X. (2012) proposed two methods considering the problem of joint cargo routing and empty container repositioning at the operation level for a shipping network with multiple service routes, multiple deployed vessels and multiple regular voyages. The first is a two-stage shortest-path based integer programming method, which combines a cargo routing algorithm with an integer programming of the dynamic system. The second is a two-stage heuristic-

rules based integer programming method, which combines an integer programming of the static system with a heuristic implementation algorithm in dynamic system. According to the results of two case studies, two solution methods perform substantially better than the practical policy. The shortest-path based is preferable for relatively small-scale problems as it yields slightly better solution than the heuristic-rules based method. However, the heuristic-rules based method has advantages in its applicability to large-scale realistic systems while producing good performance, to which the shortest-path based method may be computationally inapplicable.

The Container World project³, which attempted to develop such a model, took an agent-based simulation approach. Every ship, port, service, shipping line, trucking company and rail operator was represented as a separate agent. A global network was constructed using the actual port rotations used by shipping lines at the time of the study (sourced from the MDS-Transmodal Containership Databank). Containers were moved from their origins, via vessels, trucks and trains, to their destinations with each agent involved in this process operating according to its own set of rules. Although there is still interest in this approach (Newton, 2008, in the context of WORLDNET), Container World proved to be too data intensive in an industry where companies in competition with each other are reluctant to share data.

In the absence of access to confidential information from individual shipping lines needed to create a microscopic simulation model, a macroscopic approach is more feasible. Perrin et al. (2008) describe a macroscopic container assignment model. A network is created where the

³ The container World Project is a three year research project funded jointly by the UK Government and some of the major companies involved in containerised transport. The aim of the project is to improve strategic modelling of the container transport system both within the UK and internationally. Sinha-Ray, P. et al. (2003), Polak, J.W. et al. (2004) and Song, D.P. et al. (2005) present the contributions of this work.

nodes represent origins, destinations, ports and maritime waypoints while maritime links represent connections operated by shipping lines and land links represent connections between origins or destinations and ports. An origin-destination matrix of container flows in TEUs between countries, obtained from UNCTAD⁴ and Eurostat⁵ sources, is input. For each origin-destination pair a set of routes is generated, based on all the available ports for the countries considered and a *k*-best path algorithm (Fiorenzo-Catalano, 2007). After creating sets of routes, a logit route choice model is applied. Currently this is a simple multinomial logit model, but it is planned to replace this by a path-size multinomial logit model to allow for the correlations engendered by overlapping paths. After the assignment of container flows to paths, flow is aggregated for each string operated by shipping lines. Port choice is modelled indirectly by picking a route from the choice set. To calibrate the model, shadow prices are sought for port calls which, after the assignment, reproduce as closely as possible port throughput data. Interpretation of these shadow prices is unclear.

3.3 Empty container repositioning

Empty container repositioning is required to balance demand and supply between major production and consumption regions, though it is a non-revenue generating, expensive and undesirable business. Along with the process of containerization, a general increase has been observed in the liner shipping industry in productivity, efficiency, safety, and reduction in cost and service time. Despite these advantages, global intermodal container transport has suffered from the chronic imbalance of trade. As a result, there is a need for empty container management covering repositioning at different geographical levels and dealing with storage and accumulation in major importing areas.

⁴ United Nations Commission for Trade And Development.

⁵ Statistics Agency for the European Agency.

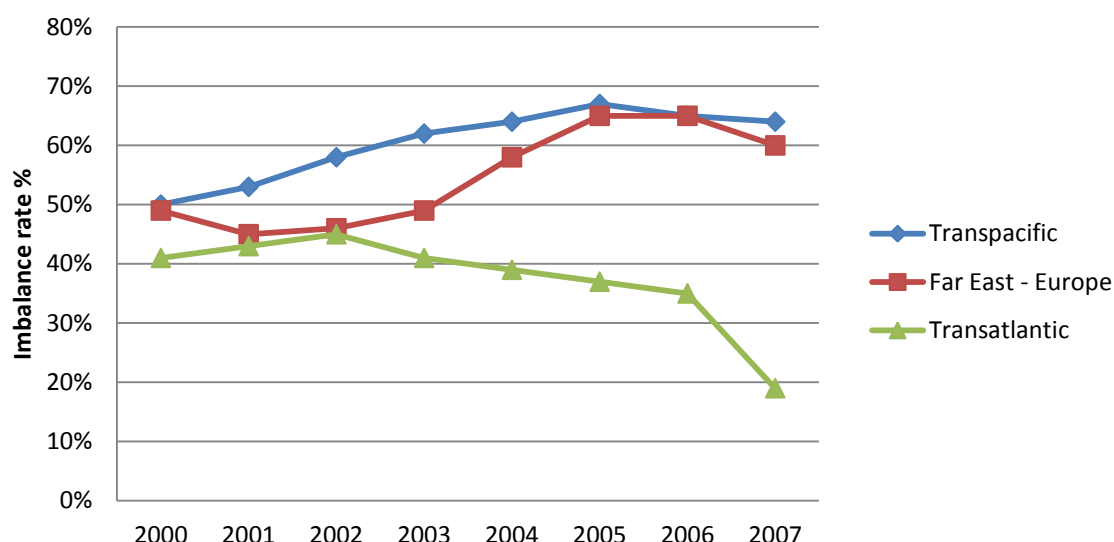


Figure 3.5 – Trade imbalance on major East-West trade lanes (Containerization International and Dyna Liners, various issues)

The main cause of the empty container issues is the fundamental global trade imbalance between the East and the West together with the North and the South. The surge of production in Asia, specifically in China, led to the dramatic increase of containerized trade. Between 2001 and 2006, total worldwide throughput handled by container ports grew at an average annual rate of 11%. A substantial endemic increase in trade imbalance is due to the structural changes in Global Production Networks (Notteboom and Merckx, 2006). These imbalances have spread very quickly as shown in Figure 3.5. Compared with imbalance figures of Transpacific and Far East – Europe trade lanes for 18% and 27% respectively in the year 1995 (GlobalInsight, 2005), a dramatic increase can be observed with figures 67% and 65% respectively in the year 2005. In addition, other causes can be identified by Boile (2006) which are tariff imbalance and the relative costs of repositioning empty containers from surplus to deficit regions, cost of inland transportation, marginal and volatile profitability of the leasing industry, cost of manufacturing and purchasing new containers in

relation to the cost of leasing containers, leasing contract terms, the cost of inspection and maintenance of aged containers and the cost of disposal.

There are four geographical levels regarding the empty container repositioning which are local, regional, interregional and global. Local and regional level can be merged as they mainly involve drayage operations. Interregional and global level involves massive empty container sea repositioning. And also, empty container repositioning at international level is extremely complicated, especially when treating the issue as an integral part of an overall efficient global container transport system. Because it is tightly integrated with parameters such as the availability of backhaul commodities, structure of ocean carriers' global service network, availability of empty slots in certain liner service strings, price of new containers, collaborative agreements between ocean carriers, the percentage mix of own and leased containers of the ocean carriers, and the degree of the vertical integration of the carriers' own activities.

3.3.1 Parties involved in empty container repositioning

Comprehensive understanding on the dynamics of empty container repositioning, especially the attributes of the involved major parties, clearly motivates the simultaneous treatment of full and empty container flows into a global maritime network. Specifically, the ownership, the deployment pattern of the container stock, the levels of empty container balancing and the decision making of repositioning are to be investigated.

Basically, two main groups of marine container owners are the key players involved in empty container repositioning, which are the ocean carriers and the container leasing companies. The container leasing business was developed in the 1970s due to the flexibility and economic interest lessors offer to carriers, especially under the circumstance of high demand of containers. The annual growth rates of the container leasing business in the 1970s were about 20%. And then, it was followed by a lower growth rate period in the 1980s and a subsequent increase during the 1990s. When it comes to year 2000, the ownership share of the container leasing companies started to decrease steadily due to the volatile situation of the market.

In addition, a small share of container is owned and leased by all types of transport operators and transportation intermediaries. The depot operators own a small number of containers, mostly old ones close to the end of their commercial life. In the meantime, they also handle, store and repair empty containers. Some major shippers may also own or lease a relatively small number of containers for their dedicated use. However, it is not very common, because shippers are trying to avoid owning containers since transportation is not their core business and due to liability issues associated with container ownership. Currently, discounting the tiny share of containers owned by the third parties, 59% of the total global container fleet is owned by the ocean carriers and other transport operators, while the rest is owned by the container leasing companies (S. Theofanis&M. Boile, 2009).

It is worth noting that ocean carriers and container leasing companies have essentially different and conflicting interests. Generally, the fundamental objectives in terms of container management for the ocean carriers are concentrating on facilitating cargo movement and

minimizing transport and handling costs, while the leasing companies, with containers as their core business, try to cover depreciation and make sustainable profits out of their leasing. The relationship between ocean carriers and container leasing companies are very complicated. Ocean carriers have extensively deployed leased containers in order to pursue the flexibility of leasing arrangements, on hiring them in areas of high demand and off hiring them in surplus areas. Currently, increasing integration with ocean carriers, who prefer a tight management in operation, can be observed along with their increasing ownership of container stock. Furthermore, Boile (2006) pointed out that some of the major ocean carriers have expanded into the container manufacturing industry to incorporate container ownership and direct availability with their existing container liner business.

As to leasing agreements, there are three types which are long term leases, master leases and short term leases. The characteristics of these agreements are summarized in Table 3.5. First, long term leases, associated with extended use by the ocean carrier, usually start with the purchase of new container by the container leasing company, which does not engage in any management service by the lessor. The container leasing company manages to amortize the investment during the long term lease period. Second, master leases are massive and medium term container leasing agreements. They usually involve complicated conditions regarding on hire and off hire and debits and credits between contracting parties depending on the condition of the containers at the time of interchange. The full management of the container stock, including repositioning, maintenance and repair, is dealt with by the container leasing company. In the meantime, they are responsible for repositioning following off hire and contract termination. Third, short term leases are usually associated with urgent demand for containers by the operators. Lease prices under such circumstances are very volatile. And also, generally, container leasing companies try to maintain a relative low percentage of their

containers on short term leases, because the risk exposure to unused containers during low demand period is very high.

Table 3.5 – Summary of characteristics of the container leasing agreements (S. Theofanis&M. Boile, 2009)

Agreement type	Duration	Repositioning, maintenance and repair	Other characteristics
Long term lease	5 – 8 years	Lessee	Number of containers fixed Delivery schedule predetermined
Master lease	Short to medium term	Container leasing company	Number of container variable Lease duration variable On hire and off hire debits/credits (Depend on location and equipment condition)
Short term lease	Trip/round trip/short period	Lessee	–

During the last few years, the balance has been shifted by the trends favouring long term leases over master leases. Initially, the trends were driven by high repositioning volumes and repositioning costs paid by the container leasing companies, though a fee for off hiring containers would be paid by the ocean carriers in certain areas where the surplus empty container level is high. Currently, ocean carriers prefer long term leases and try to integrate the leased equipment with their own in order to achieve lower unit cost.

3.3.2 Literature of empty container repositioning

The existing literature mainly focuses on optimising the management of the container stock under the assumption that it can be achieved by a single entity. A deterministic approach is generally applied by studies, due to the dynamic nature of container stock management. Classical linear programming formulations have been applied dynamically (White, 1972;

Dejax and Crainic, 1987). During the 1990s, the stochastic aspects of empty container allocation problem have been reviewed (Crainic et al., 1993). More recently, many works on empty container repositioning at multiple planning levels, namely strategic, tactical and operational levels, can be observed. A hierarchical relationship exists between these levels. General policies are determined at the strategic level. These policies form the guidelines for decisions at the tactical level, while tactical decisions set the framework for operational and real-time decisions. Since the model proposed in this thesis mainly concentrates on the empty container repositioning at global level, published works contribute to this field will be reviewed thoroughly.

A number of studies have been made of empty container repositioning between ports (Shen and Khoong, 1995; Lai et al., 1995; Cheung and Chen, 1998; Choong et al., 2002) and structure of empty container allocation in a single port or a multi-port system (Li et al., 2004; Song, 2007; Li et al., 2007; Song and Dong, 2008) at global level in various approaches namely deterministic, stochastic and simulation. In addition, a lot of recent works conducted at a global level can be observed. Two research directions can be distinguished concerning global empty container allocation models. One direction is the use of mathematical programming. According to Song and Dong (2011), these mathematical models often successfully capture the stochastic and dynamic nature of the problem, but they may give rise to some issues such as determining an appropriate planning horizon, ensuring computational tractability and ensuring robustness of the policy to uncertainties. Cheang and Lim (2005) present a minimum cost flow model to optimise empty container positioning and leasing decisions between ports. Many other works are included in this direction such as Lam et al. (2007), Feng and Chang (2008), Di Francesco et al. (2009), Erera et al. (2009), Feng and Chang (2010) and Moon et al. (2010). The other research direction is the use of inventory

theory to determine optimal empty container repositioning policies for shipping networks with a specific topological structure. External collaboration among carriers has been observed in order to achieve effectiveness of container operations and cost reduction. Song (2007) conducted a theoretical analysis to quantify the cost savings produced by a collaborative strategy between two shipping lines in a shuttle service, subject to uncertain customer demand. Factors such as the fleet size, the demand patterns and the variance of demand impact the performance of the collaborative strategy significantly. Other models are referred to the following publications Song and Carter (2008), Song et al. (2010), Song and Zhang (2010), Song and Dong (2011) and Yun et al. (2011). In the mean time, a lot of these models considered both full containers and empty containers according to Kris et al. (2011).

In recent years, some researchers focus on the technological and strategic aspects of empty container repositioning. For example, the IT support systems such as SynchroNet and InterBox can serve as a neutral platform to facilitate container sharing among shipping lines, shippers and freight forwarders. Traffic and emission impacts of the currently applied industrial methodologies such as the reuse of empty containers, off-dock empty return depots, and IT support systems are explored in a number of studies (Tioga Group, 2002; Hanh, 2003; Lopez, 2003; Jula et al., 2006).

3.4 Summary

Qualitative and quantitative port choice models, specifically econometric models, have been reviewed. The qualitative analysis mainly addressed who selects the port for each shipment and what factors influence the selection of port, while the econometric models investigated

fleet assignment in simplified situations, the costs of carriers or ports, and carriers' decisions making. However, ports are part of global maritime network. Therefore, based on the understanding that a port is an important element of the supply chain, new approaches to port choice modelling mainly involving application of system and bundling theories have been presented.

Previous freight flow models mainly applied in the Europe have been reviewed. The evolution of freight flow models and the characteristics of various types of model have been described. Since the conventional four stage approach remains the basis of most freight flow models, the summary of the models' characteristics are categorized according to generation, distribution, model split and assignment. When it comes to the container flow perspective, some studies have investigated the routing problem of seaborne freight. However, none of these incorporate a comprehensive view of global networks and flows. Latterly, models applying microscopic agent-based simulation generated some interest, but proved to be too data intensive in an industry where companies in competition with each other are reluctant to share data. As a result, a macroscopic approach is more feasible in the absence of access to confidential information from individual shipping lines.

As to the empty container repositioning problem, two issues have been addressed which are the motivation to incorporate the empty container repositioning into the maritime container flow assignment model and techniques applied to investigate empty container repositioning. Starting with analyzing the ownership, the deployment pattern of the container stock, the levels of empty container balancing and the decision making of repositioning, it turns out that

ocean carriers prefer long term leases and try to integrate the leased containers with their own in order to achieve lower unit cost.

To conclude, a model capable of representing full and empty container flows at a global level would be useful to almost every stakeholder in the container liner shipping industry such as shippers, shipping lines, port authorities, terminal operating companies, regional and national planning authorities, marine insurance companies, and others.

Chapter 4

Time-based container assignment model

This model focuses specifically on the maritime transport of containers and builds on the observation that the maritime container assignment problem shares a greater affinity with transit assignment than with traffic assignment conventionally applied in the four stage approach, because containers are generally carried by shipping lines which operate services on routes or port rotations.

To date, it is believed that this model constitutes the first attempt to adapt the classic Spiess and Florian (1989) frequency-based transit assignment method to maritime container transport. This method assigns an origin-destination matrix of passenger trips to a transit network, usually a bus network, to minimize expected travel time. Where bus stops are shared by a number of bus routes, it assumes that passengers choose the first bus on an attractive route to arrive at the stop. Buses are assumed to arrive randomly, so the division of traffic across the attractive routes leaving a stop is in proportion to their frequency. At a bus stop, a route is labelled as attractive for a given destination if by excluding it from the choice set the expected travel time is increased. Spiess and Florian showed that this assignment problem can be solved as a linear program.

The Spiess and Florian model has been transferred into the domain of maritime container transport by replacing passengers by containers and buses by ships. The model needs to be extended by firstly including empty container repositioning and secondly by introducing constraints to represent the maximum number of containers a port can handle per unit time. As the resulting maritime container flow assignment model is also a linear program, the interpretation of the dual variables will be carefully examined, showing by proposition and proof that they provide useful information about the solution. Note that this chapter is mainly based on the published work by Bell et al. (2011). The following section will discuss the assumptions and methodology behind the proposed maritime container assignment model. Finally, a simple numerical example will be presented to illustrate how the model works in practice.

4.1 Assumptions and methodology

In order to simplify the problem and demonstrate the basic theory clearly, some assumptions have to be made. In the proposed maritime container assignment model, the following are some key assumptions made:

- There is only one type of container which is assumed to be interchangeable and routed to minimise an objective function measured in time units (the objective function consists of the sum of the sailing time, expected dwell time in ports, and any loading or unloading surcharge measured in time units, for full and empty containers). The extension to containers of different types leads to a multi-class formulation of the problem, increasing its complexity but not changing its nature.
- Container terminals are operated by profit maximising companies, so if demand threatens to exceed the capacity of the terminal, a surcharge is levied for each loading or unloading which is sufficient to reduce demand to the available capacity.
- Containers are carried by shipping lines operating routes. Each route has a given service frequency, but the departure time at each port of ships on any route is random and uncoordinated with the departure time of ships on any other route. Note that frequency in the context of this thesis represents the number of liner services per unit time. As a result, the division of containers between alternative attractive routes leaving a port is in proportion to their service frequencies and the expected dwell time of a container at that port is equal to the inverse of the sum of these service frequencies. A route is attractive for a given destination at a port if, by excluding it from the choice set, the objective function is increased. This model assumes that the rate at which containers are shipped between origins and destinations, as expressed by the origin-destination matrix, does not vary with time. As the departure times of ships

are random and uncoordinated, it makes no difference to the expected waiting time and therefore to the assignment whether the containers are shipped (leave the origin) regularly or randomly – one of the strengths of the proposed model.

- Full and empty containers are considered separately. Constraints ensure that a net outflow of full containers from any port is balanced by a net inflow of empty containers, and vice versa. As with full containers, empty containers are repositioned to minimize the sum of sailing and dwell time, with a facility to discount the dwell time of empty containers in recognition of the absence of inventory.

Regarding the network underlying this model, the virtual network approach described in Jourquin et al. (2008) is adopted. In this approach, each leg represents a particular transport task, thus a path represents a series of transport tasks. For instance, transporting a container from port A to port B on one route, transshipping, and then transporting the container to port C on another route constitutes two tasks and therefore two legs, irrespective of the number of ports of call between port A and port C. A leg thus represents a movement from a port of loading to a port of unloading, where the port of loading may be the origin or a transshipment port and the port of unloading may be the destination or a transshipment port. Each leg is associated with a travel time and a service frequency. If the port of loading and the port unloading are connected by a number of routes, the randomness assumption allows us to add the route service frequencies to get the leg service frequency. Leg travel time includes the cost of loading and unloading the container, measured in time units, before any surcharge.

To describe the relationship between routes, transport tasks and legs, consider the following data published in International Freight Weekly (26/01/2010). The CKYH Alliance (COSCON, K Line, Yang Ming and Hanjin) operates the following three routes:

- NE1 Rotation: Ningbo (Sat/Sun), Shanghai (Sun/Mon), Hong Kong (Wed/Thu), Nansha (Thu/Fri), Rotterdam (Wed/Fri), Hamburg (Sat/Mon), Felixstowe (Tue/Wed), Antwerp (Wed/Thu), Singapore (Sat/Sun), Ningbo (Sat/Sun)
- NE2 Rotation: Xiamen (Sun/Sun), Kaohsiung (Mon/Tue), Yantian (Wed/Wed), Singapore (Sat/Sun), Rotterdam (Tue/Thu), Felixstowe (Fri/Sat), Hamburg (Sun/Mon), Antwerp (Tue/Wed), Jeddah (Mon/Mon), Hong Kong (Thu/Thu), Yantian (Fri/Fri), Xiamen (Sun/Sun)
- NE4 Rotation: Kwangyang (Sat/Sun), Pusan (Sun/Mon), Ningbo (Tue/Wed), Shanghai (Thu/Thu), Singapore (Tue/Wed), Hamburg (Fri/Sat), Rotterdam (Sun/Tue), Le Havre (Tue/Wed), Port Said (Wed/Thu), Singapore (Thu/Thu), Hong Kong (Tue/Tue), Kwangyang (Sat/Sun)

Each route provides a weekly service and serves both Singapore and Rotterdam, which are important transshipment hubs. The schedule is more certain at the ends of each route than in the middle, but presents significant uncertainty throughout, lending some credence to the randomisation assumption. Consider the shipment of a container from Ningbo to Shanghai without transshipment, there are two legs since NE1 and NE4 connect two ports directly. However, as there are no intervening ports of call, the sailing time will be similar so these two legs can be merged into one. Under the randomisation assumption, two frequencies would be summed up, leading to a combined twice-weekly service frequency. If a task is to ship a container from Singapore to Rotterdam, it in theory could be carried on any of the

three routes. However, 4, 0, 1 port calls are made on the way of the routes NE1, NE 2 and NE4 respectively and therefore the routes will have rather different sailing times. In addition, NE4 calls at Singapore in both directions, but the other direction involves 6 ports of call and is therefore not likely to be attractive. NE1 is less interesting as it takes significantly longer to reach Rotterdam. Since it also leaves Singapore around the same time as NE2, it can be ignored leaving two legs, named NE2 which is direct and NE4 which calls at Hamburg.

When it comes to the input from the user, an Origin-Destination matrix for containers is assigned to the virtual network described above. At the origin port or any transshipment port, containers are assigned to the first available service on an attractive leg. A leg is attractive for a given destination if, by including it in the choice set at a given node, the objective function is reduced. In this model, it is assumed that the rate at which containers are shipped between origins and destinations, as expressed by the Origin-Destination (O-D) matrix, does not vary with time. As the departure times of ships are random and uncoordinated, it makes no difference to the expected dwell time and therefore to the assignment whether the containers are shipped regularly or randomly. This is recognized as one of the strengths of the proposed model. The destination for a full container is the origin for an empty container and vice versa. While there is an O-D matrix for full containers, the empty containers are distributed to minimise the objective function. The upper limits are set to port throughput measured in container time units, adding loading moves to unloading moves. If demand exceeds capacity, a surcharge is sought to reduce demand to capacity by diverting the excess demand onto alternative paths. In the absence of the surcharge, the necessary diversion would be achieved by queuing delay. Transhipped containers pay the surcharge twice, both on arrival and on departure, as the container is handled twice.

As a result of the randomness assumption, the probability that a container is assigned to a particular leg in the attractive set for a given node and destination is proportional to the service frequency of that leg, unless a downstream throughput constraint prevents this or, trivially, there is only one attractive leg. This can therefore lead to a set of paths, referred to in the transit assignment literature as a Hyperpath (Nguyen and Pallotino, 1988), being used. In the case of binding throughput constraints, the concept of effective frequency (Spiess and Florian, 1989) is invoked. If a container cannot always be loaded on the next service of an attractive leg because of a downstream throughput constraint, this is equivalent to a reduction in the respective leg service frequency. In that case, the effective leg service frequency can be inferred by looking at the spread of assigned leg flows across the attractive legs exiting a given node.

One issue has to be emphasized and will be demonstrated in the following section is that the model is a linear program. This is good news as efficient solvers exist for very large linear programs. The shadow price interpretation of the dual variables allows us to make use of the dual variables, as will be shown later. The dual variables for the port throughput constraints give the optimal port surcharges. The dual variables for the container flow conservation constraints measures the optimal cost in time units of transporting a full container between any origin and destination. Other dual variables allow us to determine when the effective leg service frequency deviates from the actual leg service frequency.

Last but not the least, the model allows the dwell time for an empty container to be discounted by a factor δ , in recognition of the fact that empty containers by definition carry no inventory. By setting $\delta = 0$, the dwell time of empty container can be excluded from the objective function. The value of δ correlates negatively with the number of empty containers in the system, which provides a basis for its calibration.

At the first step, the notation for the container assignment model is given as follows:

Define

c_a Sailing time on leg a , including loading and unloading time at the ends

t_{rs}^f Flow of full containers from origin r to destination s

x_{as}^f Flow of full containers on leg a en route to destination s

x_a^e Flow of empty containers on leg a

b_{is}^f Net inflow of full containers en route to destination s at node i

b_i^e Net outflow of empty containers at node i

f_a Frequency of sailing on leg a

k_i Maximum throughput of node i

w_{is}^f Expected dwell time at node i for a full container en route to destination s

w_i^e Expected dwell time at node i for an empty container

A Set of legs

- O Set of origin nodes
- D Set of destination nodes
- I Set of nodes
- A_i^+ Set of legs entering node i
- A_i^- Set of legs leaving node i
- δ Discount factor for empty container dwell time

Note that the link capacity constraint due to vessel size is not considered in this time-based version. It will be presented later in Chapter 5. And then, the container assignment model can be expressed as the following linear program:

$$P_0: \quad \min_{x,w} (\sum_{a \in A} (x_{a+}^f + x_a^e) c_a + w_{++}^f + \delta w_+^e)$$

Subject to

- (1) $\sum_{a \in A_i^+} x_{as}^f - \sum_{a \in A_i^-} x_{as}^f = b_{is}^f$ for all $i \in I, s \in D$
- (2) $\sum_{a \in A_i^+} x_a^e - \sum_{a \in A_i^-} x_a^e = -b_i^e$ for all $i \in I$
- (3) $x_{as}^f \leq w_{is}^f f_a$ for all $a \in A_i^-, i \neq s \in I, s \in D$
- (4) $x_a^e \leq w_i^e f_a$ for all $a \in A_i^-, i \in I$
- (5) $k_i \geq \sum_{a \in A_i^-} (x_{a+}^f + x_a^e) + \sum_{a \in A_i^+} (x_{a+}^f + x_a^e)$ for all $i \in I$
- (6) $x_{as}^f \geq 0$ for all $a \in A, s \in D$
- (7) $x_a^e \geq 0$ for all $a \in A$
- (8) $b_{is}^f = \begin{cases} -t_{rs}^f & \text{if } i = r \in O \\ t_{+s}^f & \text{if } i = s \in D \\ 0 & \text{otherwise} \end{cases}$

$$(9) \quad b_i^e = \begin{cases} t_{+i}^f - t_{i+}^f & \text{if } i = r \in O \text{ or } i = s \in D \\ 0 & \text{otherwise} \end{cases}$$

Note that subscript + denotes summation by the respective subscript, for example $x_{a+}^f = \sum_{s \in D} x_{as}^f$. Note also that leg flow for full containers is disaggregated by destination, because of the requirement to reproduce an input origin-destination matrix. Empty containers are distributed to minimise sailing and dwell time given origin and destination constraints, but without the need to reproduce a given origin-destination matrix, so leg flows for empty containers do not need to be disaggregated by destination.

The objective function is the sum of the sailing and dwell time for full and empty containers. The dwell time for empty containers has been discounted by δ , to allow for a lower value of time saved resulting from the absence of inventory. As there is an inverse relationship between the number of empty containers in the system and the value of δ , data on the size of the stock of empty containers could be used in practice for calibration.

