Ocean Container Transport in Global Supply Chains: Overview and Research Opportunities

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Abstract: This paper surveys the extant research in the field of ocean container transport. A wide range of issues is discussed including strategic planning, tactical planning and operations management issues, which are categorized into six research areas. The relationships between these research areas are discussed and the relevant literature is reviewed. Representative models are selected or modified to provide a flavour of their functions and application context, and used to explain current shipping practices. Future research opportunities bearing in mind the emerging phenomena in the field are discussed. The main purpose is to raise awareness and encourage more research into and application of operations management techniques and tools in container transport chains.

Keywords: Container transport; competition and cooperation; pricing and contracting; shipping service design and scheduling; empty container repositioning and disruption management.

1. Introduction

With the globalization of the supply chain, intercontinental transport has become an essential component. Lloyd's Marine Intelligence Unit conducted a comprehensive research in 2009 and found that the majority of world trade is carried by sea (75% by volume and 60% by value); and within the sea transport industry (including tanker, dry bulk, container, and general cargo), 52% of cargoes by value were carried by container ships. Since emerging in the 1960s, containerization has experienced a modest growth in the first three decades and then a rapid development in the last two decades. The container traffic has increased from nearly 85 million TEUs (twenty-foot equivalent unit) in 1990 to 651 million TEUs in 2013 with an annual growth rate of 9.3%. Containerization has greatly reduced the transport cost and contributed significantly to the global supply chain. The transport cost per unit of consumer goods (e.g. TV sets, vacuum cleaners, whisky, coffee, biscuits, and beer) accounts for approximately 1% of their shelf price only. Levinson (2006) discussed at great length the impact of containerization on the global economy.

The key concept of containerization is standardization, which leads to the advantage of ease of handling in the entire transport chain. In other words, a container can be transported efficiently from origin to destination by different transport means (vessel, train, truck) without the need to reorganize/re-handle the content within. In that sense, containerization is naturally suited to integration in global supply chains. However, in reality container shipping operations are still fragmented and the market environment is volatile. Operations management techniques and tools are seldom applied in container transport industries compared to other transport sectors such as air transport due to the special characteristics of sea transport. There are some typical differences between the air and the sea industry. First, in the air industry, many carriers have switched to electronic Airway Bills (AWB), yet for sea freight, the legal document—Bill of Lading (BOL)—is still printed on paper. Second, the air industry is a passenger network, hence revenue management is widely applied, yet very few sea liners have adopted such a tool. Third, in the air industry, service differentiation is important, yet in the sea industry, limited differentiation of services means that the competition is mainly cost-based. Hence, forming alliances is very popular and important in the sea cargo liner industry. Fourth, in the air industry, no one company dominates because of the existence of air traffic rights; in the sea industry, there has been much consolidation and the world market is now dominated by a few major players. For example, the top 10 liners claim two-thirds whereas the top 20 liners own nine-tenths of the market. Hedging (e.g. on oil price) is very popular in the air industry, yet very few sea liners can afford it (a liner may end up bearing even higher risk if it adopts hedging but no other liner does). Finally, in the ocean container transport industry, slow steaming is adopted across the board, yet in the air industry, slow steaming is generally impractical because there is not much room for aircraft to slow down (Wang 2012).

Container liner shipping is a capital-intensive industry with long investment lead times. As mentioned above, service differentiation is low in liner services, so the competition is mainly on a cost basis. Since the financial crisis of 2008, economic recession and declining trade demand have led to overcapacity in transport services. The situation is worsened by a fragmented market and carriers' relentless pursuit of economies of scale. Freight prices have grown extremely volatile in recent years. Lloyd's List reported that freight rates slumped 40% within a week in November 2015. Dynamic operations and uncertain activities associated with long geographical distances in container shipping bring challenges to the quality of shipping services. Increasing concerns about the social and environmental impacts of shipping are also affecting shipping operations and performance. All these issues bring massive challenges to the container shipping industry.

According to MergeGlobal, the value chain in the container shipping industry may be classified into five segments (with the estimated revenues in year 2006):

1. Shipment routing and capacity procurement (US$32 billion);
2. Container fleet and repositioning (US$8 billion);
3. Vessel fleet and operations (US$102 billion);
4. Terminal operations and container handling (US$35 billion);
5. Inland transport vehicle and container handling (US$28 billion).

With an emphasis on the first three segments (i.e. maritime container transportation problems), this paper aims to survey the extant research in the field of ocean container transport. This includes a wide range of strategic planning, tactical planning and operations management issues (see Figure 1.1). The strategic planning issues include: competition and cooperation between carriers, ports and terminals (Segments 1–4), and pricing and contracting (Segments 1–3). The tactical planning include: network design and routing (Segment 1 and 3), and ship scheduling and slow steaming (Segment 3). The operations management issues include: empty container repositioning (Segment 2), and safety and disruption management (Segment 3). It should be noted that empty container repositioning and safety and disruption management include tactical planning tasks. The reason we classify them as operational level is that: empty container repositioning usually has a lower priority than laden container movements and the decisions are often decentralized; safety and disruption management intends to cope with unexpected but occasional (or one-off) events that often require real-time actions. The double arrows in Figure 1.1 indicate that the planning issues may influence each other and are sometimes considered jointly. Please note also that according to a report by Notteboom (2006), port congestion contributed to 65.5% of the containership's schedule unreliability. Clearly, improving the efficiency of port operations is critical in the maritime container transportation. Nevertheless, a plethora of studies has existed on container port/terminal productivity. Readers may refer to the survey papers such as Steenken et al. (2004); Stahlbock and Voss (2008); Bierwirth and Meisel (2010); and Kim and Lee (2015) for detailed discussions in this area. Due to the length limit, we will not cover this issue in our paper.