Constraints (1) and (2) enforce flow conservation for full and empty containers respectively. For transshipment nodes, flow in must be equal to flow out, for full containers distinguished by destination and for empty containers without differentiation. Source and sink constraints are given in (8) and (9). Constraints (3) and (4) ensure that for the legs that are attractive at node i , the delay per full or empty container is at least as large as the inverse of the combined service frequency, differentiating by destination in the case of full containers. Given the randomness assumptions, the expected delay is equal to the inverse of the combined service frequency, so where the constraint does not bind (where the corresponding dual variable is zero), there must be a divergence between effective and actual leg service frequency. More

specifically, for leg a leaving node i , the dwell time for containers en route to destination s is the flow on leg a en route to destination s divided by the frequency of service on leg a . It is based on the strong assumption that container ships arrive and depart randomly. If this assumption does not hold, schedules are needed in order to calculate container dwell times. Constraints (5) ensure that the throughput of a port does not exceed an upper limit. In practice this upper limit will be determined by the length of quay, the number of ship-to-shore cranes, the extent and nature of the horizontal transport, and the stacking arrangements. Constraints (6) and (7) are non-negativity constraints.

As we have to introduce the Lagrangian equation later, the dual variables have to be defined first:

q_{as}^f	Dual variable for a full container on leg a en route to destination s
q_a^e	Dual variable for an empty container on leg a
u_{is}^f	Expected sailing, dwell and surcharge time for a full container from node i en route to destination s
u_i^e	Expected repositioning time for an empty container at node i
v_i	Surcharge for loading or unloading a container at node i

Note that the definition of these dual variables would be interpreted in Proposition 1. Note also that constraints (3) and (4) are divided by f_a on both sides. This transformation would facilitate better expression of P_1 . The Lagrangian equation for P_0 is:

$$\begin{aligned}
(10) \quad L_{x,w,q,u,v} = & \sum_{a \in A} (x_{a+}^f + x_a^e) c_a + w_{++}^f + \delta w_+^e - \\
& \sum_{i \in I} \sum_{s \neq i \in D} u_{is}^f (b_{is}^f + \sum_{a \in A_i^-} x_{as}^f - \sum_{a \in A_i^+} x_{as}^f) - \\
& \sum_{i \in I} u_i^e (-b_i^e + \sum_{a \in A_i^-} x_a^e - \sum_{a \in A_i^+} x_a^e) - \\
& \sum_{i \in I} \sum_{a \in A_i^-} \sum_{s \neq i \in D} q_{as}^f (w_{is}^f f_a - x_{as}^f) - \\
& \sum_{i \in I} \sum_{a \in A_i^-} q_a^e (w_i^e f_a - x_a^e) - \\
& \sum_{i \in I} v_i (k_i - \sum_{a \in A_i^-} (x_{a+}^f + x_a^e) - \sum_{a \in A_i^+} (x_{a+}^f + x_a^e))
\end{aligned}$$

The decision variables are x and w while q , u and v are the dual variables. At the optimum, the Lagrangian equation is minimised with respect to x and w but maximised with respect to q , u and v . Without loss of generality, we can set:

$$(11) \quad u_{ss}^f = 0 \text{ for all } s \in D$$

Using a more compact notation, the Lagrangian equation can be rearranged to yield:

$$\begin{aligned}
(12) \quad L_{x,w,q,u,v} = & \sum_{rs} t_{rs}^f u_{rs}^f + \sum_s (t_{+s}^f - t_{s+}^f) u_s^e - \sum_i v_i k_i + \sum_{as} x_{as}^f (c_a + \frac{q_{as}^f}{f_a} - u_{is}^f + u_{js}^f + \\
& v_i + v_j) + \sum_a x_a^e (c_a + \frac{q_a^e}{f_a} - u_i^e + u_j^e + v_i + v_j) + \sum_{as} w_{is}^f (1 - q_{as}^f) + \sum_a w_i^e (\delta - \\
& q_a^e)
\end{aligned}$$

Where implicitly node i is the entrance to link a and node j is the exit to link a . This notation includes the possibility of more than one leg connecting node i to node j . From this, the following dual problem can be extracted:

$$P_1: \quad \max_{q,u,v} (\sum_{rs} t_{rs}^f u_{rs}^f + \sum_s (t_{+s}^f - t_{s+}^f) u_s^e - \sum_i v_i k_i)$$

Subject to:

$$(13) \quad c_a + \frac{q_{as}^f}{f_a} - u_{is}^f + u_{js}^f + v_i + v_j \geq 0 \text{ for all } a \in A, s \in D$$

$$(14) \quad c_a + \frac{q_a^e}{f_a} - u_i^e + u_j^e + v_i + v_j \geq 0 \text{ for all } a \in A$$

$$(15) \quad 1 - \sum_{j \in A_i^-} q_{as}^f \geq 0 \text{ for all } i \neq s \in I, s \in D$$

$$(16) \quad \delta - \sum_{j \in A_i^-} q_a^e \geq 0 \text{ for all } i \in I$$

$$(17) \quad q_{as}^f \geq 0 \text{ for all } a \in A, s \in D$$

$$(18) \quad q_a^e \geq 0 \text{ for all } a \in A$$

$$(19) \quad v_i \geq 0 \text{ for all } i \in I$$

Let L_{is}^f be the set of legs leading out of node i that are used by full containers en route to s . Similarly, let L_i^e be the set of legs leading out of node i that are used by empty containers. If a leg is used then it must be attractive, in the sense that its must reduce the objective function of P_0 . Unattractive legs are not used. As stated earlier, we assume that containers are put on the first available service on an attractive leg and that services arrive randomly but with leg-specific frequencies. If all services are available, then the total delay at node i for full containers is

$$(20) \quad w_{is}^f = \frac{x_{i+s}^f}{\sum_{j \in L_{is}^f} f_a}$$

and for empty containers is

$$(21) \quad w_i^e = \frac{x_{i+}^e}{\sum_{j \in L_i^e} f_a}$$

However, it is possible that, as a result of a downstream throughput constraint, not all services on certain attractive legs are available because if they were then too many containers would arrive downstream. In this situation, the effective frequency may be less than the actual frequency and the delay at node i may be larger than given by (20) and (21). The use of

effective frequency to accommodate capacity constraints is referred to in Spiess and Florian (1989).

Legs where the effective frequency deviates from the actual frequency will have a value of q equal to 0 because the corresponding flows given by constraints (3) and (4), if binding, would be too large. The total delay at such nodes may be calculated by limiting the summations in the numerator and denominator of (20) and (21) to those legs where q is positive and the effective frequency may be calculated by looking at the division of flows at the solution to P_0 (or equivalently P_1). If we replace actual frequency by effective frequency, where there is a difference, then by definition equations (20) and (21) hold.

Proposition 1: $\sum_{rs} t_{rs}^f u_{rs}^f$ is the total cost of shipping full containers and $\sum_s (t_{+s}^f - t_{s+}^f) u_s^e$ is the total cost of shipping empty containers. Note that cost refer to time since the model is measured in time unit.

Proof of 1: If $x_{as}^f > 0$ then from complementary slackness and (13)

$$(22) \quad u_{is}^f - u_{js}^f = c_a + \frac{q_{as}^f}{f_a} + v_i + v_j$$

To obtain the total cost of shipping full containers, we multiply (22) by x_{as}^f and sum the result with respect to i, j and s . Noting that if $q_{as}^f > 0$ then $x_{as}^f = w_{is}^f f_a$ and if $w_{is}^f > 0$ then $\sum_{j \in A_i^-} q_{as}^f = 1$, and using (15) and (8), we obtain

$$(23) \quad \sum_{as} x_{as}^f (u_{is}^f - u_{js}^f) = \sum_{rs} t_{rs}^f u_{rs}^f - \sum_s t_{+s}^f u_{ss}^f = w_{++}^f + \sum_a x_{a+}^f (c_a + v_i + v_j)$$

Without loss of generality, set $u_{ss}^f = 0$ for all $s \in D$. Hence

$$(24) \quad \sum_{rs} t_{rs}^f u_{rs}^f = w_{++}^f + \sum_a x_{a+}^f (c_a + v_i + v_j)$$

Similarly, if $x_a^e > 0$ then from complementary slackness and (14)

$$(25) \quad u_i^e - u_j^e = c_a + \frac{q_a^e}{f_a} + v_i + v_j$$

To obtain the total cost of shipping empty containers, we multiply (23) by x_a^e and sum the result with respect to i and j . Noting that if $q_a^e > 0$ then $x_a^e = w_i^e f_a$ and if $w_i^e > 0$ then $\sum_{j \in A_i^-} q_a^e = \delta$, and using (16) and (9), we obtain

$$(26) \quad \sum_a x_a^e (u_i^e - u_j^e) = \sum_s (t_{+s}^f - t_{s+}^f) u_s^e = \delta w_+^e + \sum_a x_a^e (c_a + v_i + v_j)$$

From (24) it is clear that $\sum_{rs} t_{rs}^f u_{rs}^f$ is the total cost of shipping full containers and from (26) it is clear that $\sum_s (t_{+s}^f - t_{s+}^f) u_s^e$ is the total cost of shipping empty containers. QED

Proposition 1 shows that after appropriate initialisation (i) u_{rs}^f is the cost of shipping a container from r to s including the expected dwell time and any port surcharges, in time units, and (ii) u_s^e is the average cost of returning an empty container from s including the expected dwell time (possibly discounted) and any port surcharges in time units.

Regarding the computational complexity of the proposed linear programming model, it is that of a LP solver which depends on the solution method. It is likely to be identified as $O(n^4)$, where n denote as the number of decision variables.

4.2 Numerical example

As depicted in Figure 4.1, the example network consists of 5 legs which are labelled with five different colours. The black leg connects Port A to Port F directly with a sailing time of 6 days. By contrast, the red leg takes 2 days to sail between Port A and Port C and the blue leg takes 3 days to sail between Port C and Port F. Alternatively, the green leg takes 1 day to sail between Port C and Port D and the yellow leg takes 1 day to sail between Port D and Port F. All legs are operated with a daily service frequency. In the meantime, all ships depart port randomly which comply with the randomness assumption. The objective is to ship 1000 full containers per day from Port A to Port F. The results presented in the following are obtained via the Excel solver and presented with four scenarios.

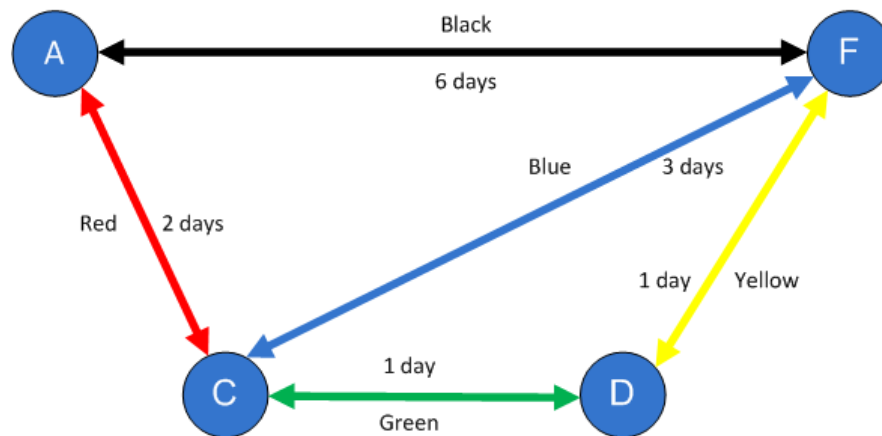


Figure 4.1 – Example network with 5 legs in different colours

Scenario 1: without any throughput constraints, delay to empty containers is given equal weight to delay to full container where $\delta = 1$. The results are shown in Tables 4.1 and 4.2, all legs are used and therefore attractive. Total sailing and dwell time is 12583.33 container – days per day. Since there are no throughput constraints, no port surcharges are imposed.

Table 4.1 – Leg flows without throughput constraints ($\delta = 1$)

Leg	Container	Sailing time	Frequency	Flow	q
A to F	Full	6.00	1.00	500.00	0.25
A to C	Full	2.00	1.00	500.00	0.75
C to F	Full	3.00	1.00	250.00	0.50
C to D	Full	1.00	1.00	250.00	0.50
D to F	Full	1.00	1.00	250.00	1.00
F to A	Empty	6.00	1.00	333.33	0.33
C to A	Empty	2.00	1.00	666.67	1.00
F to C	Empty	3.00	1.00	333.33	0.33
D to C	Empty	1.00	1.00	333.33	1.00
F to D	Empty	1.00	1.00	333.33	0.33

Table 4.2 – Node delays and flows without throughput constraints ($\delta = 1$)

Port	Container	Dwell time	In	Out
A	Full	500.00	1000.00	1000.00
C	Full	250.00	500.00	500.00
D	Full	250.00	250.00	250.00
F	Full		1000.00	1000.00
A	Empty		1000.00	1000.00
C	Empty	666.67	666.67	666.67
D	Empty	333.33	333.33	333.33
F	Empty	333.33	1000.00	1000.00

Scenario 2: without any throughput constraints, delay to empty containers is omitted from the objective function where $\delta = 0$. The results are presented in Tables 4.3 and 4.4. As to be expected, all the empty containers take the route with the shortest sailing time even though this involves two transshipments. The objective function is now reduced to 10250.00

container-days per day due to empty container dwell time being zero weighted. However, the throughput of Port C is now 3000 container moves per day, counting transshipment as two moves including loading and unloading.

Table 4.3 – Leg flows without throughput constraints ($\delta = 0$)

Leg	Container	Sailing time	Frequency	Flow	q
A to F	Full	6.00	1.00	500.00	0.25
A to C	Full	2.00	1.00	500.00	0.75
C to F	Full	3.00	1.00	250.00	0.50
C to D	Full	1.00	1.00	250.00	0.50
D to F	Full	1.00	1.00	250.00	1.00
F to A	Empty	6.00	1.00	0.00	0.00
C to A	Empty	2.00	1.00	1000.00	0.00
F to C	Empty	3.00	1.00	0.00	0.00
D to C	Empty	1.00	1.00	1000.00	0.00
F to D	Empty	1.00	1.00	1000.00	0.00

Table 4.4 – Node delays and flows without throughput constraints ($\delta = 0$)

Port	Container	Dwell time	In	Out
A	Full	500.00	1000.00	1000.00
C	Full	250.00	500.00	500.00
D	Full	250.00	250.00	250.00
F	Full		1000.00	1000.00
A	Empty		1000.00	1000.00
C	Empty	1000.00	1000.00	1000.00
D	Empty	1000.00	1000.00	1000.00
F	Empty	1000.00	1000.00	1000.00

Scenario 3: with throughput constraint on Port C for 2500 container moves per day, delay to empty containers is omitted from the objective function where $\delta = 0$. The throughput constraint indicates that there must be a reduction of 500 container moves per day on Port C, the results are as shown in Tables 4.5 and 4.6. The best solution to the throughput constraint appears to be to reduce the full containers shipped from Port A to Port C on the red leg from 500 containers per day to 250 containers per day while increasing those shipped from Port A directly to Port F on the black leg from 500 containers per day to 750 containers per day. Both black and red legs are used, and therefore remain attractive, so the effective frequency on the red leg is reduced from 1 sailing per day to 1 sailing per 3 days. In addition, the value of q for the red leg is zero, which also confirms a divergence between the effective and actual leg service frequency. As a result, this increases the total dwell time at Port A from 500 container-days per day to 750 container-days per day. The port surcharge is 0.75 days per container and the objective function has increased to 10625.00 container-days per day. The total surcharge is 1875.00 container-days per day, making the total cost of moving containers 12500.00 container-days per day.

Table 4.5 – Leg flows with throughput constraint at Port C ($\delta = 0$)

Leg	Container	Sailing time	Frequency	Flow	q
A to F	Full	6.00	1.00	750.00	1.00
A to C	Full	2.00	1.00	250.00	0.00
C to F	Full	3.00	1.00	125.00	0.50
C to D	Full	1.00	1.00	125.00	0.50
D to F	Full	1.00	1.00	125.00	1.00
F to A	Empty	6.00	1.00	0.00	0.00
C to A	Empty	2.00	1.00	1000.00	0.00
F to C	Empty	3.00	1.00	0.00	0.00
D to C	Empty	1.00	1.00	1000.00	0.00
F to D	Empty	1.00	1.00	1000.00	0.00

Table 4.6 – Node delays and flows with throughput constraint at Port C ($\delta = 0$)

Port	Container	Dwell time	In	Out
A	Full	750.00	1000.00	1000.00
C	Full	125.00	250.00	250.00
D	Full	125.00	125.00	125.00
F	Full		1000.00	1000.00
A	Empty		1000.00	1000.00
C	Empty	1000.00	1000.00	1000.00
D	Empty	1000.00	1000.00	1000.00
F	Empty	1000.00	1000.00	1000.00

Scenario 4: with throughput constraint on Port C for 2500 container moves per day, delay to empty containers is partially taken into account by setting $\delta = 0.2$. Tables 4.7 and 4.8 present the results as shown below. The required surcharge is 0.70 days per container and the objective function is 11200.00 container-days per day. The total surcharge is now 1750.00 container-days per day, making the total cost of moving containers 12950.00 container-days per day.

Table 4.7 – Leg flows with throughput constraint at Port C ($\delta = 0.2$)

Leg	Container	Sailing time	Frequency	Flow	q
A to F	Full	6.00	1.00	500.00	0.95
A to C	Full	2.00	1.00	500.00	0.05
C to F	Full	3.00	1.00	250.00	0.50
C to D	Full	1.00	1.00	250.00	0.50
D to F	Full	1.00	1.00	250.00	1.00
F to A	Empty	6.00	1.00	250.00	0.00

C to A	Empty	2.00	1.00	750.00	0.20
F to C	Empty	3.00	1.00	0.00	0.00
D to C	Empty	1.00	1.00	750.00	0.20
F to D	Empty	1.00	1.00	750.00	0.20

Table 4.8 – Node delays and flows with throughput constraint at Port C ($\delta = 0.2$)

Port	Container	Dwell time	In	Out
A	Full	500.00	1000.00	1000.00
C	Full	250.00	500.00	500.00
D	Full	250.00	250.00	250.00
F	Full		1000.00	1000.00
A	Empty		1000.00	1000.00
C	Empty	750.00	750.00	750.00
D	Empty	750.00	750.00	750.00
F	Empty	750.00	1000.00	1000.00

4.3 Summary

A promising first step toward a global maritime container assignment model is presented, which represents the effects of sailing time, service frequency and port capacity on the pattern of full and empty container flows and therefore on port choice. It presents the attractiveness of the ports within the network very efficiently. In order to make the model fit reality better, two things need to be considered:

- Container ship size. The model as currently formulated is time-based, whereas decisions taken by shipping lines to use particular routes will in practice be cost-based.

- Cost factors involved in the container liner shipping business. Both fixed and variable costs have to be taken into account in the perspective of shipping lines operating container liner services.

The first consideration indicates that container ship size plays an influential role since larger container ships offer significant economies of scale. For a given leg flow, larger ships mean a less frequent service, implying in turn larger average dwell times at the origin and transshipment ports, but lower sailing costs. Very large container ships will call at fewer, mainly hub, ports offering lower sailing times at the cost of transshipment. The second point mainly regards a comprehensive cost structure analysis of container liner shipping operation. Both of the considerations will be incorporated into the maritime container assignment model in the following chapter, which transforms the current time-based version into a cost-based version.

Chapter 5

Cost-based container assignment model

As presented in the last chapter, the container ship size and cost factors will be taken into account in order to transform the time-based container assignment model into a cost-based one. In fact, economies of scale are the main concern during the transformation, which focuses on the unit cost for each route within the network. First, the cost factors in the liner shipping business are analyzed, specifically from the perspective of economies of scale. Second, the cost-based container assignment model is presented including assumptions, methodology and a numerical example. In addition, the innovations on network design and link capacity constraints are highlighted. Finally, a summary of the cost-based container assignment model is given together with recommended for further work.

5.1 Cost factors in container liner shipping business

With the respect to the costs in the container liner shipping, the cost of running a container liner shipping service is dictated by three factors. First, the general cost structure for the ship consists of its fuel consumption, the number of crew to operate it and its physical condition which dictates the requirement for maintenance and repairs. Second, prices of bought-in items are subject to economic trends out of the ship-owner's control, particularly bunkers, crew wages, consumables, maintenance costs and interest rates. Third, costs depend on efficiency of the liner's management including operational efficiency and administrative overheads. Although the liner industry has no worldwide accepted universal cost classification, costs can be generally classified into five categories which are operating costs, capital costs, voyage costs and cargo-handling costs and periodic maintenance.

Operating costs include expenses of the ship on crew, store, insurance, maintenance and administration, which connected with the day-to-day operation, repair and maintenance of the ship. Fuel consumption is excluded since it is included in the voyage costs. There are many factors which define the operating cost structure, which are the size and nationality of the crew, the age and insured value of the ship, maintenance policy and administrative efficiency of the owner. In terms of economies of scale, some of these components offer more than others. Insurance and maintenance costs are likely to increase in line with the capital cost of the ship, though by less than the capacity of the ship. According to a survey of German container ships conducted in 2006, it is shown that the daily cost increase from \$4600 for a 1200 TEU container ship to around \$7000 for an 8500 TEU container ship, which indicates significant scale economies. However, costs of crew, stores and administration generally do not increase very much as the capacity of the container ship gets bigger.

Capital costs are obligations which have no direct effect on the physical operation of the container ship. In practice, capital costs take three forms as far as the shipping line's cash flow is concerned, which are initial purchase and the obligation to pay the shipyard, periodic cash payments to banks or equity investors who put up the capital to purchase the ship and cash received from the sale of the vessel. Capital costs are subject to economies of scale because big ships cost less per container slot than small ones. For example, in 2006, the costs of 1200 TEU container ship and 6500 TEU container ship are \$25 million and \$89 million respectively, which represent \$20000 per slot and \$13700 per slot correspondingly. However, as the ship gets bigger and beyond 5000 TEU, the saving diminished because the major fixed cost is the engine room which does not change that much with respect to a bigger container ship, where indicates different degrees of economies of scale.

Voyage costs are the variable costs incurred in undertaking a particular voyage, which includes fuel costs, port charges and canal dues. Fuel cost is the single most important element in voyage costs. The fuel prices were low in the early 1970s therefore less attention was paid to fuel costs. However, the fuel prices rocketed during the period 1970 to 1985, which increased by 950%, the whole balance of costs changed. As a result, much more resources were poured into designing more fuel efficient ships and operating patterns were adjusted, so that fuel costs were reduced dramatically in the liner shipping industry. From 1986 fuel prices fell, so there was less interest in efficient ship design. The situation changed in 2000, when fuel prices began to increase again. Consider the economies of scale for bunker costs, a similar pattern can be observed as with the capital costs, where economies diminish as the ship capacity gets bigger. This can be illustrated in Figure 5.1.

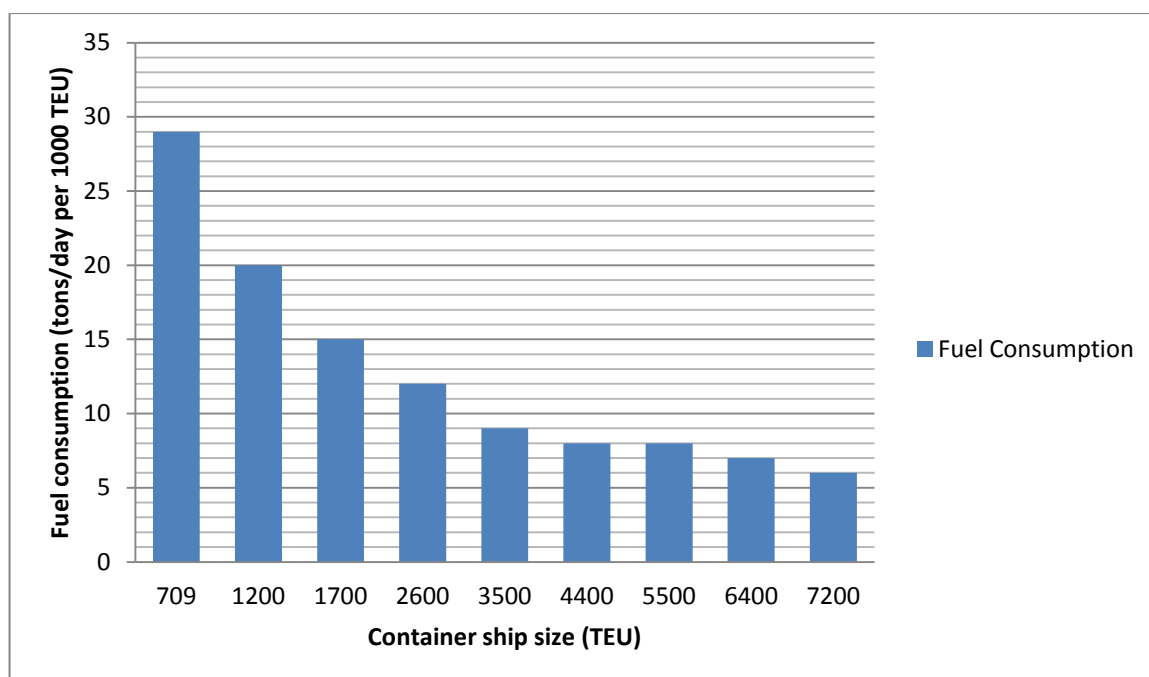


Figure 5.1 – Fuel consumption of container ships (Clarkson Research Services Ltd, 2006)

Port charges represent a major element in voyage costs, which include various fees levied against the ship for the use of the facilities and services provided by the port. Generally, charging practices fall into two components, which are port dues and service charges. Port dues are imposed on the ship for the provision of the basic port infrastructure and the general use of port facilities including docking and wharfage charges. The service charges cover various types of services that ship uses in port, including pilotage and towage. Since port charges are generally levied on the basis of the container ship's tonnage, this indicates an additional element of economies of scale, because the port costs per TEU reduce as the capacity of the ship gets bigger. As a result, an incentive was created to develop container ship designs with a low tonnage relative to capacity. As shown in Figure 5.2, a reduction is observed in the port costs per TEU from \$22 for the 1200 TEU container ship to \$10 for the 11000 TEU container ship. The main canal dues are for transiting the Suez and Panama canals. The toll structure of the Suez Canal is very complicated since two tariff measurements

are used, which are Suez Canal net ton and Special Drawing Rights (SDRs). As to the Panama Canal, only a flat rate charge per Panama Canal net ton is used.

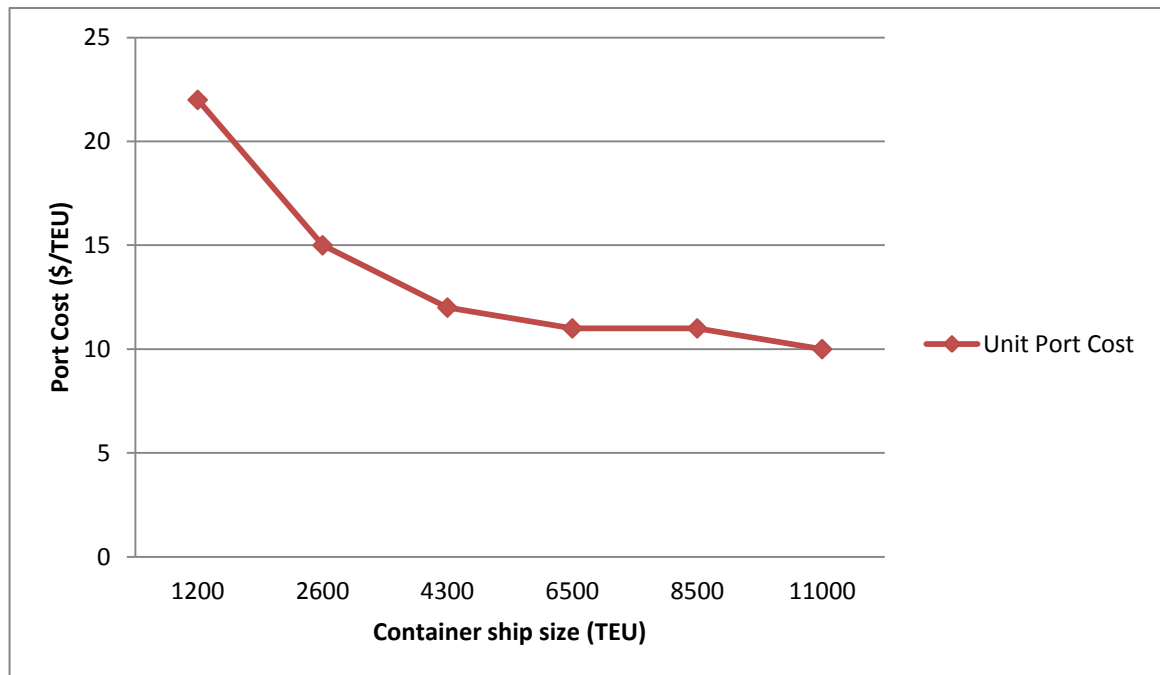


Figure 5.2 – Unit port cost of container ships (Clarkson Research Services Ltd, 2006)

Cargo handling costs are given by the sum of loading costs, unloading costs and an allowance for the cost of any claims that may arise. The level of these costs may be reduced by investment in improved ship design – to facilitate efficient cargo handling, along with advanced cargo handling gear. The cost of loading and unloading cargo represents a significant element in the total cost, particularly in the container liner business where considerable attention has been paid to this. In addition, the cost regarding the container includes rental, repair and maintenance costs. Since container management involves another maritime market, which is subject to its own cycles, only the rental cost of the container is considered in determining the dwell cost at port for full and empty containers.

Finally, periodic maintenance represents a cash payment to cover the cost of interim dry docking and special surveys. To maintain a ship in class for insurance purposes, it must undergo regular surveys with a dry docking every 2 years and a special survey every 4 years to determine its seaworthiness.

In this practice, charter rates represent the sum of operating costs, periodic maintenance and capital costs for a particular size of container ship, where the sum of fuel consumption and port costs constitute voyage costs. Two types of cargo handling cost, loading/unloading and transshipment, are distinguished due to the large difference between them. For example, the average loading/unloading cost on the transpacific trade lane in 2006 was \$200, whereas the average transshipment cost was \$225 involving loading, unloading and any other necessary port service (Clarkson Research Services Ltd, 2007). This is reflected on the virtual network design in order to achieve a more precise measurement on the unit costs for each route in the network.

5.2 Assumptions and methodology

As with the time-based version, the classic frequency-based transit assignment approach of Spiess and Florian (1989) is applied to develop a cost-based global maritime container assignment model and assess the promise of the method. As mentioned in the previous chapter, the virtual network approach described in Jourquin et al. (2008) is adopted but in this case the physical network is added in order to include route capacity constraints. The basic concepts adopted in the network design are therefore route, link and leg defined as follows:

- Route – A scheduled sequence of port calls
- Link – An adjacent pair of port calls along a route
- Leg – A particular transport task, thus a path represents a chain of transport tasks

In Figure 5.3, an example network with two routes is presented in order to clarify the concepts.

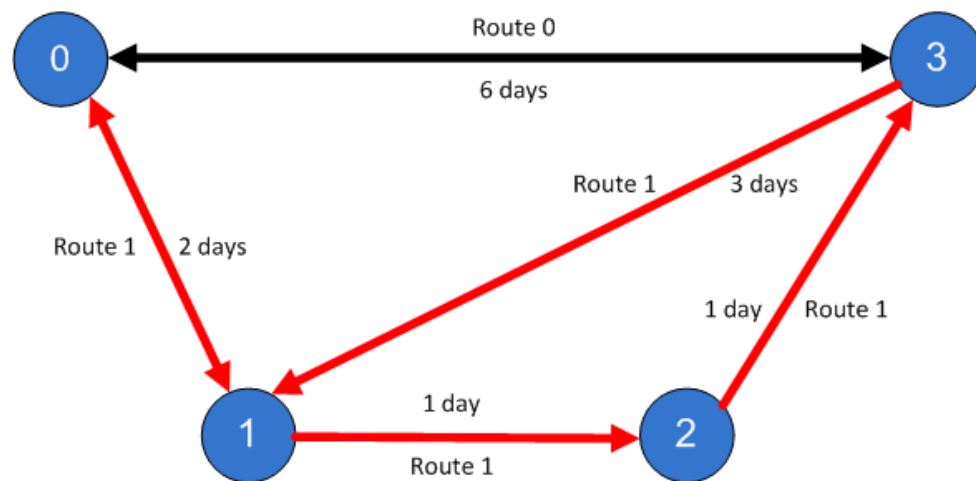


Figure 5.3 – Example network with two routes

The rotations for Route 0 and Route 1 in Figure 5.3 are shown as below:

- Port 0 (Mon/Tue), Port 3 (Mon/Tue), Port 0 (Mon/Tue)
- Port 0 (Sat/Sun), Port 1 (Tue/Wed), Port 2 (Thu/Fri), Port 3 (Sat/Sun), Port 1 (Wed/Thu), Port 0 (Sat/Sun)

The black and red lines represent the real links on Route 0 and Route 1 respectively. The procedure for converting from real network to virtual network and coding the legs is given in Figure 5.4.

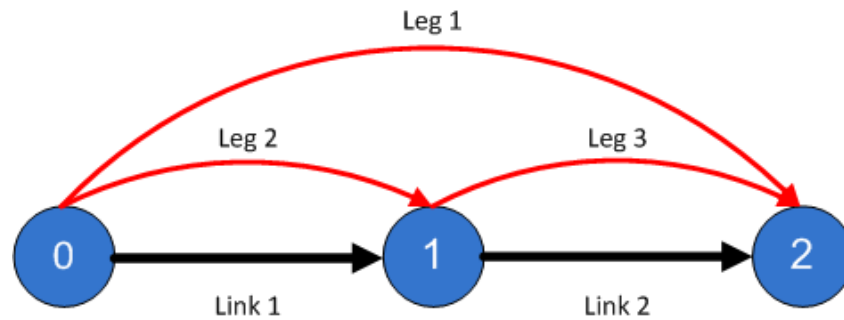


Figure 5.4 – Task oriented legs

Basically, a leg is labelled with three attributes the port of loading, the port of unloading and the route to be served. In addition, different cargo handling types contribute to another attribute on the virtual network design. Therefore, the virtual network is coded according to the following rules:

- 2 digits for the node number
- 2 digits for the route number
- 2 digits for cargo handling cost type
 - D – D type
 - D – T type
 - T – D type
 - T – T type

Note that there are four types of leg as shown above; legs which connect the origin port to the destination port, legs which connect origin port to a transshipment port, legs which connect a transshipment port to the destination port, and finally legs which connect two transshipment ports. The container handling cost is different for each leg type; basically transshipment costs less than loading or unloading at the origin or destination.

For example, consider leg 1 in Figure 5.4 as a task carrying containers from Port 0 to Port 2 on Route 1 for transshipment, it can be coded as F0T2R1DT. And also, due to the consideration of link capacity constraint, a discount factor has to be introduced during the procedure of network design in order to identify the link or links used by each leg. For example, in Figure 5.4, leg 2 uses real link 1 and real link 2, therefore the values of the discount factors for real link 1 and real link 2 should be equal to 1. In the meantime, it also allows the analysis on both leg flows and real link flows simultaneously. Each leg is associated with the service frequency and the travel time which includes the time for loading and unloading the container.

In order to simplify the problem and demonstrate the basic theory clearly in the proposed maritime container assignment model, some key assumptions have to be clarified first:

- Only one type of container is considered. Containers are assumed to be interchangeable and are assigned to minimise an objective function measured in cost units
- Containers are carried by shipping lines operating routes. Each route has a given service frequency, but the arrival and departure time at each port of ships on any route is random and uncoordinated with the arrival and departure time of ships on any other route.
- Container terminals are operated by profit maximising companies, so if demand threatens to exceed the capacity of the terminal, a surcharge is levied for each loading or unloading movement which is sufficient to reduce demand to the available capacity.

- Full and empty containers are considered separately. Constraints ensure that a net outflow of full containers from any port is balanced by a net inflow of empty containers, and vice versa.
- Costs factors considered include operating costs, voyage costs, container handling costs and capital costs.

The only difference between the cost-based version and time-based regarding the assumptions is about the cost factors that have been included. It is based on a general classification according to the cost structure of the container liner shipping industry. The objective function consists of the sum of the full and empty containers' sailing costs at sea and their expected dwell costs in ports, and any loading or unloading surcharge. Full and empty containers are managed separately under a principle that a net outflow of full containers from any port is balanced by a net inflow of empty containers and vice versa. As a result of the above randomisation assumption, the assignment of containers among alternative attractive routes departing a port is proportional to their service frequencies. Consequently, the inverse of the sum of these service frequencies should be equal to the expected dwell time of a container at that port. In the meanwhile, the probability that a container is assigned to a particular leg in the attractive set for a given node and destination is in proportion to the service frequency of that leg, unless either an upper limit on port throughput or only one attractive leg prevents this. Under the strategy of assigning a container to the next service on an attractive leg, a set of paths also known as a hyperpath (Nguyen and Pallotino, 1988) in the transit assignment literature could be used. In the case of binding throughput constraints, the concept of effective frequency (Spiess and Florian, 1989) is invoked. If a container cannot always be loaded on the next service of an attractive leg because of a downstream throughput constraint, this is equivalent to a reduction in the respective leg service frequency. In that

case, the effective leg service frequency can be inferred by looking at the spread of assigned leg flows across the attractive legs exiting a given node.

An Origin-Destination (O-D) matrix for full containers is assigned to the virtual network constructed above, while the empty containers are distributed to minimize the objective function. The destination for a full container is the origin for an empty container and vice versa. Containers are assigned to the first available service on an attractive leg at the origin port or any transshipment port. For a given destination, a leg is attractive if the objective function is reduced by including it in the choice set at a given node. The port throughput measured in containers per unit time is subject to an upper limit for total loading and unloading moves. The surcharge sufficient to eliminate queuing is levied. Transhipped containers are charged twice since the container is handled both on arrival and on departure.

The model remains a linear programme, so efficient solvers can be applied and the shadow price interpretation of the dual variables gives us further understanding about the solution. The expected dwell cost for full containers is the sum of rental cost of the container and depreciation value of the cargo within the container whereas for empty containers only the rental cost of container is considered.

The notation for the container assignment model is as follows:

Define

c_a Sailing time on leg a , including loading and unloading time at the ends

Y_n	Cost per container per unit time on route n , including the cost of loading and unloading
t_{rs}^f	Flow of full containers from origin r to destination s
x_{as}^f	Flow of full containers on leg a en route to destination s
x_a^e	Flow of empty containers on leg a
f_a	Frequency of sailing on leg a
k_i	Maximum throughput of node i
w_{is}^f	Expected dwell time at node i for a full container en route to destination s
w_i^e	Expected dwell time at node i for an empty container
A	Set of legs
T	Set of leg types
N	Set of routes
A_n	Set of legs on route n
A_n^t	Set of legs of type t on route n
O	Set of origin nodes
D	Set of destination nodes
I	Set of nodes
L	Set of links

L_n	Set of links on route n
A_i^+	Set of legs entering node i
A_i^-	Set of legs leaving node i
RC_n	Capacity on route n
δ_{aln}	1 if leg a uses link l on route n , and 0 otherwise
CR_n	Charter cost on route n
FC_n	Fuel cost on route n
PC_n	Port costs on route n
C_n^t	Cargo handling cost per container for a leg of type t on route n
DV	Depreciation value of the cargo per container
RC	Rental cost per container
M	Number of iteration

The container assignment model can now be expressed as the following linear program:

$$P_0: \quad \min_{x,w} (\sum_{a \in A} (x_{a+}^f + x_a^e) Y_n c_a + w_{++}^f (RC + DV) + w_+^e RC)$$

Subject to

$$(1) \quad \sum_{a \in A_i^+} x_{as}^f - \sum_{a \in A_i^-} x_{as}^f = b_{is}^f \text{ for all } i \in I, s \in D$$

$$(2) \quad \sum_{a \in A_i^+} x_a^e - \sum_{a \in A_i^-} x_a^e = -b_i^e \text{ for all } i \in I$$

$$(3) \quad x_{as}^f \leq w_{is}^f f_a \text{ for all } a \in A_i^-, i \neq s \in I, s \in D$$

$$(4) \quad x_a^e \leq w_i^e f_a \text{ for all } a \in A_i^-, i \in I$$

$$(5) \quad k_i \geq \sum_{a \in A_i^-} (x_{a+}^f + x_a^e) + \sum_{a \in A_i^+} (x_{a+}^f + x_a^e) \text{ for all } i \in I$$

$$(6) \quad RC_n \geq \sum_{a \in A} (x_{a+}^f + x_a^e) \delta_{aln} \text{ for } l \in L_n, n \in N$$

$$(7) \quad x_{as}^f \geq 0 \text{ for all } a \in A, s \in D$$

$$(8) \quad x_a^e \geq 0 \text{ for all } a \in A$$

$$(9) \quad b_{is}^f = \begin{cases} -t_{rs}^f & \text{if } i = r \in O \\ t_{+s}^f & \text{if } i = s \in D \\ 0 & \text{otherwise} \end{cases}$$

$$(10) \quad b_i^e = \begin{cases} t_{+i}^f - t_{i+}^f & \text{if } i = r \in O \text{ or } i = s \in D \\ 0 & \text{otherwise} \end{cases}$$

Unit cost of any route Y_n is given as below:

$$(11) \quad Y_n = \frac{CC_n + FC_n + PC_n}{\sum_{a \in A_n} (x_{a+}^f + x_a^e) c_a} + \frac{\sum_{t \in T} \sum_{a \in A_n^t} C_n^t (x_{a+}^f + x_a^e)}{\sum_{a \in A_n} (x_{a+}^f + x_a^e) c_a} \text{ for } n \in N$$

Note also that the MSA⁶ (Method of Successive Averages) and the convergence test are applied to Y_n between iterations to achieve better efficiency of equilibrium for the loop. The step size used in this variant of the MSA is set as $SS = 1/(1 + m)$. The averaged value of Y_n is calculated as below:

$$(12) \quad AVGY_n = (1 - SS)Y_n^{m-1} + SSY_n^m \text{ for } n \in N, m \in M$$

It is clearly that P_0 is not a classic linear programming. The introduction of endogenous route specific unit costs per unit time factors leads to a non-linear problem. In this thesis, the MSA procedure is applied in order to find mutually consistent unit costs. As a result, the unit costs are updated from iteration to iteration, within each iteration, the model is still handled as a linear program. The objective function is the sum of the sailing and dwell cost for full and empty containers. Constraints (1) and (2) enforce flow conservation for full and empty

⁶ Method of Successive Averages (first introduced by Robbins and Monro, 1951) has been proven popular among transport researchers as a heuristic method of achieving network equilibrium. The MSA method uses the step sizes which are related to the number of iterations carried out. The simplicity of this method makes it rather attractive to use.

containers respectively. For transshipment nodes, flow in must be equal to flow out, for full containers distinguished by destination and for empty containers without differentiation. Constraints (3) and (4) ensure that for the legs that are attractive at node i , the delay per full or empty container is at least as large as the inverse of the combined service frequency, differentiating by destination in the case of full containers. Given the randomness assumptions, the expected delay is equal to the inverse of the combined service frequency, so where the constraint does not bind (where the corresponding dual variable is zero), there must be a divergence between effective and actual leg service frequency. Constraints (5) ensure that the throughput of a port does not exceed an upper limit. In practice this upper limit will be determined by the length of quay, the number of ship-to-shore cranes, the extent and nature of the horizontal transport, and the stacking arrangements. Constraints (6) ensure that the flows of each link including full containers and empty containers on both directions do not exceed the route capacities. Constraints (7) and (8) are non-negativity constraints. Source and sink constraints are given in (9) and (10).

As we have to introduce the Lagrangian equation later, the dual variables have to be defined first:

q_{as}^f Dual variable for a full container on leg a en route to destination s

q_a^e Dual variable for an empty container on leg a

u_{is}^f Expected sailing, dwell and surcharge cost for a full container from node i en route to destination s

u_i^e Expected repositioning cost for an empty container at node i

v_i Surcharge for loading or unloading a container at node i

v_{nl} Surcharge for loading or unloading a container on link l of route n

Note that the definition of these dual variables would be interpreted in Proposition 1. Note also that constraints (3) and (4) are divided by f_a on both sides. This transformation would facilitate better expression of P_1 .

The Lagrangian equation for P_0 is:

$$\begin{aligned}
 (13) \quad L_{x,w,q,u,v} = & \sum_{a \in A} (x_{a+}^f + x_a^e) Y_n c_a + w_{++}^f (RC + DV) + w_+^e RC - \\
 & \sum_{i \in I} \sum_{s \neq i \in D} u_{is}^f (b_{is}^f + \sum_{a \in A_i^-} x_{as}^f - \sum_{a \in A_i^+} x_{as}^f) - \\
 & \sum_{i \in I} u_i^e (-b_i^e + \sum_{a \in A_i^-} x_a^e - \sum_{a \in A_i^+} x_a^e) - \\
 & \sum_{i \in I} \sum_{a \in A_i^-} \sum_{s \neq i \in D} q_{as}^f (w_{is}^f f_a - x_{as}^f) - \\
 & \sum_{i \in I} \sum_{a \in A_i^-} q_a^e (w_i^e f_a - x_a^e) - \\
 & \sum_{i \in I} v_i (k_i - \sum_{a \in A_i^-} (x_{a+}^f + x_a^e) - \sum_{a \in A_i^+} (x_{a+}^f + x_a^e)) - \\
 & \sum_{n \in N} v_{nl} (RC_n - \sum_{a \in A} (x_{a+}^f + x_a^e) \delta_{aln})
 \end{aligned}$$

At the optimum, the Lagrangian equation is minimised with respect to the decision variables x and w but maximised with respect to the dual variables q , u and v . Without loss of generality, we can set:

$$(14) \quad u_{ss}^f = 0 \text{ for all } s \in D$$

The Lagrangian equation can be rearranged using a more compact notation to yield:

$$(15) \quad L_{x,w,q,u,v} =$$

$$\begin{aligned} & \sum_{rs} t_{rs}^f u_{rs}^f + \sum_s (t_{+s}^f - t_{s+}^f) u_s^e - \sum_i v_i k_i - \sum_{n \in N} v_{nl} RC_n + \sum_{as} x_{as}^f (Y_n c_a + \frac{q_{as}^f}{f_a} - \\ & u_{is}^f + u_{js}^f + v_i + v_j + v_{nl} \delta_{aln}) + \sum_a x_a^e (Y_n c_a + \frac{q_a^e}{f_a} - u_i^e + u_j^e + v_i + v_j + v_{nl} \delta_{aln}) + \\ & \sum_{as} w_{is}^f ((RC + DV) - q_{as}^f) + \sum_a w_i^e (RC - q_a^e) \end{aligned}$$

where implicitly nodes i, j represent the entrance and the exit to link a respectively. The possibility of more than one leg connecting nodes i, j is included in this notation. Thus, the dual problem can be formulated as follow:

$$P_1: \quad \max_{q,u,v} (\sum_{rs} t_{rs}^f u_{rs}^f + \sum_s (t_{+s}^f - t_{s+}^f) u_s^e - \sum_i v_i k_i - \sum_{n \in N} v_{nl} RC_n)$$

Subject to:

$$(16) \quad Y_n c_a + \frac{q_{as}^f}{f_a} - u_{is}^f + u_{js}^f + v_i + v_j + v_{nl} \delta_{aln} \geq 0 \text{ for } a \in A_n, s \in D, n \in N$$

$$(17) \quad Y_n c_a + \frac{q_a^e}{f_a} - u_i^e + u_j^e + v_i + v_j + v_{nl} \delta_{aln} \geq 0 \text{ for } a \in A_n, n \in N$$

$$(18) \quad (RC + DV) - \sum_{j \in A_i^-} q_{as}^f \geq 0 \text{ for all } i \neq s \in I, s \in D$$

$$(19) \quad RC - \sum_{j \in A_i^-} q_a^e \geq 0 \text{ for all } i \in I$$

$$(20) \quad q_{as}^f \geq 0 \text{ for all } a \in A, s \in D$$

$$(21) \quad q_a^e \geq 0 \text{ for all } a \in A$$

$$(22) \quad v_i \geq 0 \text{ for all } i \in I$$

$$(23) \quad v_{nl} \geq 0 \text{ for all } l \in L_n, n \in N$$

Define L_{is}^f and L_i^e as the sets of legs leaving node i that are used by full container en route to destination s and that are used by empty containers to all destinations respectively. If a leg is used then it must be attractive, in the sense that it must reduce the objective function of P_0 . Unattractive legs are not used. According to a previously stated assumption, containers are

loaded on the first available service on an attractive leg and services depart randomly but with leg-specific frequencies. If all attractive services are available, then the total delay at node i for full container is

$$(24) \quad w_{is}^f = \frac{x_{i+s}^f}{\sum_{j \in L_{is}^f} f_a}$$

And for empty containers is

$$(25) \quad w_i^e = \frac{x_{i+}^e}{\sum_{j \in L_i^e} f_a}$$

However, it is possible that not all services on certain attractive legs are available due to a downstream throughput constraint because if they were then too many containers would arrive downstream. Consequently, the effective frequency may be less than the actual frequency and the delay at node i may be larger than given by (24) and (25). The use of effective frequency to accommodate capacity constraints is referred to in Spiess and Florian (1989). Legs where the effective frequency deviates from the actual frequency will have a 0 value of q due to the extremely large corresponding flows induced by constraints (3) and (4). The effective frequency may be calculated by investigating the distribution of flows at the solution to P_0 or equivalently P_1 and the total delay at such nodes may be calculated by restraining the summations in the numerator and denominator of (24) and (25) to those legs where q is positive. Equations (24) and (25) will hold by definition if actual frequency is replaced by effective frequency where there is a difference.

Proposition 1: $\sum_{rs} t_{rs}^f u_{rs}^f$ is the total cost of shipping full containers and $\sum_s (t_{s+}^f - t_{s+}^e) u_s^e$ is the total cost of repositioning empty containers.

Proof: If $x_{as}^f > 0$ then from complementary slackness and (16)

$$(26) \quad u_{is}^f - u_{js}^f = Y_n c_a + \frac{q_{as}^f}{f_a} + v_i + v_j + v_{nl} \delta_{aln}$$

where described as above nodes i and j represent the entrance and the exit to leg a respectively. To obtain the total cost of shipping full containers, we multiply (26) by x_{as}^f and sum the result with respect to a and s . Noting that if $q_{as}^f > 0$ then $x_{as}^f = w_{is}^f f_a$ and if $w_{is}^f > 0$ then $\sum_{j \in A_i^-} q_{as}^f = (RC + DV)$, and using (18) and (9), we obtain

$$(27) \quad \sum_{as} x_{as}^f (u_{is}^f - u_{js}^f) = \sum_{rs} t_{rs}^f u_{rs}^f - \sum_s t_{+s}^f u_{ss}^f = w_{++}^f (RC + DV) + \sum_a x_{a+}^f (Y_n c_a + v_i + v_j + v_{nl} \delta_{aln})$$

Without loss of generality, set $u_{ss}^f = 0$ for all $s \in D$. Hence

$$(28) \quad \sum_{rs} t_{rs}^f u_{rs}^f = w_{++}^f (RC + DV) + \sum_a x_{a+}^f (Y_n c_a + v_i + v_j + v_{nl} \delta_{aln})$$

Similarly, if $x_a^e > 0$ then from complementary slackness and (17)

$$(29) \quad u_i^e - u_j^e = Y_n c_a + \frac{q_a^e}{f_a} + v_i + v_j + v_{nl} \delta_{aln}$$

To obtain the total cost of shipping empty containers, we multiply (29) by x_a^e and sum the result with respect to i and j . Noting that if $q_a^e > 0$ then $x_a^e = w_i^e f_a$ and if $w_i^e > 0$ then $\sum_{j \in A_i^-} q_a^e = RC$, and using (19) and (10), we obtain

$$(30) \quad \sum_a x_a^e (u_i^e - u_j^e) = \sum_s (t_{+s}^f - t_{s+}^f) u_s^e = w_+^e RC + \sum_a x_a^e (Y_n c_a + v_i + v_j + v_{nl} \delta_{aln})$$

It is clear that $\sum_{rs} t_{rs}^f u_{rs}^f$ is the total cost of shipping full containers from (27) and $\sum_s (t_{+s}^f - t_{s+}^f) u_s^e$ is the total cost of repositioning empty containers from (30).

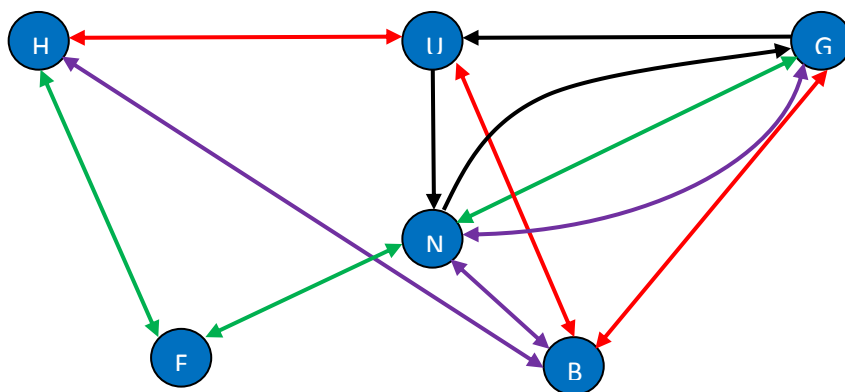
Proposition 1 shows that after appropriate initialisation u_{rs}^f is the cost of shipping a container from r to s including the expected dwell cost and any port and link surcharges and u_s^e is the average cost of returning an empty container from s including the expected dwell cost and any port and link surcharges.

Regarding the computational complexity of the proposed linear programming model in time-based version, it is that of a LP solver which depends on the solution method. It is likely to be identified as $O(n^4)$, where n denotes as the number of decision variables. When it comes to cost-based version, the computational complexity can be observed as $O(mn^4)$, where m denotes as the number of iterations.

5.3 Numerical example

In order to illustrate the properties of the proposed model, a numerical example is produced. Routes on the Asia-Europe trade lane are selected to construct a network. They are mainly sourced from the published schedules. Based on the model given above, the data regarding sailing time and frequency used in this numerical example are sourced from the published schedules. In addition, the frequency is fixed at once per week due to the weekly service promise given by the shipping lines for main services. The data regarding the cost factors are sourced from CRSL (Clarkson Research Services Ltd), Drewry Shipping Consultants, COSCON (COSCO Container Lines) and CSCL (China Shipping Container Lines). In addition, the depreciation value of the cargo within the container is based on the average cargo value on Far East-Europe trade lane.

The numerical example aims to clearly present the capability of the model with a simple virtual network of six nodes and only one O-D pair. In order to construct a reasonable network, a comprehensive analysis on all the Asia-Europe services is conducted. Therefore, some key assumptions about the network have been made. Firstly, the origins in Asia stretch from far north of Japan to the middle of Malaysia consisting of about 20 ports. Hong Kong is chosen to be the sole origin in the network due to the research focusing mainly on Europe. Secondly, the main destinations in Europe are Antwerp, Zeebrugge, Le Havre, Felixstowe, Southampton, Thamesport, Rotterdam, Hamburg and Bremerhaven. These destinations can be classified into five groups according to their nationalities Belgium (Antwerp, Zeebrugge), France (Le Havre), UK (Felixstowe, Southampton, Thamesport), Netherland (Rotterdam) and Germany (Hamburg, Bremerhaven). As a result, there are in total six nodes representing six port groups in the network. Last but not least, the group G is set as the final destination in the network due to the distance and UK transshipment issues. Under the above assumptions, the network is as constructed in Figure 5.5 complying with actual sequence of ports of call on each route together with routes information detailed in Table 5.1.



Notation: H – Hong Kong, U – United Kingdom, N – Netherlands, F – France, B – Belgium, G – Germany

Black Line – F0, Green Line – R1, Red Line – R2, Purple Line – R3

Figure 5.5 – Virtual network for the numerical example

Table 5.1 – Routes operating on the network

Route	Port Calls	Ship size/TEU	Frequency/week	Speed/Knot
F0	N – G – U – N	4300	3	22.6
R1	H – F – N – G – N – F – H	8500	1	24.2
R2	H – U – B – G – B – U – H	8500	1	24.2
R3	H – B – N – G – N – B – H	11000	1	25.2

Table 5.2 shows the characteristics of the four different container ships deployed in this numerical example. Charter rate, fuel cost and port cost represent the fixed cost of operating the container liner shipping business.

Table 5.2 – Characters of container ships deployed

Ship size/TEU	Charter rate/(\$/day)	Fuel Cost/(\$/day)	Port Cost/(\$/call)
4300	29863	44160	35000
6500	38199	64110	43000
8500	46178	69000	60000
11000	53801	72000	65000

The sailing time on each route is determined by the sailing speed of the container ship executing the service. It is increasing along with the container ship size as show in Table 5.1.

As a result, the sailing time is calculated as follows

$$Sailing\ time = \frac{Sailing\ Distance}{Speed}$$

The sailing distance is outlined in Table 5.3.

Table 5.3 – Sailing distance source from Netpas in Nautical Miles

Links	Distance
H – U	9732
H – F	9611
H – B	9809
U – G	357
N – G	303
N – U	121
F – G	499
F – N	240
B – G	385
B – U	136
B – N	129

Consider the network depicted in Figure 5.5, 25000 containers are shipped from Port H to Port G and empty containers repositioned from Port G to Port H. Four scenarios are tested which are outlined as follows:

- No port capacity constraint on any port
- Port capacity constraint on Port U of 15000 TEU
- Port capacity constraint on Port U of 15000 TEU with the frequency of route F0 decreases to weekly service
- Port capacity constraint on Port U of 15000 TEU with deploy 6500 TEU ship on route R2 and the frequency of route F0 reset to three times a week.

The flow assignments on real network are presented in Tables 5.4, 5.5, 5.6 and 5.7.

Table 5.4 – Flow assignments of route F0 on real network in four scenarios

Scenario	N – G	G – U	U – N
1	4300	4300	4300
2	4300	4300	3200
3	0	0	0
4	4300	4300	3200

Table 5.5 – Flow assignments of route R1 on real network in four scenarios

Scenario	H – F	F – N	N – G	G – N	N – F	F – H
1	8500	8500	8500	8500	8500	8500
2	8500	8500	8500	8500	8500	8500
3	8500	8500	7000	5500	8500	8500
4	8500	8500	8500	8500	8500	8500

Table 5.6 – Flow assignments of route R2 on real network in four scenarios

Scenario	H – U	U – B	B – G	G – B	B – U	U – H
1	5500	1200	2450	1200	1200	5500
2	5500	2300	3000	1200	1200	5500
3	5500	5500	8250	8500	5500	5500
4	5500	2300	3000	1200	1200	5500

Table 5.7 – Flow assignments of route R3 on real network in four scenarios

Scenario	H – B	B – N	N – G	G – N	N – B	B – H
1	11000	9750	9750	11000	11000	11000
2	11000	10300	9200	11000	11000	11000
3	11000	8250	9750	11000	8000	11000
4	11000	10300	9200	11000	11000	11000

The virtual flow assignment interprets more directly regarding the tasks on each route in Figures 5.6, 5.7, 5.8 and 5.9. And also, Table 5.8 depicts the unit costs of four routes and total costs in four scenarios.

Table 5.8 – Unit costs (\$/TEU/day) of four routes and total costs (\$) in four scenarios

Route	Scenario 1	Scenario 2	Scenario 3	Scenario 4
F0	112.7	113.4	N/A	114.4
R1	591.3	591.9	661.8	591.9
R2	665.0	709.2	688.9	669.6
R3	523.0	529.5	566.2	529.5
Total	497,421,914	508,125,134	542,827,781	502,284,558

As scenario 1 considers no port capacity constraint, no port surcharges arise. The total sailing cost and dwell cost are 497,421,914 dollars. However, the throughput of Port U is now 19600 moves counting transshipment (loading and unloading) as two moves.

With port capacity constraint at Port U for 15000 TEU in scenario 2, 1100 TEUs are assigned on the route R2 for a direct service from Port H to Port G. In other words, the feeder service F0 is less attractive under the circumstance that Port U has limited port handling capacity where port charges occur. However, the empty container assignment remains the same as Scenario 1. As a result, the objective function increases to 508,125,134 dollars.

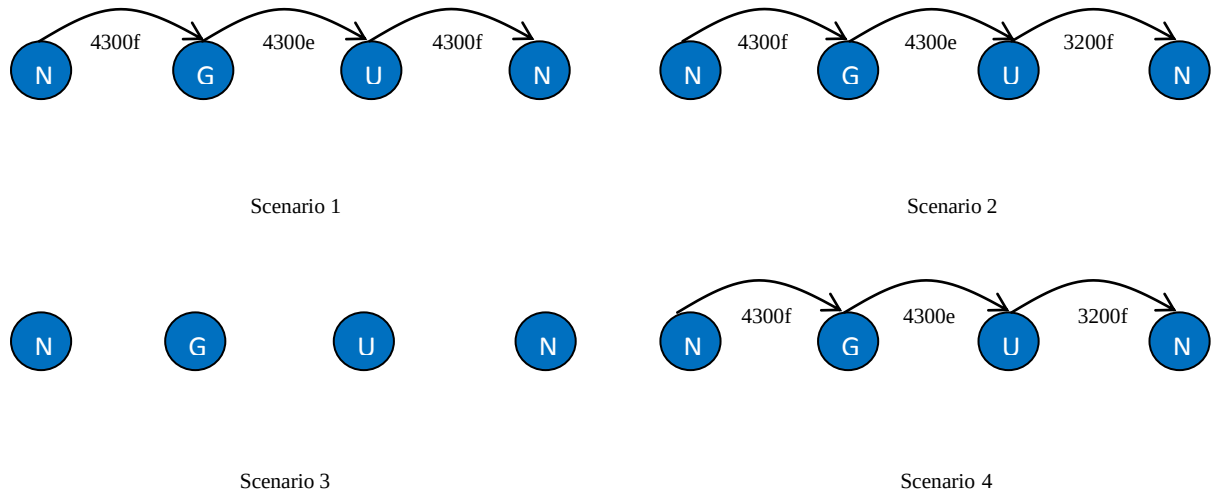


Figure 5.6 – Virtual flow assignment for route F0 in four scenarios

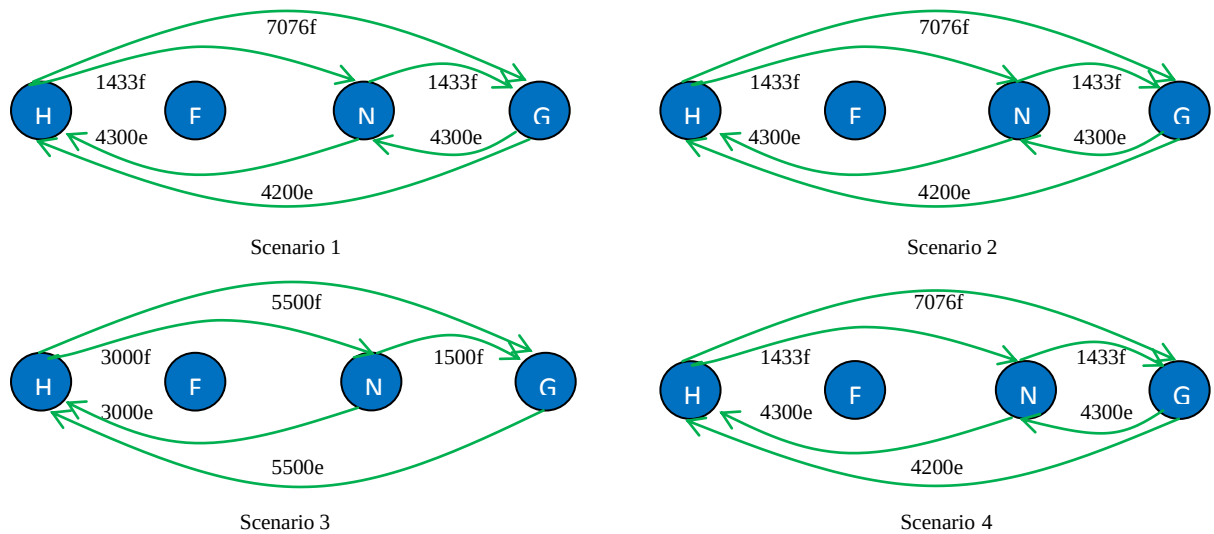


Figure 5.7 – Virtual flow assignment for route R1 in four scenarios

As to scenario 3, the service frequency of route F0 is decreased to once a week. The feeder service F0 is not attractive in this case which indicates that the attractiveness of a route mainly relies on its service frequency. Most of the diverted flows are assigned on route R2. In the meantime, routes R1 and R3 lose attractiveness slightly for full and empty containers respectively. This can be confirmed from changes of the unit costs. Route R2 achieves about

20 dollars reduction per container per day. However, the unit costs of routes R1 and R3 increase about 70 dollars and 37 dollars respectively. Ports B and N handle all the transshipment volumes where Port U generate nothing. Therefore, the total cost soars to 542,827,781 dollars.

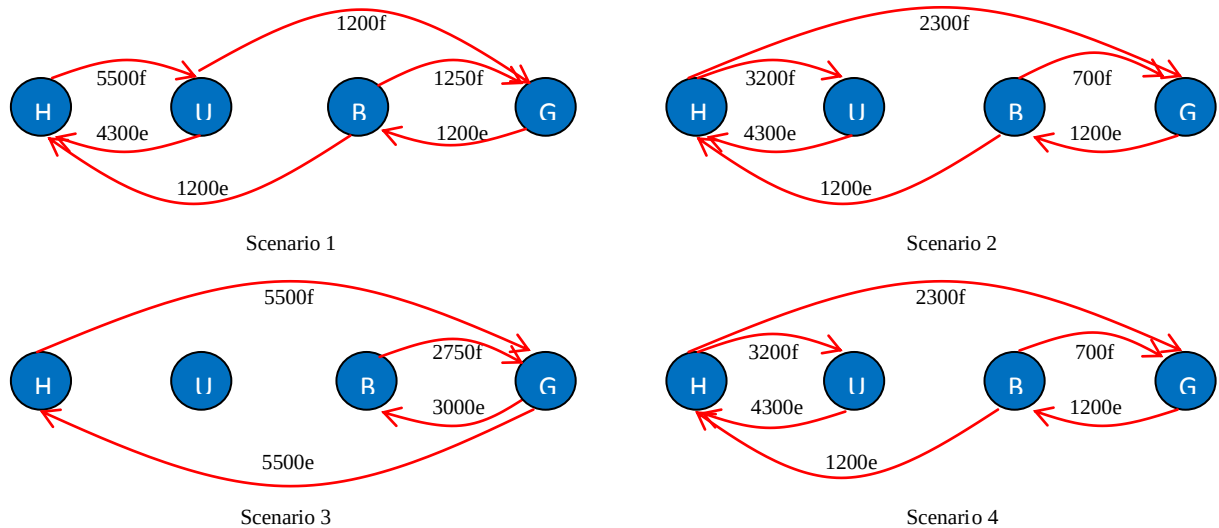


Figure 5.8 – Virtual flow assignment for route R2 in four scenarios

In scenario 4, the original 8500 TEU ship is replaced by the 6500 TEU one. Compared with strategy applied in scenario 3, deploying smaller ship performs much better. As a result, the fixed costs including charter rates, fuel consumption and port costs is dramatically lower than before. In the meantime, all other routes remain active. As can be seen from Figures 5.6, 5.7, 5.8 and 5.9, scenario 2 and scenario 4 shares the same flow assignment including full and empty containers. However, the fixed cost of route R2 has been reduced due to the deployment of a smaller ship. All the attractive services could achieve a relative high occupancy rate. The total cost objective function is reduced to 502,284,558 dollars.

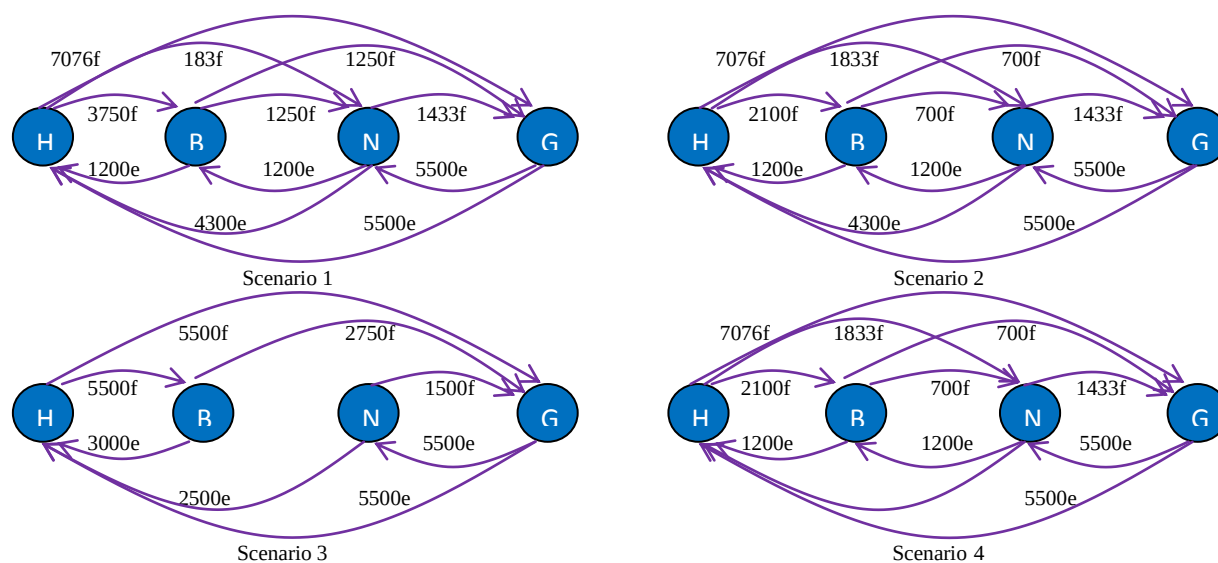


Figure 5.9 – Virtual flow assignment for route R3 in four scenarios

The depreciation value measured in dollars per day is set as 0.5% of the assumed average cargo value 4,000 dollars. The container rental cost for a standard container is assumed to be 1 dollar per day. In Tables 5.9 and 5.10, the dual variable q value distribution at Port U is presented for four scenarios. Port surcharges are imposed on the legs serving Port U for full and empty container flows respectively. The distribution of port surcharges will reflect on the corresponding total costs for four scenarios as outlined in Table 5.8.

Table 5.9 – Dual variable q (\$/TEU/week) for full containers at Port U in four scenarios

Leg	Route/full	q /scenario 1	q /scenario 2	q /scenario 3	q /scenario 4
U – N	F0	49	49	147	49
U – B	R2	0	0	0	0
U – G	R2	0	0	0	0
U – H	R2	0	0	0	0

Table 5.10 – Dual variable q (\$/TEU/week) for empty containers at Port U in four scenarios

Leg	Route/empty	q /scenario 1	q /scenario 2	q /scenario 3	q /scenario 4
U – N	F0	0	0	7	0
U – B	R2	0	0	0	0
U – G	R2	0	0	0	0
U – H	R2	7	7	0	7

5.4 Convergence test

In performing transit assignment on large scale network, the number of iterations is always a concern in terms of achieving the most accurate results efficiently. The termination criterion in static traffic assignment has been much researched. The Frank-Wolf method is applied in some studies to examine convergence. According to Boyce et al (2002), the shortcoming of this method is that link flows tend to fluctuate substantially from one iteration to another and makes it rather difficult to achieve a steady state. As a result, it is not efficient when applied to large scale networks due to the slow rate of convergence. Therefore, a termination criterion needs to be set up.

A termination criterion is referred to relative gap (RG) which usually measures the gap between current value of the variable being averaged (e.g. link flow) and its lower bound value. The value of relative gap at equilibrium should be equal to zero or as close as possible. Taylor (2003) proposes a method of convergence named the average absolute difference where the difference between link flows at each iteration is tested. The termination criterion which has been adopted in this study to determine the desired level of convergence is when route unit costs seem to retain stable after a certain number of iterations. In practice, a relative

rate of change (RRC) seems to be acceptable if it is less than 1% (Hamdouch and Lawphongpanich, 2008). The computation method of the relative rate of change is shown as below:

$$RRC = \sum_{n=0}^N \frac{|Y_{n,m} - Y_{n,m-1}|}{Y_{n,m-1}}$$

Where Y_n is the unit cost of route n ($n \in 0, \dots, N$) and m is the iteration number.

Table 5.11 outlines the iterations of the MSA (Method of Successive Averages) for the numerical example presented above. The relative rate of change is calculated at the end of each iteration according to the RRC equation.

Table 5.11 – Relative rate of change for four scenarios (%)

Iterations	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	9.960	25.356	43.697	28.974
10	2.646	4.572	8.195	4.897
20	1.001	2.015	4.010	2.019
50	0.501	0.883	1.571	0.898
100	0.085	0.496	0.893	0.401

5.5 Summary

This chapter presents a further step towards a global maritime container assignment model by converting the time-based version (Bell et al., 2011) to a cost-based version. As a result, the effects of sailing time, service frequency, port capacity, link capacity and cost factors on the pattern of full and empty container flows and therefore on port choice are presented. In order to develop this into a global maritime contain assignment model, the following would be required:

- A global maritime network with sailing times, frequencies and ship sizes. Sailing times and frequencies could be constructed from the published timetables for container liners. Container ship sizes mainly affect the link capacity constraint and can be sourced from various versions of Containerization International Yearbook.
- Global Origin-Destination matrices of container flows, differentiating by shipping line (or possibly shipping alliance) and container type as the containers within each Origin-Destination matrix need to be interchangeable. The assignment of the different Origin-Destination matrices is linked only by the port throughput constraint and link capacity constraint, so each shipping line (if each matrix corresponds to a shipping line) is minimizing its own objective function, linked only by common port surcharges and link surcharges where port capacity constraints and link capacity constraints bind.

In order to present a capability of this cost-based maritime container assignment model, a case study on Europe-Far East trade lane is conducted in the next chapter, mainly focusing on the two suggestions given above.

Chapter 6

Case study on Europe- Far East trade lane

The Europe-Far East liner market is a very long trade route stretching half way around the world. Basically, this route extends from the Sweden, Denmark, Germany, Netherlands, Belgium, UK and France in the west to Myanmar, Malaysia, Singapore, Indonesia, China, Taiwan, South Korea, North Korea and Japan in the east. In this part, the general market and service information on this specific route is reviewed based on data before the 2008 economic recession.

The following section presents the approach to Origin-Destination matrix generation and the network construction, model application to the Europe-Far East trade lane and two scenarios. Many tonne-miles of maritime transportation service are provided by the carriers along this route. The following Table 6.1 gives the general information of Europe-Far East route.

Table 6.1 – General information on Europe-Far East route (Global Insight, 2005)

Trade route	Share of EU trade	Share of EU trade	Directional	Length of route
Europe-Far East	(%) Imports	(%) Exports	imbalance	(Nautical miles on average)
	22.34	17.13	1.68	5770
Trade route	Number of carriers	Number of weekly	Conference share of	Freight rates
Europe-Far East	on route	sailings	capacity (%)	(West/East) in US dollar
	22	32	61.7	1838/769

As can be seen from Table 6.1, the Europe-Far East container route is one of the longest and accounts for about one fifth of the total EU trade volume with a high degree of trade imbalance of about 1.68 (Westbound/Eastbound). When it comes to the service, there are a sufficient number of carriers offering a good service frequency. There is a highly concentrated market where the Far East Freight Conference (FEFC) members occupy about 61.7% capacity on this route.

6.1 Market review of Europe-Far East trade lane

Generally, the following market review of Europe-Far East trade lane covers mainly two aspects, namely trade volumes and commodities types.

6.1.1 Container trade volume

The growth of trade between Europe and Far East has been impressive. If we measure the trade volume in TEUs, the overall trade volume increased around 37% from 2001 to 2004 as can be seen in Figure 6.1 (Global Insight, 2005). Besides this, according to the forecast trade volumes until 2010, the imbalance between eastbound trade and westbound is growing. As shown in Figure 6.1, the westbound trade increased over 44% from 2001 to 2004, and the imbalance is expected to continue to grow in the future. Imports from the Far East are expected to grow by over 50% until 2010.

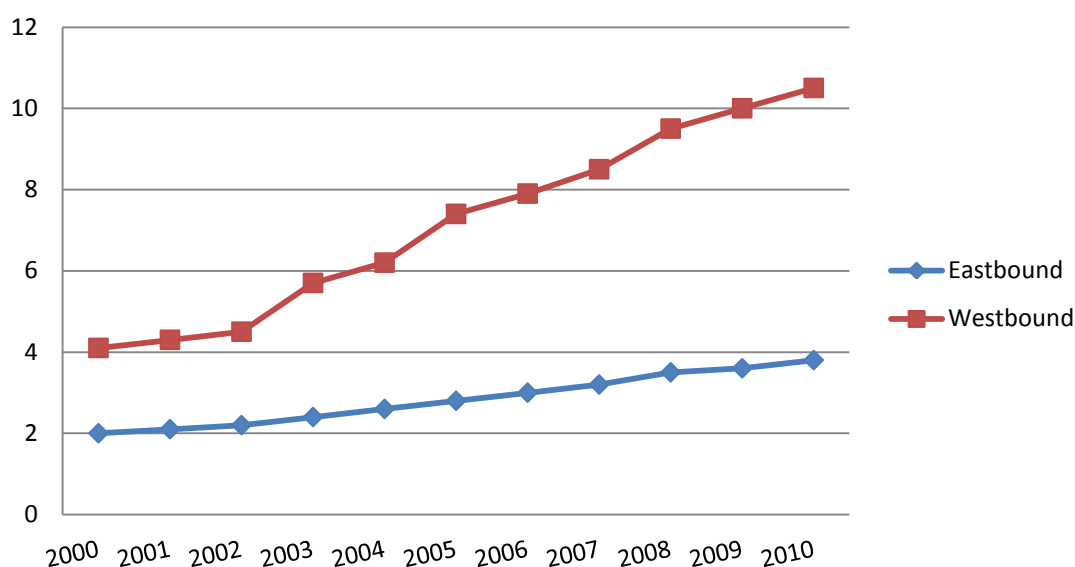


Figure 6.1 – Europe-Far East trade volumes (in 1,000,000 TEUs)

The main driving force of the impressive imports growth is the booming economy in the Far East, especially in China. This pattern can be shown in the trade commodities in the following section.

As we can see in Tables 6.2 and 6.3, the existing and forecast data sourced from Global Insight also shows a similar trade pattern between Europe and Asia. Although the absolute

trade volume is increasing until 2008, the annual average growth rate is decreasing step by step on both westbound and eastbound.

Table 6.2 – Container trade by route (thousands of TEUs) (Global Insight World Trade Service, 2005)

Export	Import	2004	2005	2006	2007	2008
N Europe	NE Asia	1416	1508	1621	1726	1846
N Europe	SE Asia	552	589	625	651	679
NE Asia	E Europe	677	809	912	1019	1122
NE Asia	N Europe	3730	4225	4670	5201	5676
SE Asia	E Europe	118	125	131	137	145
SE Asia	N Europe	1059	1113	1159	1226	1279

Table 6.3 – Annual average growth rate (Global Insight World Trade Service, 2005)

Export	Import	2005	2006	2007	2008
N Europe	NE Asia	6.5%	7.5%	6.4%	6.9%
N Europe	SE Asia	6.7%	6.0%	4.2%	4.4%
NE Asia	E Europe	19.6%	12.6%	11.8%	10.1%
NE Asia	N Europe	13.3%	10.5%	11.4%	9.1%
SE Asia	E Europe	5.8%	5.1%	4.5%	6.1%
SE Asia	N Europe	5.0%	4.1%	5.8%	4.3%
in Summary					
Europe	Asia	6.5%	7.1%	5.9%	6.2%
Asia	Europe	12.4%	10.0%	10.5%	8.4%

As seen in Table 6.3, the overall trade volume growth rate from Europe to Asia experienced a fluctuation around 6% to 7%. As to trade from Asia to Europe, the fluctuation can be slightly heavier which reduced 4% from 2004 to 2008. Although container shipments from Asia to Europe are supposed to slow down in the following years, the growth rates are still predicted to be substantial regarding the total trade volume.

In general, owing to the weak economic forecast for Europe, the westbound trade growth rate may slow down and come at the expense of other trades to Europe. However, the forecast of the ratio of westbound to eastbound TEUs is expected to keep on increasing until 2024 (the end of the forecast by Global Insight) in view of the continued consumption of fair-priced goods from Asia, despite the slowing of Europe's consumer sector. On the other hand, the higher oil price and the currency fluctuation can be challenges for the Far East countries especially China. However, they have been aggressively meeting challenges on energy and currency. Their policy initiatives on energy and currency should help ensure continued export-lead economic growth for the foreseeable future.

6.1.2 Commodities traded

As to the trade commodities, generally speaking, manufactured goods dominate the westbound trade (imports from Asia to the EU) accounting for over 50%. As to the eastbound (exports from the EU to Asia), industrial goods occupy a large share of the total trade volume, including automobile, chemical, civil aircraft, machinery and so on. Owing to the huge trade imbalance between westbound and eastbound, we are concerned more about the westbound trade commodities, simply because the westbound trade has a larger volume.

Owing to the special status of China in this region, the main patterns are illustrated by comparison between China and the other Far East countries (see Table 6.4).

Table 6.4 – Asia exports by commodity – type to EU (Global Insight World Trade Service, 2005)

Commodity type	China	Others
Manufactured Products	57%	41%
Apparel	12%	8%
Electronics	12%	5%
Agricultural Products	5%	8%
Chemicals	4%	13%
Transportation Equipment	3%	10%
Machinery	3%	4%
Raw Material	2%	3%
Wood & Paper Products	2%	6%
Energy Products	1%	2%

As illustrated above, apparel, electronics, chemicals, transportation equipment and agricultural products are also the main commodity type exported to EU. Although each country may have a different economic development path, the performance of those countries' economy especially China's play an important role on the activity, volume, rates and capacity of the Europe-Far East container liner routes.

6. 2 Services provided on the Europe-Far East trade lane

Generally, the services provided on the Europe-Far East container liner shipping route will be analyzed in service summary, service pattern, capacity utilisation and freight rates respectively. The summary and patterns give current general service information on the research route. Capacity utilisation mainly concerns the trade imbalance between westbound and eastbound. And also, the current trend of the freight rates is analyzed.

6.2.1 Data

As to the data used to analyze the service provided and market concentration on the Europe-Far East route, they are not available in original form and most of them are published in aggregated condition. Considering the reliability of the data, they are sourced from Drewry Annual Container Market Review and Forecast, Containerisation International Yearbook and the websites of container liner shipping companies. These data relating to the number and patterns of service are calculated for the container liners active on the Europe-Far East trade route. The operational routes considered in this case study have to start from or terminate at North Europe which is the longest route in this market. The purpose of this data collection approach is to narrow down the target research market and facilitate a clear analysis on the container assignment under different scenarios.

6.2.2 Service summary

The service summary here mainly analyze the market in following aspects which are demand and supply, number of services and container liners active on the Europe-Far East route. The

condition of demand and supply on the Europe-Far East route can be shown in the Table 6.5 as follow.

Table 6.5 – Demand and supply on the Europe-Far East route, 2000-2006. (In 1000 TEUs)

Direction	Demand		Supply	
	Westbound	Eastbound	Westbound	Eastbound
2000	4076	2678	4389	3496
2001	4075	2824	4899	3930
2002	4432	2987	5073	4094
2003	5204	3256	5470	4421
2004	6064	3700	6406	5211
2005	6690	3860	7354	5987
2006	7560	4158	8462	6768

As we can see from the above table, the demand kept on increasing from 2000 to 2006 on both westbound and eastbound with 85.5% and 55.3% respectively. As to the supply, this represents the capacity deployed on this route, which also grew by 92.8% and 93.6% westbound and eastbound respectively in the same period. The great increase in demand caused more capacity to be deployed on this route.

This trend is expected to continue for the foreseeable future. However, the trade volume growth might be slightly lower according to the Drewry Shipping Consultants 2006/2007 at 9.52% and 7.16% annually westbound and eastbound respectively from 2007 to 2011. This is shown in the Figure 6.2.

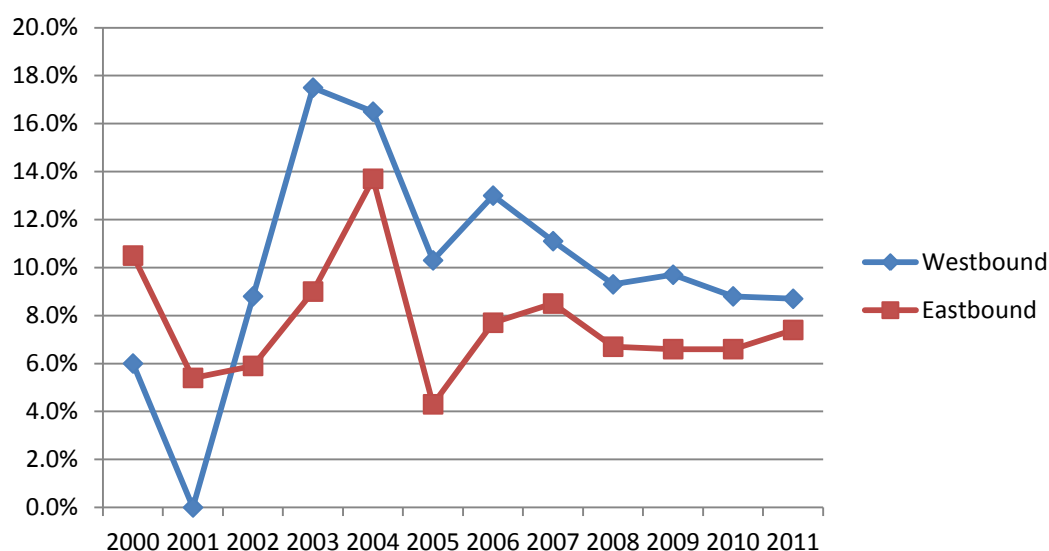


Figure 6.2 – Forecast development of the growth rate of container trade volumes on Europe-Far East route (2000-2011) before the crisis

There are mainly 26 container liner shipping companies active in this market including three major alliances, which are the Grand Alliance (Hapag-Lloyd, MISC, NYK, OOCL), CKYH (Cosco, K Line, Yangming, Hanjin) and the New World Alliance (APL, HMM, MOL). They accounted for about 48.7% of the total capacity as shown in Figure 6.3. There are at least 35 dedicated weekly scheduled sailings provided on this route (details can be found in the Appendix 1). Most of the services are round trip full container service except a handful of one-way services on this route. For instance, Contship, Marfret and Gold Star Line are capitalising on the westbound boom and operate westbound services only.

Those container liners are operating on different modes. Some of them cooperate with each other in the form of alliances as seen above. Some liners operate on individual basis such as Maersk Line and Mediterranean Shipping Company. The others may engage in various forms of agreement with other liners on such issues as slot charter and vessel sharing to provide a

joint service. For example, two privately controlled Far East carriers PIL and Wan Hai started a joint service in early 2004. Their patterns are analyzed in the following section.

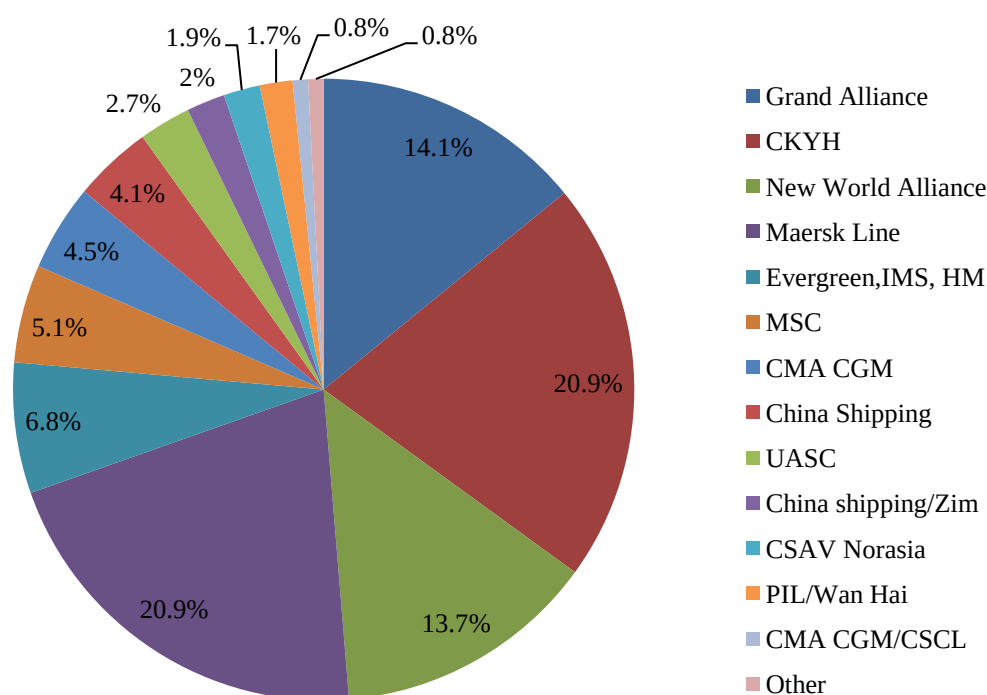


Figure 6.3 – Slot capacity shares on the Europe-Far East route (Drewry, 2007)

Note: IMS-Italia Marittima, HM-Hatsu Marine, CSAV Norasia-Compañía Sudamericana de Vapores Norasia Liner Services, Zim-Zim Integrated Shipping Services, PIL-Pacific International Lines, CSCL-China Shipping Container Line.

6.2.3 Service pattern

The service patterns mainly reveal the form of the cooperation of the carriers, the number and frequency of services they provide and the future trend of their service. It is an important aspect which gives us a clear picture of the market.

As outlined above, there are mainly three kinds of operation in this market which are shipping alliance, shipping agreements and individual operation. The three alliances also operate in different modes. The Grand Alliance is running a higher degree of cooperation with a fully integrated vessel sharing agreement. All vessel deployment and operational decisions are made by the operation centre on behalf of the members. As to the CKYH Alliance, the members of the alliance mainly operate their own strings. However, other members may take slots if they choose. The smallest alliance, the New World Alliance, takes a more flexible operational strategy with a mixture of these two models.

Shipping agreements are the most widely used operational strategy in the container liner shipping market including the Europe-Far East trade route. Many individual carriers, such as CMA CGM, China Shipping and Zim, engage in agreements with other carriers mainly in the form of vessel sharing and slot chartering. There are only two truly individual carriers on this route, which are Maersk Line and Mediterranean Shipping Company. Maersk has acquired the former largest Grand Alliance member P&O Nedlloyd and integrates its existing container shipping business with P&O Nedlloyd's to form the Maersk Line. Now, Maersk owns and runs the largest container fleet in the world. Presumably, the existing individual full service provided by Maersk Line on the Europe-Far East route will keep on upgrading and increasing in the future.

There are also a few one-way services on the Europe-Far East route. Marfret, for example, operates westbound only services on a slot agreement with CMA CGM and CP Ships-Hapag Lloyd on this route.

Generally speaking, the Grand Alliance offers four loops of weekly service with eight or nine vessels on each loop. Specific, the average capacity on the EU3 loop reaches 8404 TEU while the other three loops range from 6156 TEU to 7302 TEU. And the container ships deployed on this route are all post panamax type. As to the CKYH Alliance, it offers seven service loops on a weekly basis. The average capacity of most loops ranges from 5455 TEU to 5593 TEU, while the NCX loop provided by COSCO reaches 8457 TEU. It also deployed the post panamax container ships on above loops. Besides these, the seventh route is the Pendulum Service run by twelve container ships with an average capacity 4692 TEU. The New World Alliance also offers four loops of weekly service with seven or eight vessels on each loop. Those container ships deployed on these loops are all post panamax type ranging from 5582 TEU to 6381 TEU.

As to the section of the individual container liners, the biggest individual operator on this route, Maersk Line, offers six weekly loops. There are three loops of eight or nine vessels with the average capacity over 8100 TEU. And also, one route has seven ships averaging 7163 TEU. The other two loops operate with seven or eight vessels with average capacities 4867 TEU and 5122 TEU respectively. Basically, Maersk Line operates four loops of weekly service with larger post panamax container ships together with two weekly loops with panamax vessels. After acquiring P&O Nedlloyd, it provides three more services than before. The other independent container line, Mediterranean Shipping Company, offers three loops of weekly service. The Silk Express loop has nine post panamax vessels averaging 9200 TEU. The other two loops operate with ten and thirteen vessels averaging 6613 TEU and 3077 TEU respectively.

The other carriers have a market share of only occupy 25.3%. Most of them provide weekly services with other carriers through shipping agreements. Some of them only provide a westbound service only, the service detail can be found in the Appendix 1.

6.2.4 Capacity utilisation

The capacity utilisation is defined as a percentage of the total trade volume divided by the total capacity on a route in a certain period time. Faced with high and increasing demand, most of the carriers on this route achieved very close to full practical capacity utilisation in the westbound direction. However, there is a much lower capacity utilisation in the eastbound direction mainly owing to the trade imbalance, as the westbound trade is twice as large as the eastbound trade.

Table 6.6 – Net slot capacity utilisation on the Europe-Far East route (2000 – 2006)

Net Slot Capacity Utilisation		
Year	Eastbound	Westbound
2000	76.6%	92.9%
2001	71.9%	83.2%
2002	73.0%	87.4%
2003	73.6%	95.1%
2004	71.0%	94.7%
2005	64.5%	91.0%
2006	61.4%	89.3%

Table 6.7 – Capacity utilisation of FEFC, 2003 – 2004 (Global Insight, 2005)

Quarter	Capacity	Trade	Utility	Capacity	Trade	Utility
	Eastbound (TEUs)	volume (TEUs)		Westbound (TEUs)	volume (TEUs)	
2003: 1	871417	611692	70%	1076705	1016600	94%
2003: 2	918671	576110	63%	1138271	1095520	96%
2003: 3	986800	583789	59%	1227701	1199687	98%
2003: 4	1025787	678991	66%	1272030	1157817	91%
2004:1	1048906	693679	66%	1318528	1208840	92%
2004:2	1077161	707612	66%	1362630	1301089	95%
2004:3	1166172	672657	58%	1471851	1371074	93%
2004:4	1224068	720970	59%	1549380	1324672	85%

FEFC has 17 members including three main alliances on this route, and Maersk Line and CMA CGM which represents 61.7% of the total shipboard TEU capacity on this route by the mid 2005. The data listed in the Table 6.7 clearly shows the relationship between the capacity growth and trade volume growth as above.

Although there is a huge gap on the capacity utilisation between the westbound and the eastbound, carriers are still willing to return to Far East with partially empty ships in order to maximise their share of the booming westbound trade. The analysis of capacity utilisation on this route shows that its rates are high enough to ensure a healthy market and indicate further expansion of the capacity and service in the future.

6.2.5 Freight rates and surcharges

The booming economy of Far East countries especially China caused the great trade imbalance and the temporary shortage of capacity on this route. The freight rates on both westbound and eastbound directions are influenced dramatically by this trend. The differential on freight rates between westbound and eastbound directions have diverged dramatically for over a decade as shown in Figure 6.4.

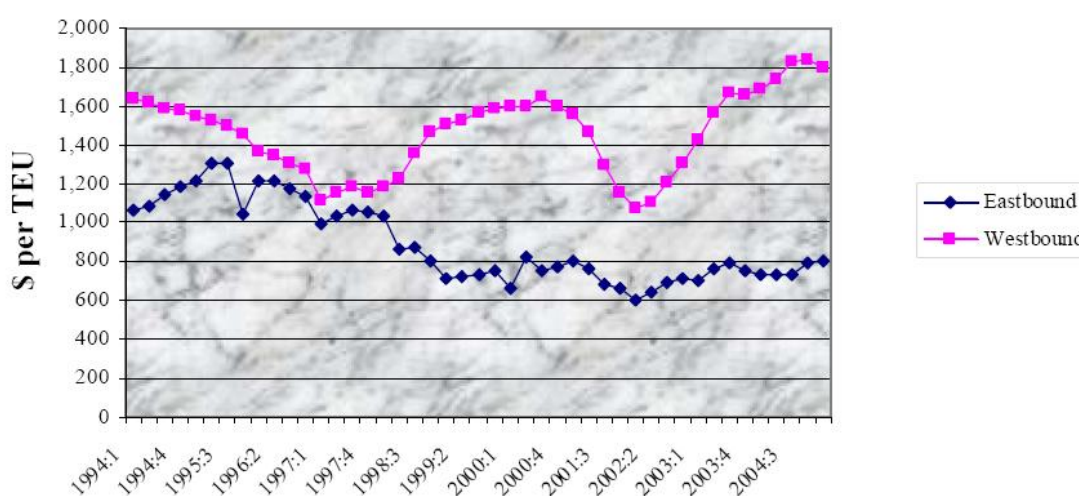


Figure 6.4 – Freight rates for the Europe-Far East route, 1994 – 2004 (ISL, 2005)

The main reason for this freight rates difference is that westbound trade volumes are larger than eastbound and they are increasing faster. According to the Drewry Annual Container Market Review and Forecast 2006/2007, this trend will continue to show in this market.

Usually, the general freight rate does not contain various surcharges, such as charges for fuel and currency fluctuations and port specific fees (e.g. CAF⁷, BAF⁸). There are two factors influencing pricing level dramatically which are fuel and currency fluctuations. According to the FEFC statistics in 2005, these two surcharges alone accounted for an additional 20% to 30%

⁷ Currency Adjustment Factor

⁸ Bunker Adjustment Factor

premium over the general freight rate depending on direction. It is supposed that these two surcharges will increase dramatically in future as fuel costs escalate and the currency fluctuates.

6.3 Cost-based container flow assignment model applied on Europe-Far East trade lane

The cost-based container flow assignment model introduced in Chapter 5 is applied in this section to the Europe-Far East trade lane. During the period considered in this case study, some trends of the liner shipping market discussed in the previous chapters have been intensified. There are mainly two changes which regard size of container ship and sailing speed needed to be outlined. The Appendix 2 outlined the current services provided on the Europe-Far East trade lane and identified the changing characteristics of lower speed and larger ship size. Many reasons such as operation innovations, increasing oil price and economic recession contribute these changes. However, the ultimate objective is to pursue the optimal unit cost under the diversified circumstances. The following sections are structured to present Origin-Destination matrix generation, trade lane network construction and model application for various scenarios.

6.3.1 Origin-Destination matrix generation and network construction

Containerisation International provides the data on route information and port traffic volume including import and export for the year 2010. 27 routes provided by 16 major container liner shipping companies are considered in the network which account for over 90% of the total deployed capacity. In the meantime, 40 container ports are identified as the origins and

destinations depicted in Appendix 3. At the top level, it is assumed that the Europe-Far East trade lane accomplish about 15% of the total world container traffic volume. Since all the routes are operating on a weekly basis, the container traffic volume for each port is about 2% of the annual volume. The gravity model is applied on total import and export container traffic volume for the 40 ports. The sailing distance between ports presented in Appendix 4 is considered as the fundamental attractiveness factor for the gravity model in this case study. As a result, the Origin-Destination matrix for target research network is generated through applying doubly constrained gravity model for 50 iterations. Starting with export/vertical side, the proximity check lies on the import/horizontal side where Figure 6.5 illustrates below.

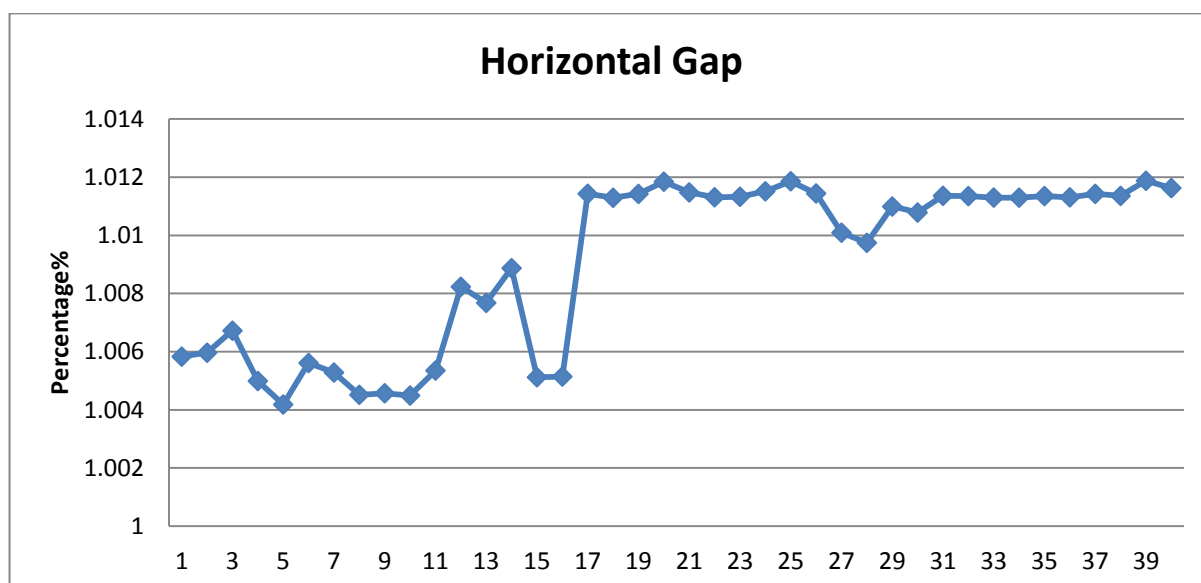


Figure 6.5 – Difference on the import/horizontal side

The case study network consists of 335 real links from 27 routes listed in Appendix 2. According to the virtual network construction approach described in chapter 5, 277600 virtual legs are included by distinguishing their origin, destination, route index and cargo handling cost type. Since all the virtual legs provide weekly service, the possibility of one leg representing one type of cargo handling costs between a pair of ports on a specific route is the same as the other three legs. Therefore one fourth of the container volume between a pair of

ports on a specific route is assigned for each type. In this case, four types of cargo handling costs could be merged into an integrated cargo handling cost, the total number of virtual legs in the network could be reduced to 69400.

CRSL (Clarkson Research Services Limited), Drewry Shipping Consultants, COSCON (COSCO Container Lines) and CSCL (China Shipping Container Lines) are the main data sources regarding the cost factors considered in this case study. In addition, the depreciation value of the cargo within the container is assumed according to the average cargo value on Europe-Far East trade lane.

6.3.2 Model application on various scenarios

In the section, the model is applied to simulate the current container flow assignment for the first named Scenario 0. And then, two scenarios regarding policy or strategy applied in the perspectives of port capacity and link capacity will be investigated. The details of two scenarios are given as follows:

1. Policy application on port expansion scheme. In this scenario, handling capacity expansion at Felixstowe is considered.
2. Strategy application on container ship capacity deployment. In this scenario, plans of possible service cancellation or average deployed ship capacity reduction regarding link capacity are simulated.

Scenario 1 considers an extra 20% port handling capacity to be deployed at Felixstowe, where Scenario 2 reduces average ship capacity on AE10 from 8300 TEU to 6500 TEU. The results are presented through comparison between Scenario 0 and any other scenario. In each

scenario, details of two routes EUD and AE1 are interpreted as examples where routes gain and lose importance respectively.

Table 6.8 – Total costs of each situation (\$)

	Scenario0	Scenario1	Scenario2
Objective	443,271,109	431,705,967	451,954,436
Full	3.9368e8	3.8201e8	3.9752e8
Empty	0.4959e8	0.4970e8	0.5444e8

As can be seen from Table 6.8, Scenario 1 representing port expansion scheme illustrates that the entire network has gained benefit. The total cost, especially the full containers, has been reduced by 11,565,142 dollars per week. In the meantime, costs of empty containers remain unchanged. As to the port traffic at Felixstowe, it is shown in Table 6.9.

Table 6.9 – Port traffic at Felixstowe

Scenario	Port	FullIn	FullOut	EmptyIn	EmptyOut	Total	Limit
0	Felixstowe	12360	10678	0	1681	24719	24719
1	Felixstowe	14832	13150	0	1681	29663	29663

The total port traffic volumes indicate a fully deployed port capacity under both scenarios at Felixstowe. In the meanwhile, the port revenue increases by 1,643,880 dollars per week. As a result, some routes may become more attractive where some may not.

Table 6.10 – Link flow on route EUD for scenarios 0 and 1 (Link details refer to Appendix 5)

Links on route EUD														
Scenario	215	216	217	218	219	220	221	222	223	224	225	226	227	228
0	4256	6050	4717	156	5797	5797	6050	0	0	0	0	0	1750	6050
1	4538	6051	6051	5296	5833	5833	6050	0	962	1173	0	0	2475	6050

Table 6.11 – Link flow on route AE1 for scenarios 0 and 1 (Link details refer to Appendix 5)

Links on route AE1														
Scenario	229	230	231	232	233	234	235	236	237	238	239	240	241	242
0	8318	8314	8320	8307	8301	8302	8303	8305	5769	8307	8305	8306	8304	8304
1	8319	8313	8319	8307	8030	5118	0	24	526	92	4919	0	4674	8300

Tables 6.10 and 6.11 present the total flows including full and empty containers on the routes EUD and AE1 respectively. The accumulated number of containers that have been diverted onto the links of route EUD is 9,689, whereas the links of route AE1 becomes less attractive by losing 48,824 containers. This also can be confirmed through Table 6.12 where the unit costs of routes EUD and AE1 are presented under both scenarios.

Table 6.12 – Unit costs of routes EUD and AE1 in scenarios 0 and 1 (\$/container/day)

	EUD	AE1
Scenario 0	262.7	61.9
Scenario 1	172.1	198.8

Table 6.13 classifies 27 routes within the network according to the changing characters of the route unit costs. The unit costs of each route under both scenarios are outlined in Appendix 6.

Table 6.13 – Classification of routes under Scenario 1

Route ID	Gain	Route ID	Lose	Route ID	Neutral
3	FAL12	6	AEX	0	EUB
10	FAL15	8	FAL2	1	EUC
11	FAL3	16	NE5	2	FAL1
13	NE2	17	AEC2	4	SCX
14	NE1	19	AE1	5	CEX
15	NE3			7	AEX1
18	EUD			9	CES2
20	AE2			12	NE4
24	AE10			21	AE7
25	Silk Express			22	AE8
26	EUA			23	AE9

In Table 6.14, the expected waiting times for the full container traffic towards all destinations at port Felixstowe are outlined as below.

Table 6.14 – Expected waiting time for full containers at Felixstowe (container·weeks)

From	To	Scenario 0	Scenario 1
Felixstowe	Aarhus	54	107
Felixstowe	Gothenburg	80	159
Felixstowe	Gdansk	22	44
Felixstowe	Bremerhaven	537	1074
Felixstowe	Zeebrugge	406	1253
Felixstowe	Hamburg	507	1860
Felixstowe	Southampton	149	256
Felixstowe	Thamesport	99	198

Felixstowe	Dunkirk	65	70
Felixstowe	Le Havre	437	402
Felixstowe	Valencia	34	34
Felixstowe	Algeciras	66	492
Felixstowe	Taranto	108	124
Felixstowe	Antwerp	1092	659
Felixstowe	Rotterdam	2565	5372
Felixstowe	Ningbo	0	1
Felixstowe	Dalian	1	1
Felixstowe	Guangzhou	1	1
Felixstowe	Xiamen	1	1
Felixstowe	Tianjin	2	1
Felixstowe	Qingdao	4	1
Felixstowe	Shanghai	3	4
Felixstowe	Shenzhen	3	1
Felixstowe	Kaohsiung	2	3
Felixstowe	Port Kelange	3	15
Felixstowe	Ho Chi Minh	2	1
Felixstowe	Busan	3	5
Felixstowe	Kobe	1	1
Felixstowe	Nagoya	1	1
Felixstowe	Tokyo	1	1
Felixstowe	Yokohama	1	1
Felixstowe	Hong Kong	3	2
Felixstowe	Singapore	13	26
Felixstowe	Total	6266	12171

The total expected waiting time for full containers at port Felixstowe has been increased by 88.5% which indicates an increased expected waiting cost for the routes calling at port Felixstowe. In terms of changing expected waiting time distinguished by destination between Scenario 0 and Scenario 1, most of them are expected higher waiting cost except for Le

Havre, Antwerp, Tianjin, Qingdao, Shenzhen, Ho Chi Minh and Hong Kong. The average depreciation value is assumed to be 140 dollars per container per week. And 7 dollars per container per week is set as the rental cost of container. As a result, 868,035 dollars are expected to be paid as an extra waiting cost by the shipping lines for the full containers handled at port Felixstowe. When it comes to the expected waiting time for empty container, it is shown in Table 6.15 as below. As can be seen from the table, empty containers are expected less waiting time at port Felixstowe. Since only rental cost of container is considered in the perspective of empty container, 5,642 dollars are expected to be discounted.

Table 6.15 – Expected waiting time for empty containers at Felixstowe (container·week)

Port	Scenario 0	Scenario 1
Felixstowe	1647	841

As to the port surcharge, the dual variables regarding surcharges at port Felixstowe for full and empty containers are presented. Since destinations have to be distinguished for full containers, Tables 6.16 and 6.17 present the dual variables for full container through comparison between Scenario 0 and Scenario 1 according to the changing pattern with respect of destinations.

Table 6.16 – Dual variable distribution unchanged at Felixstowe by destinations

(\$/container/week)

From	To	Destination	Route	Scenario 0	Scenario 1
Felixstowe	Rotterdam	Zeebrugge	Silk Express	147	147
Felixstowe	Rotterdam	Thamesport	Silk Express	147	147
Felixstowe	Rotterdam	Dunkirk	Silk Express	147	147
Felixstowe	Rotterdam	Le Havre	Silk Express	147	147
Felixstowe	Rotterdam	Algeciras	Silk Express	147	147
Felixstowe	Rotterdam	Taranto	Silk Express	147	147
Felixstowe	Rotterdam	Rotterdam	Silk Express	147	147
Felixstowe	Ningbo	Ningbo	NE1	147	147
Felixstowe	Rotterdam	Kaohsiung	Silk Express	147	147
Felixstowe	Singapore	Busan	NE1	147	147
Felixstowe	Singapore	Singapore	NE1	147	147

With respect of the destinations Zeebrugge, Thamesport, Dunkirk, Le Havre, Algeciras, Taranto, Rotterdam and Kaohsiung, only one specific leg or task committed on route Silk Express connecting Felixstowe and those destinations causes port surcharge. The same situation can be observed on route NE1 in terms of destinations Ningbo, Busan and Singapore. And also, the distribution of dual variable remains unchanged between Scenario 0 and Scenario 1 which are equal to 147 dollars per container per week. However, the port surcharge paid by the leg may vary due to changing container volumes from Scenario 0 to Scenario 1. For example, flows of full containers on leg Felixstowe – Rotterdam en route to destination Zeebrugge increase from 406 containers in Scenario 0 to 1253 containers in Scenario 1. As a result, 124,509 dollars extra port surcharge is paid in Scenario 1.

The dual variables help to detect specific legs or tasks where port surcharge occurs. In the meantime, the distribution across all the active routes serving at port Felixstowe towards different destinations can be easily extracted from Appendix 7. Taking Felixstowe – Hamburg pair for example, the changing container traffic volumes on routes NE3 and Silk Express are outline in Table 6.17. Combined with the detail in Appendix 7 regarding Felixstowe – Hamburg pair, the extra port surcharge that route NE3 paid under Scenario 1 is 207,510 dollars per week. In the meantime, route Silk Express saves 8,619 dollars per week.

Table 6.17 – Container volumes on legs of routes NE3 and Silk Express (containers/week)

From	To	Destination	Route	Scenario 0	Scenario 1
Felixstowe	Hamburg	Hamburg	NE3	507	1860
Felixstowe	Rotterdam	Hamburg	Silk Express	507	0

Since empty container repositioning does not have to distinguish the destination, Table 6.18 presents dual variables for empty container through comparison between Scenario 0 and Scenario 1. Port surcharge paid by the empty container in this model considers the rental cost of the container only.

As can be seen from Table 6.18, only route NE1 causes port surcharge in both scenarios. There are two specific legs where the port surcharge transfers from one to the other with a cost reduction for 5,600 dollars per week.

Table 6.18 – Dual variable distribution for empty container at Felixstowe (\$/container/week)

From	To	Route	Scenario 0	Flow	Scenario 1	Flow
Felixstowe	Antwerp	NE1	7	1647	0	0
Felixstowe	Ningbo	NE1	0	34	7	841

When it comes to Scenario 2, the average ship capacity on AE10 has been reduced from 8300 TEU to 6500 TEU. There are mainly two aspects that Scenario 2 expects which are lower fixed costs through the deployment of smaller container ships and more container traffic diverted to route AE10. In Tables 6.19 and 6.20, details are outlined in the perspectives of cost and container traffic on route AE10.

As depicted in Table 6.19, 1,242,957 dollars are saved in terms of fixed cost through deploying small container ship. The reduction is mainly driven by lower charter rate, bunker cost and port cost (excluding container handling cost). The total container traffic volume on route AE10 increases. This can be verified from the flow assignment on route AE10 in both Scenario 0 and Scenario 2 in Table 6.20. In the meantime, the total cost of route AE10 remains almost identical between Scenario 0 and Scenario 2. Therefore, unit costs of route AE10 is reduced by 41.5 dollars per container per day. However, as shown in Table 6.8, total cost of the whole network has increased by 2% which indicates that the flow diversification cause significant cost increase on some routes. Table 6.21 classifies 27 routes in the network according to the changing characters of the route unit costs. The unit costs of each route under both scenarios are presented in Appendix 6.

Table 6.19 – Cost facts on route AE10 (\$)

	Scenario 0	Scenario 2
Fixed Cost	9,808,750	8,565,793
Unit Cost	323.4	281.9
Total Cost	13,641,335	13,774,198

Table 6.20 – Container traffic on route AE10 (Link details refer to Appendix 5)

Links on route AE10															
Scenario	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306
0	1105	0	0	0	0	675	2702	2713	2720	2720	1129	0	729	0	318
2	1047	238	0	0	0	2152	2704	2711	2717	2722	2340	0	0	93	1428

Table 6.21 – Classification of routes under Scenario 2

Route ID	Gain	Route ID	Lose	Route ID	Neutral
1	EUC	3	FAL12	0	EUB
5	CEX	6	AEX	2	FAL1
10	FAL15	8	FAL2	4	SCX
11	FAL3	15	NE3	7	AEX1
13	NE2	17	AEC2	9	CES2
14	NE1	19	AE1	12	NE4
16	NE5	20	AE2	21	AE7
18	EUD	26	EUA	22	AE8
24	AE10			23	AE9
25	Silk Express				

Tables 6.22 and 6.23 dictate total link flows including full and empty containers on routes EUD and AE1 in order to give examples on situations routes gain and lose attractiveness respectively.

Table 6.22 – Link flow on route EUD for scenarios 0 and 2 (Link details refer to Appendix 5)

Links on route EUD														
Scenario	215	216	217	218	219	220	221	222	223	224	225	226	227	228
0	4256	6050	4717	156	5797	5797	6050	0	0	0	0	0	1750	6050
2	2373	6050	5795	5605	5834	5834	6050	0	976	1558	0	0	5562	6051

Table 6.23 – Link flow on route AE1 for scenarios 0 and 2 (Link details refer to Appendix 5)

Links on route AE1														
Scenario	229	230	231	232	233	234	235	236	237	238	239	240	241	242
0	8318	8314	8320	8307	8301	8302	8303	8305	5769	8307	8305	8306	8304	8304
2	8316	8314	8318	8307	7559	8045	3740	0	538	506	8300	0	8299	8299

The accumulated number of containers that have been diverted onto the links of route EUD is 11,065, whereas the links of route AE1 becomes less attractive by losing 35,224 containers. This also can be confirmed through Table 6.24 where the unit costs of routes EUD and AE1 are presented in Scenario 0 and Scenario 2.

Table 6.24 – Unit costs of routes EUD and AE1 in scenarios 0 and 2 (\$/container/day)

	EUD	AE1
Scenario 0	262.7	61.9
Scenario 2	182.1	158.9

As to the port traffic in the network, it is presented in Table 6.25.

Table 6.25 – Port traffic in the network between Scenario 0 and Scenario 2 (container moves/week)

	Scenario0	Scenario2	Scenario0	Scenario2	Scenario0	Scenario2
PortName	FullTotal	FullTotal	EmptyTotal	EmptyTotal	Total	Total
Aarhus	2898	2534	442	442	3340	2976
Gothenburg	2806	2322	770	770	3576	3092
Gdansk	1499	1296	132	132	1631	1428
Bremerhaven	21493	18774	6775	4136	28268	22910
Zeebrugge	16290	7642	1223	1340	17513	8982
Hamburg	48592	45984	6482	9894	55074	55878
Southampton	4640	4644	761	1381	5401	6025
Thamesport	2367	1975	199	199	2566	2174
Felixstowe	23038	23038	1681	1681	24719	24719
Dunkirk	647	647	117	117	764	764
Le Havre	14763	14507	2741	3360	17504	17867
Valencia	11204	11204	1986	1986	13190	13190
Algeciras	10149	12469	1653	1653	11802	14122
Taranto	2761	2856	606	606	3367	3462
Antwerp	37832	45088	16839	13121	54671	58209
Rotterdam	72112	73043	4545	4545	76657	77588
Ningbo	71538	74873	11106	7771	82644	82644
Dalian	14359	14797	994	994	15353	15791
Fuzhou	3698	3698	270	270	3968	3968
Guangzhou	34051	33865	2449	2449	36500	36314

Xiamen	20481	29459	1023	1023	21504	30482
Tianjin	42852	41732	2320	3893	45172	45625
Qingdao	57921	55520	2245	2245	60166	57765
Shanghai	114097	110353	8052	8052	122149	118405
Shenzhen	134609	131402	8998	12204	143606	143606
Kaohsiung	36294	45603	1878	2430	38172	48033
Port Kelange	42807	41125	6347	1674	49154	42799
Tanjung Pelepas	27875	20713	1320	1320	29195	22033
Vung Tao	736	736	19	19	755	755
Ho Chi Minh	10783	10831	779	779	11562	11610
Busan	44802	39705	4510	2937	49312	42642
Gwangyang	11296	10084	3106	4318	14402	14402
Kobe	13198	13198	4483	4483	17681	17681
Nagoya	12322	14322	2303	2303	14625	16625
Hakata	5372	5094	158	158	5530	5252
Shimizu	2672	2920	84	162	2756	3082
Tokyo	12176	12016	836	836	13012	12852
Yokohama	10176	8678	613	613	10789	9291
Hong Kong	163260	145569	3408	3408	166668	148977
Singapore	108721	108278	13572	13024	122293	121302

The port traffic volume at each port indicates the changing pattern of attractiveness in terms of full and empty containers respectively. Full container volume at port Kaohsiung increases by 9,310 container moves per week, whereas port Hong Kong loses a lot with a reduction of 17,691 container moves per week. When it comes to the empty container traffic, 25 ports have no change on traffic. In the meanwhile, port Hamburg and port Kelange are the two ports which gain and lose most by 3412 and 4673 container moves respectively. Taking full and empty containers as a whole, port Kaohsiung has 9861 extra container traffic which generates 1,372,434 dollars per week extra revenue. And port Hong Kong loses the most container traffic which is all full container traffic and causes a revenue deduction of 2,600,577 dollars per week.

Since port Ningbo reaches the capacity limit in both Scenario 0 and Scenario 2, it is a good example to make as dual variable analysis on port surcharge. Dual variables for full container in Scenario 0 and Scenario 2 are presented in Tables 6.26 and 6.28.

Table 6.26 – Dual variable distribution unchanged at Kaohsiung by destinations

(\$/container/week)

From	To	Destination	Route	Scenario 0	Scenario 2
Ningbo	Guangzhou	Guangzhou	FAL3	147	147

Only one specific leg or task committed on route FAL3 connecting Ningbo and Guangzhou deduces port surcharges. In the meantime, the distribution of dual variable remains unchanged between Scenario 0 and Scenario 2 which are equal to 147 dollars per container per week. However, container volumes on the same leg under two scenarios may vary. Flows of full containers on leg Ningbo – Guangzhou en route to destination Guangzhou increase by 181 full containers, therefore extra port surcharge needs to be paid which is 26,607 dollars per week.

As can be seen from Appendix 8, routes FAL2, FAL3, FAL15, NE1, NE3, EUD, AE1 and Silk Express are routes caused port surcharge at port Kaohsiung. The distribution across all the active routes serving at port Ningbo towards different destinations can be easily extracted from Appendix 8. Taking Ningbo – Shenzhen pair for example, the changing container traffic volumes on routes FAL2, FAL3, NE5 and EUD are presented in Table 6.27. Combined with the data in Appendix 8 with respect of Ningbo – Shenzhen pair, the extra port surcharge that routes NE5 paid under Scenario 2 is 13,248 dollars per week, whereas route FAL2 causes no

port surcharge. In the meanwhile, routes FAL3 and EUD have to pay 9,408 and 37,632 dollars per week respectively.

Table 6.27 – Container volumes on legs of routes FAL2, FAL3 NE5and EUD
(containers/week)

From	To	Destination	Route	Scenario 0	Scenario 2
Ningbo	Shenzhen	Shenzhen	FAL2	348	0
Ningbo	Shenzhen	Shenzhen	FAL3	348	448
Ningbo	Shenzhen	Shenzhen	NE5	348	448
Ningbo	Shenzhen	Shenzhen	EUD	0	448

As to the dual variables for empty container, port surcharge occurs only on the leg Ningbo – Shanghai of route NE1. Considering the changing container volume between Scenario 0 and Scenario 2, 11,676 dollars per week can be saved in Scenario 2.

In Table 6.28, the expected waiting times for full and empty containers at all the ports in the network are outlined as below.

Table 6.28 – Expected waiting time for full and empty containers for all ports
(container·weeks)

Port	S0Full	S2Full	S0Empty	S2Empty
Aarhus	906	989	188	188
Göteborg	1048	767	582	582
Gdansk	542	500	66	66
Bremerhaven	7267	6455	2702	2016
Zeebrugge	5398	2559	1223	972
Hamburg	9411	9014	2555	4704
Southampton	1940	976	761	1071

Thamesport	853	641	100	100
Felixstowe	6266	9367	1647	560
Dunkirk	189	175	117	59
Le Havre	4148	3616	1052	1145
Valencia	3809	4479	1986	1168
Algeciras	1943	3778	827	827
Taranto	1182	1230	507	507
Antwerp	13873	11994	3940	3395
Rotterdam	21018	26604	2511	1629
Ningbo	15473	15281	4404	2736
Dalian	4897	5286	0	0
Fuzhou	1984	1984	0	0
Guangzhou	12710	13578	0	0
Xiamen	7371	12369	0	0
Tianjin	13591	17372	207	994
Qingdao	19271	18636	0	0
Shanghai	26411	27293	1023	1023
Shenzhen	40075	42161	1153	2195
Kaohsiung	15181	15303	0	276
Port Kelang	14178	13952	2355	19
Tanjung Pelepas	8501	7907	0	0
Vung Tao	377	376	0	0
Ho Chi Minh	5765	5792	0	0
Busan	15435	13812	787	158
Gwangyang	5851	5009	1351	1957
Kobe	4601	4307	1383	1383
Nagoya	4771	5867	836	797
Hakata	2357	2488	0	0
Shimizu	721	816	0	39
Tokyo	5637	5412	0	0
Yokohama	4564	4418	0	0
Hong Kong	47787	41972	1296	1327
Singapore	31429	33417	6669	3747
Total	388731	397952	42228	35640

The total expected waiting time for full container at all ports increases by 2.4%, whereas the total expected waiting time for empty containers at all ports decreases by 15.6%. Taking the significant difference on unit dwell cost between full and empty containers in to account, the total dwell cost increases by 1,309,371 dollars per week. In the meantime, 7,373,956 dollars

per week extra sailing cost is deduced in Scenario 2. As a result, the total cost raised by 8,683,327 dollars per week. This can be verified from Table 6.8.

Table 6.29 – classification of ports under Scenario 2 for full container

Port ID	Gain	Port ID	Lose	Port ID	Neutral
1	Gothenburg	0	Aarhus	18	Fuzhou
2	Gdansk	8	Felixstowe		
3	Bremerhaven	11	Valencia		
4	Zeebrugge	12	Algeciras		
5	Hamburg	13	Taranto		
6	Southampton	15	Rotterdam		
7	Thamesport	17	Dalian		
9	Dunkirk	19	Guangzhou		
10	Le Havre	20	Xiamen		
14	Antwerp	21	Tianjin		
16	Ningbo	23	Shanghai		
22	Qingdao	24	Shenzhen		
26	Port Kelange	25	Kaohsiung		
27	Tanjung Pelepas	29	Ho Chi Minh		
28	Vung Tao	33	Nagoya		
30	Busan	34	Hakata		
31	Gwangyang	35	Shimizu		
32	Kobe	39	Singapore		
36	Tokyo				
37	Yokohama				
38	Hong Kong				

Table 6.30 – classification of ports under Scenario 2 for empty container

Port ID	Gain	Port ID	Lose	Port ID	Neutral
3	Bremerhaven	5	Hamburg	0	Aarhus
4	Zeebrugge	6	Southampton	1	Gothenburg
8	Felixstowe	10	Le Havre	2	Gdansk
9	Dunkirk	21	Tianjin	7	Thamesport
11	Valencia	24	Shenzhen	12	Algeciras
14	Antwerp	25	Kaohsiung	13	Taranto
15	Rotterdam	31	Gwangyang	17	Dalian
16	Ningbo	35	Shimizu	18	Fuzhou
26	Port Kelange	38	Hong Kong	19	Guangzhou
30	Busan			20	Xiamen
33	Nagoya			22	Qingdao
39	Singapore			23	Shanghai
				27	Tanjung Pelepas
				28	Vung Tao
				29	Ho Chi Minh
				32	Kobe
				34	Hakata
				36	Tokyo
				37	Yokohama

Tables 6.29 and 6.30 present the detail of expected waiting time for both full and empty containers at all ports through comparing Scenario 2 with Scenario 0. Gain means that expected waiting time at a particular port in Scenario 2 is less than in Scenario 0, where lose indicate more waiting time is expected at a particular port in Scenario 2 compared with Scenario 0.

6.4 Findings and summary

The findings mainly regarding the differences and improvements from numerical example to full – scale network are discussed. In the meantime, conclusions based on the analysis of the results from the Europe-Far East case study are presented.

6.4.1 Findings

The key difference between numerical example and case study is about the scale of the network. As a result, two problems deduced are complexity of multi Origin-Destination pairs and efficiency of the model regarding computation time and memory usage. Since many container flow assignment models are computational expensive for large shipping networks, the model proposed in this thesis is computationally efficient. Implemented in the CPLEX, it takes one minute to run a full scale network as presented in this case study on an Intel Core 2 computer.

The increasing scale of Origin-Destination matrix causes increasing imbalance on the number of legs between full flows and empty flows. Because the full flow has to be distinguished by destination, however, the empty flow does not. Therefore, the structure of the VBA coding in Excel needs to be redefined in order to make sure the unit costs are calculated correctly.

In this model, the initial unit cost for each route is set as 0 dollar per container per day. In the numerical example, scale of network is quite small which does not cause any issue. However, in practice, a proper estimation of the unit cost of each route would be very useful in terms of improving computational efficiency in the case study. Therefore, the method applied in the case study has been improved by breaking the model operation into two stages.

- Generating initial unit costs of each route.
- Reboot the model every session (50 iterations) with the unit costs updated from last session.

In other word, the model is running session by session with an updated unit cost in order to enhance computational efficiency. Table 6.31 presents the improvement measured by the RRC (Relative Rate of Change) for Scenario 0 in the case study. The number of iterations needed to reach the equilibrium has been reduced dramatically with respect to the stop criteria, and so does the time.

Table 6.31 – RRC for Scenario 0 using two methods (%)

Iteration	Original	New
50	22.5	22.5
100	16.3	8.1
150	10.3	0.8
200	8.1	0.4
250	6.9	0
300	6.1	0

The method illustrated helps to find a proper initial unit cost of each route for each session. As a result, the computation efficiency has been improved dramatically with respect to the time consumed to satisfy the stop criteria. And also, all final results in the case study are achieved with the value of RRC equal to 0 across all the routes in the network.

Another important issue is about validation of the frequency-based container flow assignment. This thesis proposes a promising first step towards a global maritime container assignment model. However, proposing an effective approach in terms of validation of the model is a rather difficult work. Firstly, there is no sufficient data source to construct a more realistic Origin-Destination matrix. Secondly, some cost related data are sourced indirectly from shipping lines and assumed to be universal for all routes. Finally, real data for benchmarking are difficult to find, because the relative parties in the industry are reluctant to share data. As a result, this thesis contributes to providing a guideline for validation of the model.

The guideline is structured into two parts. First, improved data source regarding the Origin-Destination matrix construction and cost factors are essential. Second, independent data source are needed to benchmark the results of the model in terms of the involved key variables.

6.4.2 Summary

In this chapter, starting with a brief introduction of the Europe-Far East trade lane, the cost-based container flow assignment model is applied on a full scale network with three scenarios simulated. All the functions of the model have been tested with respect of proper assumptions on Origin-Destination matrix construction and cost factors.

Two aspects regarding the market review of Europe-Far East trade lane are presented which are trade volumes and commodities types. When it comes to the services provided on the Europe-Far East trade lane, many aspects including service summary, service pattern,

capacity utilisation and freight rate have been covered. In this section, a blueprint of the target network has been illustrated which provides a sufficient background for the case study.

An Origin-Destination matrix has been successfully generated through applying doubly constrained gravity model. The sailing distance between ports in the network is considered as the fundamental attractiveness factor for the gravity model. Although many other factors may affect the weight assignment across the ports in the network, sailing distance should be sufficient enough to establish a foundation at this early stage. The network is built up based on the published container liner services operating on the Europe-Far East trade lane. According to the principles of virtual network construction, each possible task or leg has been pointed out by distinguishing its origin, destination, route index and container handling cost type.

The cost-based container assignment model is applied to three scenarios. The results pertaining to total cost, flow, port traffic, expected waiting time and port surcharge are presented. First of all, Scenario 0 simulates the current container flow assignment. And then, Scenario 1 regarding policy application on port expansion scheme is executed. As to the results, the total cost of the network has been reduced. The attractiveness of port Felixstowe has been enhanced. This can be verified from the increasing port traffic and port revenue. In the meantime, the port traffic at the port of Felixstowe still reached its capacity limit after 20% extra port handling capacity was deployed. In other words, further expansion is needed. However, in practice, the evaluation of a port expansion scheme does not consider the port revenue only. Many other aspects need to be assessed such as impact on land transport modes

and environmental issues. That would link to the further development of this model in the future.

When it comes to Scenario 2, a reduction in average ship capacity on AE10 from 8300 TEU to 6500 TEU is considered. There are two reasons contributing to the reduction on the unit cost of route AE10 which are the deployment of smaller container ship and increased container volume. However, the total cost of the network increases which indicates that some routes become less attractive in Scenario 2. And also, the benefit gained by routes like AE10 is beyond the cost paid by the other routes.

To conclude, the model is proved to work successfully and efficiently on a full scale global maritime network. Such a tool, if it were fully developed, would be useful to shipping lines, port authorities, shippers, terminal operating companies, national and regional planning authorities. Many policy and strategy applications could be simulated such as port expansion and ship capacity reduction. The application of this model in terms of the decision level would be at strategic level (e.g. shipping network design) and tactical level (e.g. the container flow optimization for a given shipping network). It seems that the current model is not applicable to dynamic operational level since the time dimension is not considered explicitly. Beside this, a couple of limitations of this model could be identified such as efficiency of virtual network construction, more comprehensive justification of the probability distribution function. And also, it can be validated from independent data though this is very difficult at the current stage.

Chapter 7

Conclusions and recommendations

In this final chapter of this thesis, conclusions and recommendations for future research are given based on the findings of previous chapters. In the meantime, the main contributions from this research and results are summarised.

7.1 Conclusions

The main aim of this research was to formulate a new approach to a maritime container flow assignment model at a global level, which represents full and empty container flows within the network simultaneously. Taking an origin-destination matrix of full containers, service and cost data as input, the model minimizes total expected cost and outputs link flows and implicitly port choice. The following conclusions are structured according to the objectives set out at the beginning of this thesis:

- Investigate the characters of the container liner shipping system including evolution of liner shipping business and analysis of the liner shipping market and its competitive conduct.
- Determine the effects of containerisation and globalization on liner shipping business especially on port systems. As the liner shipping service pattern has been changing dramatically, the functions and key components of container port systems need to be reviewed thoroughly.
- Identify the principles of the proposed frequency-based container assignment model. Previously freight flows have been modelled by the conventional four-step approach using traffic assignment for the fourth step. The approach proposed here is based on the observation that the maritime container assignment problem shares a greater affinity with transit assignment rather than with traffic assignment conventionally applied in the four-step approach. In the meantime, integrating empty container repositioning with full container assignment has raised great interest, especially from container shipping lines.
- Formulate a method to minimise the total expected cost (as opposed to expected time) of a global maritime network, but which is at the same time less data intensive,

computationally efficient and accurate enough to be deployed in various policy and strategy applications.

In Chapter 2, the first and the second objectives are achieved through the reviews of the evolution of liner shipping, the contemporary liner shipping business and port systems. Many key aspects were highlighted such as the development of liner shipping industry, the effects of containerization, key components, the state of competition in the current liner shipping market and key factors influencing port choice. It noted the prospects for innovation in the liner shipping industry in terms of technologies and operations.

The lessons learned from the above can be concluded as follows. First, the process of containerization has connected the whole world with a competitive market successfully providing a cost effective service. Second, the service pattern and competition has changed dramatically due to containerization and globalization. An extensive hub-and-spoke global container network is operating at the centre of the liner business. Third, the port system has experienced a tough time in order to keep pace with the changes in liner shipping. Therefore, to solve port choice problem becomes a challenging problem with complex circumstances and many stakeholders involved.

Chapter 3 reviews the literature contributing to the foundation of this research which includes port choice modelling, freight flow models and empty container repositioning studies. This addresses the third objective.

Firstly, the port choice literature leads to the understanding that ports are nodes in global supply chains. Secondly, the review of freight transport modelling confirms that the conventional four-step approach remains the basis of most freight flow models. The limitations of current freight flow models, especially container assignment models, are outlined. As a result, two key principles are deduced. One is that the maritime container assignment problem shares a greater affinity with transit assignment rather than with traffic assignment conventionally applied in the four step approach. The other one is that a macroscopic approach is more feasible in the absence of access to confidential information from individual shipping lines. Last but not the least, there is a review of empty container repositioning which motivates the integration of empty container flows with full container flows. An analysis of the ownership, the deployment pattern of the container fleet, the levels of empty container balancing and the decision making of repositioning leads to the conclusion that ocean carriers prefer long-term leases and try to integrate the leased equipment with their own in order to achieve lower unit costs. To conclude, a model capable of representing full and empty container flows at a global level would be useful to almost all stakeholders in the container liner shipping industry, including shippers, shipping lines, port authorities, terminal operating companies, regional and national planning authorities, marine insurance companies, and others.

Due to the limitations and principles emerging from the reviews, the Spiess and Florian (1989) method is adopted and transferred into the domain of maritime container transport. Chapter 4 presents the first attempt to formulate a maritime container assignment model measured in time units. It consists of an O-D matrix, a network and liner services with sailing time and frequency. The numerical example presents the capabilities of the model covering full and empty container flows, port traffic and dual variable interpretation.

In Chapter 5, considerations regarding container ship size and cost factors are taken into account to make a further step to transform the model from time-based version to cost-based version. As a result, the effects of sailing time, service frequency, port capacity, link capacity and cost factors on the pattern of full and empty container flows and therefore on port choice are presented. In the meantime, the method for constructing the virtual network used in the case study of Europe-Far East trade lane is finalised.

A full scale network of Europe-Far East trade lane is deployed in Chapter 6 in order to interpret the cost-based global maritime container flow assignment model in real world. First, the framework of the case study is defined by a market review and the services provided. Second, two scenarios are tested for the network constructed mainly regarding port and link capacity. The results are interpreted by comparing each scenario with the base results without any policy or strategy applied. Finally, the results are analyzed and interpreted thoroughly in terms of unit costs and dual variables.

To conclude that the main contributions of this work could be categorized in the following aspects the computational efficiency, the applicability to large scale real liner shipping network and strategic and tactical decision making support.

7.2 Recommendations

This section outlines a number of research directions which can be taken to improve the model formulated in this study. The following areas would merit further research:

- Origin-Destination (O-D) matrix generation needs to be enhanced. Since the model mainly focuses on container assignment, less attention is paid to investigating a systematic approach of generating an O-D matrix. A conventional gravity model where distance is the only factor is applied to produce an O-D matrix for the case study. There are a number of aspects would merit further investigation. First, the quality of port import and export information needs to be improved. Although it is difficult to get confidential disaggregate data from individual port authorities, proper aggregate data at national level could be sufficient. Second, the gravity model could be improved by incorporating more factors such as hinterland coverage, import-export pattern and status of ports in the network.
- More automated procedure of constructing virtual network has to be finalised. The current method for creating virtual legs requires manually identifying all the possible tasks along each route. In order to achieve the computational efficiency on the network construction, a more comprehensive analysis on the route pattern is essential. The main purpose is to eliminate impossible tasks, rationalize the scale of the virtual network and automate the procedure in programming codes.
- Possible improvement on the probability distribution function regarding the flow assignment mechanism needs to be assessed. That would result in converting the current static assignment model to a dynamic one. A time circle would probably be introduced at each node or port in order to present the attractiveness for each route serving the port at different times.
- The validation procedure for the model has to be enhanced. The calibration is processed along with the analysis and interpretation of the results and dual variables

due to the lack of independent data. The common understanding on operations and economics of the container liner shipping industry is applied to facilitate that procedure. Therefore, improved data sources become a vital component.

- Expansion of the current maritime container assignment model is possible. This would mainly involve intermodal transportation, specifically rail and truck, to be introduced and incorporated into the model. One issue worth noting is how to define the service frequency of the truck system. As a result, the operation pattern of the truck system has to be analyzed.

Publications related to this work

Peer-reviewed journal publications

Liu, X. and Bell, M.G.H. (2012) Port Choice: A cost-based maritime container assignment model, *Transportation Research B*. (To be published)

Bell, M.G.H., Liu, X. and et al. (2011) A frequency-based maritime container assignment model, *Transportation Research B*, 45(8), 1152-1161.

Conference proceedings

Liu, X. and Bell, M.G.H. (2012) Port Choice: A cost-based maritime container assignment model, 1st European Symposium on Quantitative Methods in Transportation Systems, Lausanne, Switzerland.

Bell, M.G.H., Liu, X. and et al., (2010) A frequency-based maritime container assignment model, *Transportation Research Board Annual Meeting*, Washington D.C., USA.

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Appendices

Appendix 1 Service summary on the Europe-Far East route (July 1, 2006)

Carrier/String	Loop	Freq. (Days)	Rvoy. (Days)	No. of Vessels	Ave. Capacity (TEU)
Grand Alliance	EU1	7	56	8	6433
	EU2	7	56	8	6156
	EU3	7	56	8	8404
	EU4	7	63	9	7302
CKYH Alliance	JES/AE2	7	56	8	5593
	AE1/AES	7	56	8	5560
	NCX	7	56	8	8457
	AEX	7	56	8	5544
	FEX	7	56	8	5455
	SCX	7	49	7	5567
	PDS	7	84	12	4692
	JEX	7	56	8	6281
New World Alliance	AEX	7	56	8	5882
	CEX	7	56	8	5751
	SCX	7	49	7	5582
	AE1	7	63	9	8867
Maersk Line	AE2	7	63	9	8133
	AE7	7	56	8	8431
	AE8	7	49	7	7163
	AE9	7	49	7	4867
	AE10	7	56	8	5122
	WAE	7	84	12	5860
Evergreen, IMS, HM	CEM	7	56	8	8073
	Silk	7	63	9	9200
MSC	Express				
	Lion service	7	70	10	6613
	Australia service	7	91	13	3077
CMA CGM	FAL	7	56	8	8649
	NCX	7	56	8	6543
China Shipping	AEX1	7	63	9	6936
UASC	AEC	7	70	10	3802
China Shipping/Zim	AEX2	7	63	9	5470
CSAV Norasia	AME	7	56	8	5145
PIL/Wan Hai	(ETE)	7	56	8	2870
CMA CGM/CSCL	AEX5	7	49	7	3039

CMA CGM/CP Ships- Hapag Lloyd/Marfret	(RTW)	7	84	12	2280
Chipolbarok	n/a	12-13	n/a	n/a	500
Rickmers	n/a	15-16	n/a	n/a	600

Appendix 2 Service summary on the Europe – Far East route for case study (Jan, 2010)

Carrier/String	Loop	Freq. (Days)	Rvoy. (Days)	No. of Vessels	Ave. Capacity (TEU)
Grand Alliance	EUA	7	70	10	8700
	EUB	7	84	12	8750
	EUC	7	70	10	8063
	EUD	7	70	10	6050
CKYH Alliance	AEX	7	63	9	9000
	SCX	7	63	9	7750
	NE1	7	56	8	9000
	NE2	7	56	8	8200
	NE3	7	70	10	9000
	NE4	7	63	9	8400
New World Alliance	NE5	7	63	9	6500
	JEX	7	63	9	6700
	CEX	7	70	10	6150
Maersk Line	AE1	7	69	10	8300
	AE2	7	76	11	8400
	AE7	7	76	11	14700
	AE8	7	69	10	13200
	AE9	7	70	10	6500
	AE10	7	77	11	8300
Evergreen, IMS, HM	CEM	7	56	8	9150
MSC	Silk Express	7	77	11	13750
CMA CGM	FAL1	7	59	9	11500
	FAL2	7	70	10	10100
	FAL3	7	60	9	9250
	FAL15	7	63	9	7150
China Shipping/Zim	AEX2	7	63	9	8084
UASC/COSCO	AEC2	7	70	10	6775

Appendix 3 Origins and destinations in the network

0	Aarhus	20	Xiamen
1	Gothenburg	21	Tianjin
2	Gdansk	22	Qingdao
3	Bremerhaven	23	Shanghai
4	Zeebrugge	24	Shenzhen
5	Hamburg	25	Kaohsiung
6	Southampton	26	Port Kelange
7	Thamesport	27	Tanjung Pelepas
8	Felixstowe	28	Vung Tao
9	Dunkirk	29	Ho Chi Minh
10	Le Havre	30	Busan
11	Valencia	31	Gwangyang
12	Algeciras	32	Kobe
13	Taranto	33	Nagoya
14	Antwerp	34	Hakata
15	Rotterdam	35	Shimizu
16	Ningbo	36	Tokyo
17	Dalian	37	Yokohama
18	Fuzhou	38	Hong Kong
19	Guangzhou	39	Singapore

Appendix 4 Sailing distances between container ports (Nautical miles)

	Aarhus	Gothenburg	Gdansk	Bremerhaven	Zeebrugge
Aarhus	0	151	379	456	627
Gothenburg	151	0	406	373	544
Gdansk	379	406	0	746	917
Bremerhaven	456	373	746	0	292
Zeebrugge	627	544	917	292	0
Hamburg	223	326	434	117	347
Southampton	779	696	1069	457	186
Thamesport	652	569	942	349	95
Felixstowe	606	523	896	311	83
Dunkirk	668	585	958	346	76
Le Havre	774	691	1064	452	181
Valencia	2275	2192	2565	1953	1682
Algeciras	1892	1809	2182	1570	1299
Taranto	3121	3038	3411	2799	2528
Antwerp	680	589	970	357	87
Rotterdam	584	501	874	255	87
Ningbo	11000	10919	11300	10680	10409
Dalian	11434	11351	11724	11112	10841
Fuzhou	10640	10557	10930	10318	10047
Guangzhou	10358	10275	10648	10036	9765
Xiamen	10468	10385	10758	10146	9875
Tianjin	11579	11496	11869	11257	10986
Qingdao	11278	11195	11568	10956	10685
Shanghai	11052	10969	11342	10730	10459
Shenzhen	10308	10225	10600	9985	9715
Kaohsiung	10436	10353	10726	10114	9843
port kelang	8618	8535	8908	8296	8025
Tanjung Pelepas	8800	8725	9100	8490	8218
Vung Tao	9461	9380	9800	9150	8880
Ho Chi Minh	9416	9378	9751	9139	8868
Busan	11318	11235	11608	10996	10725
Gwangyang	11270	11185	11560	10950	10675
Kobe	11506	11423	11796	11184	10913
Nagoya	11605	11522	11895	11283	11012
Hakata	11315	11232	11605	10993	10722
Shimizu	11639	11556	11929	11317	11046
Tokyo	11719	11636	12009	11397	11126
Yokohama	11707	11624	11997	11385	11114
Hong Kong	10275	10192	10565	9953	9682
Singapore	8815	8732	9105	8493	8222

	Hamburg	Southampton	Thamesport	Felixstowe	Dunkirk
Aarhus	223	779	652	606	668
Gothenburg	326	696	569	523	585
Gdansk	434	1069	942	896	958
Bremerhaven	117	457	349	311	346
Zeebrugge	347	186	95	83	76
Hamburg	0	505	398	360	394
Southampton	505	0	177	183	161
Thamesport	398	177	0	52	79
Felixstowe	360	183	52	0	79
Dunkirk	394	161	79	79	0
Le Havre	500	114	172	178	142
Valencia	2001	1528	1673	1679	1649
Algeciras	1618	1145	1290	1296	1266
Taranto	2847	2374	2519	2525	2495
Antwerp	405	257	163	141	146
Rotterdam	305	252	153	121	141
Ningbo	10728	10255	10400	10406	10375
Dalian	11160	10687	10832	10838	10808
Fuzhou	10366	9893	10038	10044	10014
Guangzhou	10084	9611	9756	9762	9732
Xiamen	10194	9721	9866	9872	9842
Tianjin	11305	10832	10977	10983	10953
Qingdao	11004	10531	10676	10682	10652
Shanghai	10778	10305	10450	10456	10426
Shenzhen	10034	9560	9706	9712	9680
Kaohsiung	10162	9689	9834	9840	9810
port kelang	8344	7871	8016	8022	7992
Tanjung Pelepas	8535	8060	8200	8205	8170
Vung Tao	9200	8725	8870	8880	8850
Ho Chi Minh	9187	8714	8859	8865	8835
Busan	11044	10571	10716	10722	10692
Gwangyang	11000	10521	10670	10672	10650
Kobe	11232	10759	10904	10910	10880
Nagoya	11331	10858	11003	11009	10979
Hakata	11041	10568	10713	10719	10689
Shimizu	11365	10892	11037	11043	11013
Tokyo	11445	10972	11117	11123	11093
Yokohama	11433	10960	11105	11111	11081
Hong Kong	10001	9528	9673	9679	9649
Singapore	8541	8068	8213	8219	8189

	Le Havre	Valencia	Algeciras	Taranto	Antwerp
Aarhus	774	2275	1892	3121	680
Gothenburg	691	2192	1809	3038	589
Gdansk	1064	2565	2182	3411	970
Bremerhaven	452	1953	1570	2799	357
Zeebrugge	181	1682	1299	2528	87
Hamburg	500	2001	1618	2847	405
Southampton	114	1528	1145	2374	257
Thamesport	172	1673	1290	2519	163
Felixstowe	178	1679	1296	2525	141
Dunkirk	142	1649	1266	2495	146
Le Havre	0	1543	1160	2389	252
Valencia	1543	0	389	973	1753
Algeciras	1160	389	0	1235	1370
Taranto	2389	973	1235	0	2599
Antwerp	252	1753	1370	2599	0
Rotterdam	247	1748	1365	2594	149
Ningbo	10270	8870	9116	8141	10480
Dalian	10702	9302	9548	8573	10912
Fuzhou	9908	8508	8754	7779	10118
Guangzhou	9626	8226	8472	7497	9836
Xiamen	9736	8336	8582	7607	9946
Tianjin	10847	9447	9693	8718	11057
Qingdao	10546	9146	9392	8417	10756
Shanghai	10320	8920	9166	8191	10530
Shenzhen	9575	8175	8452	7447	9785
Kaohsiung	9704	8304	8550	7575	9914
port kelang	7886	6486	6732	5757	8096
Tanjung Pelepas	8070	6670	6910	5935	8280
Vung Tao	8750	7350	7600	6625	8955
Ho Chi Minh	8729	7326	7575	6600	8939
Busan	10586	9186	9432	8457	10796
Gwangyang	10540	9140	9382	8410	10750
Kobe	10774	9374	9620	8645	10984
Nagoya	10873	9473	9719	8744	11083
Hakata	10583	9183	9429	8454	10793
Shimizu	10907	9507	9753	8778	11117
Tokyo	10987	9587	9833	8858	11197
Yokohama	10975	9575	9821	8846	11185
Hong Kong	9543	8143	8389	7414	9753
Singapore	8083	6683	6929	5954	8293

	Rotterdam	Ningbo	Dalian	Fuzhou	Guangzhou
Aarhus	584	11000	11434	10640	10358
Gothenburg	501	10919	11351	10557	10275
Gdansk	874	11300	11724	10930	10648
Bremerhaven	255	10680	11112	10318	10036
Zeebrugge	87	10409	10841	10047	9765
Hamburg	305	10728	11160	10366	10084
Southampton	252	10255	10687	9893	9611
Thamesport	153	10400	10832	10038	9756
Felixstowe	121	10406	10838	10044	9762
Dunkirk	141	10375	10808	10014	9732
Le Havre	247	10270	10702	9908	9626
Valencia	1748	8870	9302	8508	8226
Algeciras	1365	9116	9548	8754	8472
Taranto	2594	8141	8573	7779	7497
Antwerp	149	10480	10912	10118	9836
Rotterdam	0	10475	10970	10113	9831
Ningbo	10475	0	600	415	875
Dalian	10970	600	0	866	1335
Fuzhou	10113	415	866	0	545
Guangzhou	9831	875	1335	545	0
Xiamen	9941	535	1002	208	370
Tianjin	11052	745	198	1011	1480
Qingdao	10751	450	356	715	1183
Shanghai	10525	50	551	460	928
Shenzhen	9780	825	1285	495	50
Kaohsiung	9909	550	1029	249	425
port kelang	8091	2400	2829	2035	1753
Tanjung Pelepas	8270	2205	2635	1840	1560
Vung Tao	8960	1625	2100	1310	1000
Ho Chi Minh	8934	1640	2119	1327	1010
Busan	10791	540	543	760	1223
Gwangyang	10745	495	500	715	1180
Kobe	10979	835	860	999	1455
Nagoya	11078	970	1049	1111	1566
Hakata	10788	560	612	715	1213
Shimizu	11112	1015	1084	1146	1600
Tokyo	11192	1095	1164	1228	1679
Yokohama	11180	1085	1152	1216	1667
Hong Kong	9748	795	1256	462	83
Singapore	8288	2185	2619	1825	1543

	Xiamen	Tianjin	Qingdao	Shanghai	Shenzhen
Aarhus	10468	11579	11278	11052	10308
Gothenburg	10385	11496	11195	10969	10225
Gdansk	10758	11869	11568	11342	10600
Bremerhaven	10146	11257	10956	10730	9985
Zeebrugge	9875	10986	10685	10459	9715
Hamburg	10194	11305	11004	10778	10034
Southampton	9721	10832	10531	10305	9560
Thamesport	9866	10977	10676	10450	9706
Felixstowe	9872	10983	10682	10456	9712
Dunkirk	9842	10953	10652	10426	9680
Le Havre	9736	10847	10546	10320	9575
Valencia	8336	9447	9146	8920	8175
Algeciras	8582	9693	9392	9166	8452
Taranto	7607	8718	8417	8191	7447
Antwerp	9946	11057	10756	10530	9785
Rotterdam	9941	11052	10751	10525	9780
Ningbo	535	745	450	50	825
Dalian	1002	198	356	551	1285
Fuzhou	208	1011	715	460	495
Guangzhou	370	1480	1183	928	50
Xiamen	0	1147	846	585	325
Tianjin	1147	0	412	696	1430
Qingdao	846	412	0	399	1160
Shanghai	585	696	399	0	875
Shenzhen	325	1430	1160	875	0
Kaohsiung	164	1174	876	600	375
port kelang	1863	2974	2673	2447	1705
Tanjung Pelepas	1670	2780	2480	2250	1510
Vung Tao	1135	2250	1950	1670	945
Ho Chi Minh	1150	2264	1963	1687	960
Busan	886	688	502	492	1175
Gwangyang	840	640	450	430	1125
Kobe	1114	1005	808	783	1405
Nagoya	1228	1194	999	933	1515
Hakata	882	777	540	510	1160
Shimizu	1262	1229	1032	967	1550
Tokyo	1348	1309	1114	1048	1625
Yokohama	1336	1298	1101	1036	1615
Hong Kong	287	1401	1100	845	35
Singapore	1653	2764	2463	2237	1495

	Kaohsiung	port kelang	Tanjung Pelepas	Vung Tao	Ho Chi Minh
Aarhus	10436	8618	8800	9461	9416
Göteborg	10353	8535	8725	9380	9378
Gdansk	10726	8908	9100	9800	9751
Bremerhaven	10114	8296	8490	9150	9139
Zeebrugge	9843	8025	8218	8880	8868
Hamburg	10162	8344	8535	9200	9187
Southampton	9689	7871	8060	8725	8714
Thamesport	9834	8016	8200	8870	8859
Felixstowe	9840	8022	8205	8880	8865
Dunkirk	9810	7992	8170	8850	8835
Le Havre	9704	7886	8070	8750	8729
Valencia	8304	6486	6670	7350	7326
Algeciras	8550	6732	6910	7600	7575
Taranto	7575	5757	5935	6625	6600
Antwerp	9914	8096	8280	8955	8939
Rotterdam	9909	8091	8270	8960	8934
Ningbo	550	2400	2205	1625	1640
Dalian	1029	2829	2635	2100	2119
Fuzhou	249	2035	1840	1310	1327
Guangzhou	425	1753	1560	1000	1010
Xiamen	164	1863	1670	1135	1150
Tianjin	1174	2974	2780	2250	2264
Qingdao	876	2673	2480	1950	1963
Shanghai	600	2447	2250	1670	1687
Shenzhen	375	1705	1510	945	960
Kaohsiung	0	1831	1640	1100	1121
port kelang	1831	0	230	870	856
Tanjung Pelepas	1640	230	0	686	666
Vung Tao	1100	870	686	0	25
Ho Chi Minh	1121	856	666	25	0
Busan	908	2713	2525	1980	2005
Gwangyang	858	2663	2475	1930	1955
Kobe	1130	2901	2715	2190	2213
Nagoya	1234	3000	2815	2300	2322
Hakata	893	2710	2525	1970	1995
Shimizu	1268	3034	2850	2330	2355
Tokyo	1349	3114	2930	2405	2430
Yokohama	1337	3102	2920	2990	2418
Hong Kong	342	1670	1485	900	927
Singapore	1621	210	25	680	646

	Busan	Gwangyang	Kobe	Nagoya	Hakata
Aarhus	11318	11270	11506	11605	11315
Gothenburg	11235	11185	11423	11522	11232
Gdansk	11608	11560	11796	11895	11605
Bremerhaven	10996	10950	11184	11283	10993
Zeebrugge	10725	10675	10913	11012	10722
Hamburg	11044	11000	11232	11331	11041
Southampton	10571	10521	10759	10858	10568
Thamesport	10716	10670	10904	11003	10713
Felixstowe	10722	10672	10910	11009	10719
Dunkirk	10692	10650	10880	10979	10689
Le Havre	10586	10540	10774	10873	10583
Valencia	9186	9140	9374	9473	9183
Algeciras	9432	9382	9620	9719	9429
Taranto	8457	8410	8645	8744	8454
Antwerp	10796	10750	10984	11083	10793
Rotterdam	10791	10745	10979	11078	10788
Ningbo	540	495	835	970	560
Dalian	543	500	860	1049	612
Fuzhou	760	715	999	1111	715
Guangzhou	1223	1180	1455	1566	1213
Xiamen	886	840	1114	1228	882
Tianjin	688	640	1005	1194	777
Qingdao	502	450	808	999	540
Shanghai	492	430	783	933	510
Shenzhen	1175	1125	1405	1515	1160
Kaohsiung	908	858	1130	1234	893
port kelang	2713	2663	2901	3000	2710
Tanjung Pelepas	2525	2475	2715	2815	2525
Vung Tao	1980	1930	2190	2300	1970
Ho Chi Minh	2005	1955	2213	2322	1995
Busan	0	50	365	554	116
Gwangyang	50	0	315	504	66
Kobe	365	315	0	245	305
Nagoya	554	504	245	0	494
Hakata	116	66	305	494	0
Shimizu	590	540	279	143	529
Tokyo	669	619	365	226	609
Yokohama	657	607	353	214	597
Hong Kong	1140	1090	1372	1483	1130
Singapore	2503	2453	2691	2790	2500

	Shimizu	Tokyo	Yokohama	Hong Kong	Singapore
Aarhus	11639	11719	11707	10275	8815
Gothenburg	11556	11636	11624	10192	8732
Gdansk	11929	12009	11997	10565	9105
Bremerhaven	11317	11397	11385	9953	8493
Zeebrugge	11046	11126	11114	9682	8222
Hamburg	11365	11445	11433	10001	8541
Southampton	10892	10972	10960	9528	8068
Thamesport	11037	11117	11105	9673	8213
Felixstowe	11043	11123	11111	9679	8219
Dunkirk	11013	11093	11081	9649	8189
Le Havre	10907	10987	10975	9543	8083
Valencia	9507	9587	9575	8143	6683
Algeciras	9753	9833	9821	8389	6929
Taranto	8778	8858	8846	7414	5954
Antwerp	11117	11197	11185	9753	8293
Rotterdam	11112	11192	11180	9748	8288
Ningbo	1015	1095	1085	795	2185
Dalian	1084	1164	1152	1256	2619
Fuzhou	1146	1228	1216	462	1825
Guangzhou	1600	1679	1667	83	1543
Xiamen	1262	1348	1336	287	1653
Tianjin	1229	1309	1298	1401	2764
Qingdao	1032	1114	1101	1100	2463
Shanghai	967	1048	1036	845	2237
Shenzhen	1550	1625	1615	35	1495
Kaohsiung	1268	1349	1337	342	1621
port kelang	3034	3114	3102	1670	210
Tanjung Pelepas	2850	2930	2920	1485	25
Vung Tao	2330	2405	2990	900	680
Ho Chi Minh	2355	2430	2418	927	646
Busan	590	669	657	1140	2503
Gwangyang	540	619	607	1090	2453
Kobe	279	365	353	1372	2691
Nagoya	143	226	214	1483	2790
Hakata	529	609	597	1130	2500
Shimizu	0	128	116	1517	2824
Tokyo	128	0	18	1596	2904
Yokohama	116	18	0	1584	2892
Hong Kong	1517	1596	1584	0	1460
Singapore	2824	2904	2892	1460	0

Appendix 5 Links of all routes on Europe – Far East trade lane (days)

Link ID	From	To	Route ID	Route	Sailing Time
1	Buan	Qingdao	0	EUB	2
2	Qingdao	Shanghai	0	EUB	3
3	Shanghai	Ningbo	0	EUB	1
4	Ningbo	Shenzhen	0	EUB	3
5	Shenzhen	Singapore	0	EUB	5
6	Singapore	Hamburg	0	EUB	22
7	Hamburg	Antwerp	0	EUB	3
8	Antwerp	Southampton	0	EUB	2
9	Southampton	Singapore	0	EUB	27
10	Singapore	Shenzhen	0	EUB	5
11	Shenzhen	Ningbo	0	EUB	5
12	Ningbo	Shanghai	0	EUB	2
13	Shanghai	Qingdao	0	EUB	3
14	Qingdao	Busan	0	EUB	1
15	Ningbo	Shanghai	1	EUC	1
16	Shanghai	Xiamen	1	EUC	2
17	Xiamen	Kaohisung	1	EUC	1
18	Kaohisung	Hong Kong	1	EUC	2
19	Hong Kong	Shenzhen	1	EUC	1
20	Shenzhen	Singapore	1	EUC	4
21	Singapore	Port Kelange	1	EUC	1
22	Port Kelange	Southampton	1	EUC	18
23	Southampton	Rotterdam	1	EUC	2
24	Rotterdam	Hamburg	1	EUC	3
25	Hamburg	Southampton	1	EUC	3
26	Southampton	Singapore	1	EUC	22
27	Singapore	Shenzhen	1	EUC	4
28	Shenzhen	Hong Kong	1	EUC	1
29	Hong Kong	Kaohisung	1	EUC	2
30	Kaohisung	Ningbo	1	EUC	3

31	Southampton	Hamburg	2	FAL1	1
32	Hamburg	Rotterdam	2	FAL2	1
33	Rotterdam	Zeebrugge	2	FAL3	1
34	Zeebrugge	Le Havre	2	FAL4	1
35	Le Havre	Port Kelange	2	FAL5	20
36	Port Kelange	Shenzhen	2	FAL6	4
37	Shenzhen	Dalian	2	FAL7	3
38	Dalian	Tianjin	2	FAL8	1
39	Tianjin	Shanghai	2	FAL9	1
40	Shanghai	Xiamen	2	FAL10	2
41	Xiamen	Hong Kong	2	FAL11	1
42	Hong Kong	Shenzhen	2	FAL12	1
43	Shenzhen	Port Kelange	2	FAL13	4
44	Port Kelange	Southampton	2	FAL14	18
45	Kobe	Nagoya	3	FAL12	2
46	Nagoya	Shimizu	3	FAL13	1
47	Shimizu	Tokyo	3	FAL14	1
48	Tokyo	Hong Kong	3	FAL15	4
49	Hong Kong	Shenzhen	3	FAL16	1
50	Shenzhen	Singapore	3	FAL17	3
51	Singapore	Rotterdam	3	FAL18	18
52	Rotterdam	Hamburg	3	FAL19	2
53	Hamburg	Le Havre	3	FAL20	3
54	Le Havre	Singapore	3	FAL21	20
55	Singapore	Shenzhen	3	FAL22	4
56	Shenzhen	Hong Kong	3	FAL23	1
57	Hong Kong	Kobe	3	FAL24	3
58	Ningbo	Shanghai	4	SCX	1
59	Shanghai	Fuzhou	4	SCX	2
60	Fuzhou	Xiamen	4	SCX	1
61	Xiamen	Hong Kong	4	SCX	2
62	Hong Kong	Shenzhen	4	SCX	1
63	Shenzhen	Singapore	4	SCX	3

64	Singapore	Southampton	4	SCX	19
65	Southampton	Zeebrugge	4	SCX	2
66	Zeebrugge	Hamburg	4	SCX	3
67	Hamburg	Rotterdam	4	SCX	2
68	Rotterdam	Singapore	4	SCX	21
69	Singapore	Hong Kong	4	SCX	4
70	Hong Kong	Ningbo	4	SCX	2
71	Qingdao	Shanghai	5	CEX	2
72	Shanghai	Hong Kong	5	CEX	2
73	Hong Kong	Shenzhen	5	CEX	1
74	Shenzhen	Singapore	5	CEX	5
75	Singapore	Le Havre	5	CEX	21
76	Le Havre	Southampton	5	CEX	2
77	Southampton	Antwerp	5	CEX	2
78	Antwerp	Rotterdam	5	CEX	2
79	Rotterdam	Singapore	5	CEX	23
80	Singapore	Shenzhen	5	CEX	5
81	Shenzhen	Qingdao	5	CEX	5
82	Hakata	Gwangyang	6	AEX	1
83	Gwangyang	Busan	6	AEX	2
84	Busan	Shanghai	6	AEX	2
85	Shanghai	Kaohisung	6	AEX	2
86	Kaohisung	Hong Kong	6	AEX	1
87	Hong Kong	Shenzhen	6	AEX	1
88	Shenzhen	Singapore	6	AEX	4
89	Singapore	Rotterdam	6	AEX	15
90	Rotterdam	Hamburg	6	AEX	2
91	Hamburg	Thamesport	6	AEX	3
92	Thamesport	Singapore	6	AEX	18
93	Singapore	Hong Kong	6	AEX	5
94	Hong Kong	Kaohisung	6	AEX	1
95	Kaohisung	Hakata	6	AEX	6
96	Qingdao	Shanghai	7	AEX1	3

97	Shanghai	Ningbo	7	AEX1	1
98	Ningbo	Shenzhen	7	AEX1	2
99	Shenzhen	Felixstowe	7	AEX1	21
100	Felixstowe	Hamburg	7	AEX1	2
101	Hamburg	Rotterdam	7	AEX1	2
102	Rotterdam	Qingdao	7	AEX1	25
103	Shanghai	Ningbo	8	FAL2	2
104	Ningbo	Shenzhen	8	FAL2	2
105	Shenzhen	Hong Kong	8	FAL2	1
106	Hong Kong	Shenzhen	8	FAL2	1
107	Shenzhen	Port Kelange	8	FAL2	4
108	Port Kelange	Le Havre	8	FAL2	19
109	Le Havre	Rotterdam	8	FAL2	2
110	Rotterdam	Hamburg	8	FAL2	3
111	Hamburg	Zeebrugge	8	FAL2	2
112	Zeebrugge	Port Kelange	8	FAL2	27
113	Port Kelange	Shanghai	8	FAL2	7
114	Qingdao	Shanghai	9	CES2	1
115	Shanghai	Ningbo	9	CES2	1
116	Ningbo	Xiamen	9	CES2	1
117	Xiamen	Shenzhen	9	CES2	1
118	Shenzhen	Tanjung Pelepas	9	CES2	4
119	Tanjung Pelepas	Port Kelange	9	CES2	1
120	Port Kelange	Hamburg	9	CES2	18
121	Hamburg	Rotterdam	9	CES2	1
122	Rotterdam	Antwerp	9	CES2	1
123	Antwerp	Tanjung Pelepas	9	CES2	18
124	Tanjung Pelepas	Qingdao	9	CES2	6
125	Kaohisung	Ningbo	10	FAL15	2
126	Ningbo	Shanghai	10	FAL15	2
127	Shanghai	Hong Kong	10	FAL15	3
128	Hong Kong	Shenzhen	10	FAL15	1
129	Shenzhen	Tanjung Pelepas	10	FAL15	4

130	Tanjung Pelepas	Le Havre	10	FAL15	20
131	Le Havre	Hamburg	10	FAL15	2
132	Hamburg	Rotterdam	10	FAL15	3
133	Rotterdam	Thamesport	10	FAL15	1
134	Thamesport	Taranto	10	FAL15	6
135	Taranto	Tanjung Pelepas	10	FAL15	15
136	Tanjung Pelepas	Kaohisung	10	FAL15	4
137	Qingdao	Ningbo	11	FAL3	1
138	Ningbo	Shenzhen	11	FAL3	2
139	Shenzhen	Guangzhou	11	FAL3	1
140	Guangzhou	Port Kelange	11	FAL3	4
141	Port Kelange	Vung Tao	11	FAL3	2
142	Vung Tao	Le Havre	11	FAL3	19
143	Le Havre	Dunkirk	11	FAL3	1
144	Dunkirk	Zeebrugge	11	FAL3	1
145	Zeebrugge	Hamburg	11	FAL3	1
146	Hamburg	Rotterdam	11	FAL3	1
147	Rotterdam	Zeebrugge	11	FAL3	1
148	Zeebrugge	Southampton	11	FAL3	1
149	Southampton	Port Kelange	11	FAL3	18
150	Port Kelange	Shenzhen	11	FAL3	4
151	Shenzhen	Qingdao	11	FAL3	3
152	Qingdao	Shanghai	12	NE4	2
153	Shanghai	Ningbo	12	NE4	1
154	Ningbo	Hong Kong	12	NE4	3
155	Hong Kong	Singapore	12	NE4	4
156	Singapore	Rotterdam	12	NE4	19
157	Rotterdam	Hamburg	12	NE4	2
158	Hamburg	Antwerp	12	NE4	3
159	Antwerp	Singapore	12	NE4	22
160	Singapore	Hong Kong	12	NE4	4
161	Hong Kong	Qingdao	12	NE4	3
162	Xiamen	Kaohisung	13	NE2	1

163	Kaohisung	Shenzhen	13	NE2	2
164	Shenzhen	Singapore	13	NE2	3
165	Singapore	Rotterdam	13	NE2	19
166	Rotterdam	Hamburg	13	NE2	1
167	Hamburg	Antwerp	13	NE2	4
168	Antwerp	Hong Kong	13	NE2	23
169	Hong Kong	Shenzhen	13	NE2	1
170	Shenzhen	Xiamen	13	NE2	2
171	Ningbo	Shanghai	14	NE1	1
172	Shanghai	Hong Kong	14	NE1	3
173	Hong Kong	Guangzhou	14	NE1	1
174	Guangzhou	Rotterdam	14	NE1	20
175	Rotterdam	Hamburg	14	NE1	3
176	Hamburg	Felixstowe	14	NE1	3
177	Felixstowe	Antwerp	14	NE1	1
178	Antwerp	Singapore	14	NE1	19
179	Singapore	Ningbo	14	NE1	5
180	Tianjin	Dalian	15	NE3	1
181	Dalian	Qingdao	15	NE3	2
182	Qingdao	Ningbo	15	NE3	2
183	Ningbo	Shenzhen	15	NE3	2
184	Shenzhen	Singapore	15	NE3	5
185	Singapore	Rotterdam	15	NE3	19
186	Rotterdam	Felixstowe	15	NE3	3
187	Felixstowe	Hamburg	15	NE3	3
188	Hamburg	Antwerp	15	NE3	3
189	Antwerp	Shenzhen	15	NE3	25
190	Shenzhen	Hong Kong	15	NE3	1
191	Hong Kong	Tianjin	15	NE3	4
192	Gwangyang	Busan	16	NE5	1
193	Busan	Shanghai	16	NE5	1
194	Shanghai	Ningbo	16	NE5	2
195	Ningbo	Shenzhen	16	NE5	2

196	Shenzhen	Singapore	16	NE5	4
197	Singapore	Hamburg	16	NE5	18
198	Hamburg	Rotterdam	16	NE5	3
199	Rotterdam	Le Havre	16	NE5	2
200	Le Havre	Algeciras	16	NE5	4
201	Algeciras	Kaohisung	16	NE5	22
202	Kaohisung	Gwangyang	16	NE5	4
203	Qingdao	Busan	17	AEC2	2
204	Busan	Shanghai	17	AEC2	4
205	Shanghai	Xiamen	17	AEC2	7
206	Xiamen	Shenzhen	17	AEC2	2
207	Shenzhen	Port Kelange	17	AEC2	5
208	Port Kelange	Algeciras	17	AEC2	17
209	Algeciras	Le Havre	17	AEC2	4
210	Le Havre	Rotterdam	17	AEC2	2
211	Rotterdam	Hamburg	17	AEC2	2
212	Hamburg	Antwerp	17	AEC2	3
213	Antwerp	Port Kelange	17	AEC2	15
214	Port Kelange	Qingdao	17	AEC2	7
215	Busan	Qingdao	18	EUD	2
216	Qingdao	Shanghai	18	EUD	2
217	Shanghai	Ningbo	18	EUD	1
218	Ningbo	Shenzhen	18	EUD	3
219	Shenzhen	Ho Chi Minh	18	EUD	3
220	Ho Chi Minh	Vung Tao	18	EUD	1
221	Vung Tao	Singapore	18	EUD	1
222	Singapore	Southampton	18	EUD	20
223	Southampton	Le Havre	18	EUD	2
224	Le Havre	Hamburg	18	EUD	2
225	Hamburg	Rotterdam	18	EUD	2
226	Rotterdam	Singapore	18	EUD	23
227	Singapore	Shanghai	18	EUD	6
228	Shanghai	Busan	18	EUD	2

229	Kobe	Nagoya	19	AE1	1
230	Nagoya	Yokohama	19	AE1	1
231	Yokohama	Ningbo	19	AE1	4
232	Ningbo	Shanghai	19	AE1	1
233	Shanghai	Hong Kong	19	AE1	3
234	Hong Kong	Shenzhen	19	AE1	1
235	Shenzhen	Tanjung Pelepas	19	AE1	5
236	Tanjung Pelepas	Zeebrugge	19	AE1	18
237	Zeebrugge	Felixstowe	19	AE1	1
238	Felixstowe	Rotterdam	19	AE1	3
239	Rotterdam	Bremerhaven	19	AE1	2
240	Bremerhaven	Singapore	19	AE1	22
241	Singapore	Shenzhen	19	AE1	4
242	Shenzhen	Kobe	19	AE1	3
243	Busan	Hakata	20	AE2	1
244	Hakata	Dalian	20	AE2	2
245	Dalian	Tianjin	20	AE2	1
246	Tianjin	Qingdao	20	AE2	2
247	Qingdao	Ningbo	20	AE2	3
248	Ningbo	Shanghai	20	AE2	2
249	Shanghai	Shenzhen	20	AE2	4
250	Shenzhen	Tanjung Pelepas	20	AE2	3
251	Tanjung Pelepas	Le Havre	20	AE2	18
252	Le Havre	Rotterdam	20	AE2	2
253	Rotterdam	Bremerhaven	20	AE2	3
254	Bremerhaven	Hamburg	20	AE2	2
255	Hamburg	Antwerp	20	AE2	2
256	Antwerp	Felixstowe	20	AE2	2
257	Felixstowe	Singapore	20	AE2	22
258	Singapore	Busan	20	AE2	7
259	Qingdao	Ningbo	21	AE7	3
260	Ningbo	Shanghai	21	AE7	2
261	Shanghai	Guangzhou	21	AE7	3

262	Guangzhou	Shenzhen	21	AE7	1
263	Shenzhen	Tanjung Pelepas	21	AE7	4
264	Tanjung Pelepas	Felixstowe	21	AE7	20
265	Felixstowe	Bremerhaven	21	AE7	3
266	Bremerhaven	Rotterdam	21	AE7	1
267	Rotterdam	Guangzhou	21	AE7	34
268	Guangzhou	Qingdao	21	AE7	5
269	Ningbo	Shanghai	22	AE8	1
270	Shanghai	Shenzhen	22	AE8	4
271	Shenzhen	Tanjung Pelepas	22	AE8	4
272	Tanjung Pelepas	Port Kelange	22	AE8	1
273	Port Kelange	Le Havre	22	AE8	18
274	Le Havre	Rotterdam	22	AE8	3
275	Rotterdam	Hamburg	22	AE8	2
276	Hamburg	Rotterdam	22	AE8	3
277	Rotterdam	Zeebrugge	22	AE8	1
278	Zeebrugge	Port Kelange	22	AE8	24
279	Port Kelange	Singapore	22	AE8	1
280	Singapore	Ningbo	22	AE8	7
281	Xiamen	Ningbo	23	AE9	2
282	Ningbo	Shanghai	23	AE9	2
283	Shanghai	Fuzhou	23	AE9	2
284	Fuzhou	Shenzhen	23	AE9	2
285	Shenzhen	Tanjung Pelepas	23	AE9	4
286	Tanjung Pelepas	Rotterdam	23	AE9	19
287	Rotterdam	Bremerhaven	23	AE9	1
288	Bremerhaven	Felixstowe	23	AE9	2
289	Felixstowe	Zeebrugge	23	AE9	2
290	Zeebrugge	Algeciras	23	AE9	6
291	Algeciras	Xiamen	23	AE9	28
292	Gwangyang	Ningbo	24	AE10	1
293	Ningbo	Shanghai	24	AE10	2
294	Shanghai	Shenzhen	24	AE10	4

295	Shenzhen	Tanjung Pelepas	24	AE10	4
296	Tanjung Pelepas	Rotterdam	24	AE10	19
297	Rotterdam	Bremerhaven	24	AE10	2
298	Bremerhaven	Gdansk	24	AE10	3
299	Gdansk	Aarhus	24	AE10	5
300	Aarhus	Göteborg	24	AE10	1
301	Göteborg	Bremerhaven	24	AE10	3
302	Bremerhaven	Rotterdam	24	AE10	2
303	Rotterdam	Singapore	24	AE10	21
304	Singapore	Shenzhen	24	AE10	5
305	Shenzhen	Hong Kong	24	AE10	1
306	Hong Kong	Gwangyang	24	AE10	4
307	Felixstowe	Rotterdam	25	Silk Express	1
308	Rotterdam	Antwerp	25	Silk Express	4
309	Antwerp	Valencia	25	Silk Express	6
310	Valencia	Singapore	25	Silk Express	19
311	Singapore	Hong Kong	25	Silk Express	5
312	Hong Kong	Tianjin	25	Silk Express	3
313	Tianjin	Ningbo	25	Silk Express	3
314	Ningbo	Shanghai	25	Silk Express	1
315	Shanghai	Xiamen	25	Silk Express	3
316	Xiamen	Shenzhen	25	Silk Express	1
317	Shenzhen	Hong Kong	25	Silk Express	1
318	Hong Kong	Shenzhen	25	Silk Express	1
319	Shenzhen	Singapore	25	Silk Express	5
320	Singapore	Valencia	25	Silk Express	16
321	Valencia	Felixstowe	25	Silk Express	8
322	Rotterdam	Hamburg	26	EUA	1
323	Hamburg	Southampton	26	EUA	2
324	Southampton	Le Havre	26	EUA	2
325	Le Havre	Singapore	26	EUA	21
326	Singapore	Hong Kong	26	EUA	4
327	Hong Kong	Shenzhen	26	EUA	1

328	Shenzhen	Kobe	26	EUA	4
329	Kobe	Nagoya	26	EUA	2
330	Nagoya	Shimizu	26	EUA	1
331	Shimizu	Tokyo	26	EUA	1
332	Tokyo	Shenzhen	26	EUA	5
333	Shenzhen	Hong Kong	26	EUA	1
334	Hong Kong	Singapore	26	EUA	4
335	Singapore	Rotterdam	26	EUA	21

Appendix 6 Unit costs of each route under both scenarios (\$ per container per day)

Index	Route	Scenario 0	Scenario 1	Scenario 2
0	EUB	0	0	0
1	EUC	0	0	2141.612987
2	FAL1	0	0	0
3	JEX	1730.970027	1729.77556	1734.098217
4	SCX	0	0	0
5	CEX	0	0	955.082514
6	AEX	782.2796831	0	952.6667729
7	CEM	0	0	0
8	FAL2	167.4703718	0	0
9	AEX2	0	0	0
10	FAL15	82.82058526	71.74124184	71.05564981
11	FAL3	196.7613645	191.5306994	193.027193
12	NE4	0	0	0
13	NE2	0	51.56169949	283.5640362
14	NE1	58.10498563	57.44106793	57.23763598
15	NE3	54.52462768	52.93000004	55.37378513
16	NE5	64.51714527	66.34453056	62.175029
17	AEC2	58.13812572	59.75525393	66.15559771
18	EUD	262.6948404	172.1253287	182.0903251
19	AE1	61.92944292	198.7573076	158.9074803
20	AE2	183.0512532	169.93594	258.6971437
21	AE7	0	0	0
22	AE8	0	0	0
23	AE9	1147.658139	1147.658078	1147.658144
24	AE10	323.3887807	284.9314352	281.9532245
25	Silk Express	87.24561505	70.01321359	65.70568285
26	EUA	129.2348122	123.1098483	132.1781509

Appendix 7 Dual variable distribution changed at Felixstowe by destinations
(\$/container/week)

From	To	Destination	Route	Scenario 0	Scenario 1
Felixstowe	Bremerhaven	Aarhus	AE1	1	0
Felixstowe	Rotterdam	Aarhus	Silk Express	146	147
Felixstowe	Bremerhaven	Göteborg	AE1	1	0
Felixstowe	Rotterdam	Göteborg	Silk Express	146	147
Felixstowe	Bremerhaven	Gdansk	AE1	1	0
Felixstowe	Rotterdam	Gdansk	Silk Express	146	147
Felixstowe	Bremerhaven	Bremerhaven	AE1	25	0
Felixstowe	Rotterdam	Bremerhaven	Silk Express	122	147
Felixstowe	Hamburg	Hamburg	NE3	130	147
Felixstowe	Rotterdam	Hamburg	Silk Express	17	0
Felixstowe	Hamburg	Southampton	NE3	65	98
Felixstowe	Rotterdam	Southampton	Silk Express	82	49
Felixstowe	Zeebrugge	Felixstowe	AE9	147	0
Felixstowe	Valencia	Felixstowe	Silk Express	0	147
Felixstowe	Antwerp	Valencia	NE1	141	10
Felixstowe	Valencia	Valencia	Silk Express	6	137
Felixstowe	Antwerp	Antwerp	NE1	147	131
Felixstowe	Antwerp	Antwerp	Silk Express	0	16
Felixstowe	Antwerp	Dalian	NE1	42	7
Felixstowe	Singapore	Dalian	NE1	105	119
Felixstowe	Tianjin	Dalian	Silk Express	0	21
Felixstowe	Bremerhaven	Fuzhou	AE7	147	0
Felixstowe	Xiamen	Fuzhou	AE9	0	147
Felixstowe	Antwerp	Guangzhou	NE1	111	39
Felixstowe	Singapore	Guangzhou	NE1	36	101
Felixstowe	Hong Kong	Guangzhou	Silk Express	0	7
Felixstowe	Antwerp	Xiamen	NE1	19	94
Felixstowe	Singapore	Xiamen	NE1	4	53
Felixstowe	Ningbo	Xiamen	NE1	124	0

Felixstowe	Antwerp	Tianjin	NE1	59	7
Felixstowe	Singapore	Tianjin	NE1	88	119
Felixstowe	Tianjin	Tianjin	Silk Express	0	21
Felixstowe	Antwerp	Qingdao	NE1	147	19
Felixstowe	Singapore	Qingdao	NE1	0	113
Felixstowe	Tianjin	Qingdao	Silk Express	0	15
Felixstowe	Antwerp	Shanghai	NE1	23	0
Felixstowe	Singapore	Shanghai	NE1	7	46
Felixstowe	Ningbo	Shanghai	NE1	117	101
Felixstowe	Antwerp	Shenzhen	NE1	147	73
Felixstowe	Singapore	Shenzhen	NE1	0	23
Felixstowe	Shenzhen	Shenzhen	NE3	0	51
Felixstowe	Antwerp	Port Kelange	NE1	147	131
Felixstowe	Antwerp	Port Kelange	Silk Express	0	16
Felixstowe	Busan	Tanjung Pelepas	AE2	147	0
Felixstowe	Xiamen	Tanjung Pelepas	AE9	0	147
Felixstowe	Busan	Vung Tao	AE2	147	0
Felixstowe	Xiamen	Vung Tao	AE9	0	147
Felixstowe	Antwerp	Ho Chi Minh	NE1	147	73
Felixstowe	Singapore	Ho Chi Minh	NE1	0	23
Felixstowe	Shenzhen	Ho Chi Minh	NE3	0	51
Felixstowe	Busan	Gwangyang	AE2	147	0
Felixstowe	Algeciras	Gwangyang	AE9	0	147
Felixstowe	Antwerp	Kobe	NE1	44	2
Felixstowe	Singapore	Kobe	NE1	103	145
Felixstowe	Antwerp	Nagoya	NE1	53	10
Felixstowe	Singapore	Nagoya	NE1	94	137
Felixstowe	Rotterdam	Hakata	Silk Express	0	147
Felixstowe	Antwerp	Hakata	Silk Express	147	0
Felixstowe	Antwerp	Shimizu	Silk Express	147	0
Felixstowe	Antwerp	Tokyo	NE1	58	10
Felixstowe	Singapore	Tokyo	NE1	89	137
Felixstowe	Antwerp	Yokohama	NE1	49	10

Felixstowe	Singapore	Yokohama	NE1	98	137
Felixstowe	Antwerp	Hong Kong	NE1	58	21
Felixstowe	Singapore	Hong Kong	NE1	89	110
Felixstowe	Hong Kong	Hong Kong	Silk Express	0	16

Appendix 8 Dual variable distribution changed at Kaohsiung by destinations
(\$/container/week)

From	To	Destination	Route	Scenario 0	Scenario 2
Ningbo	Shenzhen	Aarhus	FAL2	63	0
Ningbo	Rotterdam	Aarhus	NE3	84	111
Ningbo	Singapore	Aarhus	NE5	0	36
Ningbo	Shenzhen	Gothenburg	FAL2	63	0
Ningbo	Rotterdam	Gothenburg	NE3	84	111
Ningbo	Singapore	Gothenburg	NE5	0	36
Ningbo	Shenzhen	Gdansk	FAL2	63	0
Ningbo	Rotterdam	Gdansk	NE3	84	111
Ningbo	Singapore	Gdansk	NE5	0	36
Ningbo	Shenzhen	Bremerhaven	FAL2	75	0
Ningbo	Rotterdam	Bremerhaven	NE3	72	111
Ningbo	Singapore	Bremerhaven	NE5	0	36
Ningbo	Shenzhen	Zeebrugge	FAL2	131	0
Ningbo	Shenzhen	Zeebrugge	FAL3	0	5
Ningbo	Rotterdam	Zeebrugge	NE3	0	35
Ningbo	Shenzhen	Zeebrugge	NE5	16	27
Ningbo	Hamburg	Zeebrugge	NE5	0	12
Ningbo	Shenzhen	Zeebrugge	EUD	0	68
Ningbo	Shenzhen	Hamburg	FAL2	23	0
Ningbo	Hamburg	Hamburg	NE5	124	147
Ningbo	Shenzhen	Southampton	FAL2	131	0
Ningbo	Shenzhen	Southampton	NE5	16	0
Ningbo	Hamburg	Southampton	NE5	0	147
Ningbo	Shenzhen	Thamesport	FAL2	44	0
Ningbo	Rotterdam	Thamesport	NE3	94	83
Ningbo	Singapore	Thamesport	NE5	9	23
Ningbo	Hamburg	Thamesport	NE5	0	39
Ningbo	Shenzhen	Thamesport	EUD	0	2
Ningbo	Shenzhen	Felixstowe	FAL2	131	0

Ningbo	Shenzhen	Felixstowe	NE5	16	17
Ningbo	Singapore	Felixstowe	NE5	0	72
Ningbo	Shenzhen	Felixstowe	EUD	0	58
Ningbo	Shenzhen	Dunkirk	FAL2	131	0
Ningbo	Shenzhen	Dunkirk	FAL3	0	21
Ningbo	Shenzhen	Dunkirk	NE5	16	42
Ningbo	Shenzhen	Dunkirk	EUD	0	84
Ningbo	Shenzhen	Le Havre	FAL2	131	0
Ningbo	Shenzhen	Le Havre	FAL3	0	21
Ningbo	Shenzhen	Le Havre	NE5	16	42
Ningbo	Shenzhen	Le Havre	EUD	0	84
Ningbo	Shenzhen	Valencia	FAL2	85	0
Ningbo	Shenzhen	Valencia	NE5	0	17
Ningbo	Singapore	Valencia	NE5	62	71
Ningbo	Shenzhen	Valencia	EUD	0	59
Ningbo	Shenzhen	Algeciras	FAL2	131	0
Ningbo	Shenzhen	Algeciras	FAL3	0	21
Ningbo	Shenzhen	Algeciras	NE5	16	42
Ningbo	Shenzhen	Algeciras	EUD	0	84
Ningbo	Shenzhen	Taranto	FAL2	44	0
Ningbo	Rotterdam	Taranto	NE3	94	83
Ningbo	Singapore	Taranto	NE5	9	23
Ningbo	Hamburg	Taranto	NE5	0	39
Ningbo	Shenzhen	Taranto	EUD	0	2
Ningbo	Shenzhen	Antwerp	FAL2	23	0
Ningbo	Hamburg	Antwerp	NE5	124	147
Ningbo	Shenzhen	Rotterdam	FAL2	39	0
Ningbo	Rotterdam	Rotterdam	NE3	97	111
Ningbo	Singapore	Rotterdam	NE5	11	36
Ningbo	Hong Kong	Dalian	FAL2	147	0
Ningbo	Shanghai	Dalian	NE1	0	3
Ningbo	Hong Kong	Dalian	NE1	0	59
Ningbo	Shenzhen	Dalian	NE5	0	21

Ningbo	Shenzhen	Dalian	EUD	0	64
Ningbo	Shanghai	Fuzhou	FAL15	20	3
Ningbo	Shanghai	Fuzhou	NE1	100	83
Ningbo	Shanghai	Fuzhou	AE1	20	32
Ningbo	Shanghai	Fuzhou	Silk Express	7	29
Ningbo	Shanghai	Xiamen	NE1	78	51
Ningbo	Xiamen	Xiamen	Silk Express	69	96
Ningbo	Hong Kong	Tianjin	FAL1	147	0
Ningbo	Shanghai	Tianjin	NE1	0	3
Ningbo	Hong Kong	Tianjin	NE1	0	59
Ningbo	Shenzhen	Tianjin	NE5	0	21
Ningbo	Shenzhen	Tianjin	EUD	0	64
Ningbo	Shenzhen	Qingdao	FAL2	131	0
Ningbo	Shenzhen	Qingdao	FAL3	0	21
Ningbo	Shenzhen	Qingdao	NE5	16	42
Ningbo	Shenzhen	Qingdao	EUD	0	84
Ningbo	Shanghai	Shanghai	FAL15	20	3
Ningbo	Shanghai	Shanghai	NE1	100	83
Ningbo	Shanghai	Shanghai	AE1	20	32
Ningbo	Shanghai	Shanghai	Silk Express	7	29
Ningbo	Shenzhen	Shenzhen	FAL2	131	0
Ningbo	Shenzhen	Shenzhen	FAL3	0	21
Ningbo	Shenzhen	Shenzhen	NE5	16	42
Ningbo	Shenzhen	Shenzhen	EUD	0	84
Ningbo	Shenzhen	Kaohsiung	FAL2	9	0
Ningbo	Hong Kong	Kaohsiung	FAL2	138	0
Ningbo	Shanghai	Kaohsiung	NE1	0	51
Ningbo	Xiamen	Kaohsiung	Silk Express	0	96
Ningbo	Shenzhen	Port Kelange	FAL2	100	0
Ningbo	Port Kelange	Port Kelange	FAL2	47	0
Ningbo	Shenzhen	Port Kelange	FAL3	0	21
Ningbo	Shenzhen	Port Kelange	NE5	0	42
Ningbo	Shenzhen	Port Kelange	EUD	0	84

Ningbo	Shenzhen	Tanjung Pelepas	FAL2	131	0
Ningbo	Shenzhen	Tanjung Pelepas	FAL3	0	21
Ningbo	Shenzhen	Tanjung Pelepas	NE5	16	42
Ningbo	Shenzhen	Tanjung Pelepas	EUD	0	84
Ningbo	Shenzhen	Vung Tao	FAL2	118	0
Ningbo	Shenzhen	Vung Tao	NE5	3	0
Ningbo	Vung Tao	Vung Tao	EUD	26	147
Ningbo	Shenzhen	Ho Chi Minh	FAL2	118	0
Ningbo	Shenzhen	Ho Chi Minh	NE5	2	0
Ningbo	Ho Chi Minh	Ho Chi Minh	EUD	27	147
Ningbo	Shanghai	Busan	FAL15	20	3
Ningbo	Shanghai	Busan	NE1	100	83
Ningbo	Shanghai	Busan	AE1	20	32
Ningbo	Shanghai	Busan	Silk Express	7	29
Ningbo	Hong Kong	Gwangyang	FAL2	147	0
Ningbo	Shanghai	Gwangyang	NE1	0	17
Ningbo	Hong Kong	Gwangyang	NE1	0	48
Ningbo	Shenzhen	Gwangyang	NE5	0	7
Ningbo	Shenzhen	Gwangyang	EUD	0	50
Ningbo	Xiamen	Gwangyang	Silk Express	0	25
Ningbo	Shenzhen	Kobe	FAL2	131	0
Ningbo	Shenzhen	Kobe	FAL3	0	21
Ningbo	Shenzhen	Kobe	NE5	16	42
Ningbo	Shenzhen	Kobe	EUD	0	84
Ningbo	Shenzhen	Nagoya	FAL2	131	0
Ningbo	Shenzhen	Nagoya	FAL3	0	21
Ningbo	Shenzhen	Nagoya	NE5	16	42
Ningbo	Shenzhen	Nagoya	EUD	0	84
Ningbo	Shanghai	Hakata	FAL15	20	3
Ningbo	Shanghai	Hakata	NE1	100	83
Ningbo	Shanghai	Hakata	AE1	20	32
Ningbo	Shanghai	Hakata	Silk Express	7	29
Ningbo	Shenzhen	Shimizu	FAL2	131	0

Ningbo	Shenzhen	Shimizu	FAL3	0	21
Ningbo	Shenzhen	Shimizu	NE5	16	42
Ningbo	Shenzhen	Shimizu	EUD	0	84
Ningbo	Shenzhen	Tokyo	FAL2	131	0
Ningbo	Shenzhen	Tokyo	FAL3	0	21
Ningbo	Shenzhen	Tokyo	NE5	16	42
Ningbo	Shenzhen	Tokyo	EUD	0	84
Ningbo	Shenzhen	Yokohama	FAL2	131	0
Ningbo	Shenzhen	Yokohama	FAL3	0	21
Ningbo	Shenzhen	Yokohama	NE5	16	42
Ningbo	Shenzhen	Yokohama	EUD	0	84
Ningbo	Hong Kong	Hong Kong	FAL2	147	0
Ningbo	Shanghai	Hong Kong	NE1	0	17
Ningbo	Hong Kong	Hong Kong	NE1	0	74
Ningbo	Shenzhen	Hong Kong	EUD	0	42
Ningbo	Hong Kong	Hong Kong	AE1	0	14
Ningbo	Singapore	Singapore	NE3	43	38
Ningbo	Singapore	Singapore	NE5	104	109