In all six research areas, previous survey papers and representative literature are reviewed. Representative models with specifics will be introduced to provide a flavour of their function and application context. In each identified research area, future research opportunities bearing in mind the emerging phenomena in the current practice will be discussed. It should be noted that it is not our intention to include all relevant literature in this paper due to its wide coverage. Instead, our focus is to provide a broad picture of various maritime container transportation problems and their relationships by explaining the key planning issues, introducing representative models, and identifying further research opportunities.

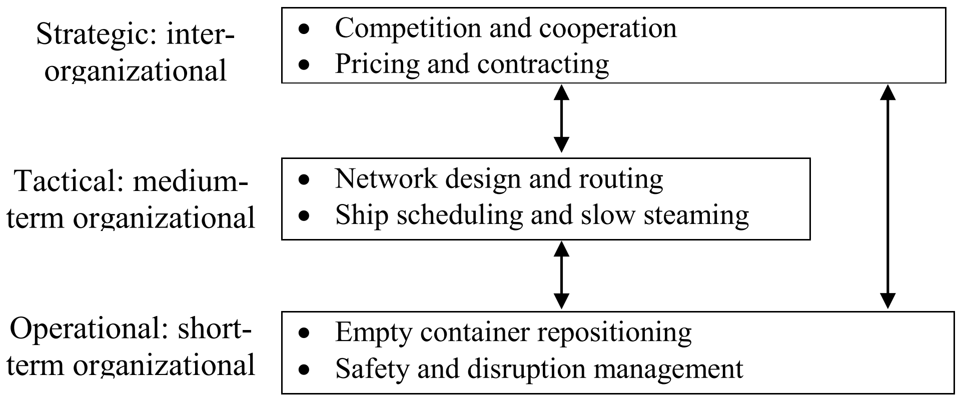

Figure 1.1 Six planning issues in maritime container transportation

The rest of the paper is organized as follows. In Sections 2–3, we focus on two strategic planning issues that concern the relationship management between channel members, i.e. (i) competition and cooperation between ocean carriers, ports and terminals; (ii) pricing and contracting. In Sections 4-5, we focus on two tactical planning issues from ocean carrier's organizational perspective, i.e. (i) network design and routing; (ii) ship scheduling and slow steaming. In Sections 6-7, we focus on two operations management issues, i.e. (i) empty container management; (ii) safety and disruption management. In each of Sections 2-7, we explain the research context and the linkage between planning issues, and review the relevant literature for each issue. Representative models are introduced to complement the general literature review and explain the application of some operations management methods. The research opportunities are then identified to stimulate further study. Finally, conclusions are drawn in Section 8.

2. Competition and cooperation between carriers, ports and terminals

Ocean carrier and container port are two key players in global container supply chain. There exist both competition and cooperation between carriers, ports and terminals horizontally and vertically. A number of papers have provided overviews on these issues, e.g. competition and cooperation between ocean carriers (Heaver et al. 2000; Panayides and Cullinane 2002; Notteboom 2004; Cariou 2008; Alexandrou et al. 2014; Caschili et al. 2014); cooperation between ocean carriers and other members in vertical channel (Heaver et al. 2000; Panayides and Cullinane 2002; Notteboom 2004; Cariou 2008; Fremont 2009); competition and cooperation between ports/terminals (Heaver et al. 2001; Song 2003; Notteboom 2004; Mclaughlin and Fearon 2013; Notteboom and de Langen 2015; Lee and Lam 2015).

In this section, we first address the competition and cooperation issues mainly from carrier perspective; then address the competition and cooperation issues from port and terminal perspective. A representative model is then presented. Finally, the research opportunities will be discussed.

2.1 Carrier competition and cooperation

Ocean carriers invest heavily on ship and container assets to provide maritime transport services to shippers. Due to the capital-intensive nature to provide regular shipping services, horizontal competition between shipping lines is fierce. In the last twenty years, cooperation between shipping lines has been popular and co-exists with competition in container shipping.

The competitive advantages that shipping lines are constantly seeking may be broadly classified into two categories: operational efficiency and service effectiveness. The former emphasizes cost reduction and asset utilisation/efficiency. Typical examples of strategies and practices include: horizontal integration by forming a strategic alliance adopting slow steaming, deploying larger vessels for economies of scale, deploying more efficient vessels (e.g. Maersk Line’s triple-E vessels), and sharing resources to improve utilisation. Service effectiveness, on the other hand, emphasizes service differentiation and quality of service. Typical examples of service effectiveness include: vertical integration with other stakeholders or expanding to logistics services, more frequent and flexible service (e.g. Maersk’s daily service), service reliability, more flexible closing time, wider shipping network and coverage. Note that different from the air industry, the ocean industry is demand in-elastic and service differentiation is limited. Thus, nowadays, the competition is mainly on the cost. This is the main reason why alliances are so popular as they provide economies of scale and cut operational costs.

Shipping lines cooperate mainly to reduce cost by enhancing the utilisation of facilities, to improve the service frequency and region of coverage by expanding capacity, to rationalise the shipping service network, and to share management resources. Notteboom (2004) provided an overview of the challenges facing port and ocean carriers in the competitive environment. Based on empirical evidence, he analysed the different paths that shipping lines might take including trade agreements, operating agreements (e.g. vessel sharing agreements, slot chartering agreements, consortia and strategic alliances) and mergers and acquisitions.

Cooperation in liner shipping takes various forms, e.g. slot purchase agreement, slot exchange agreement, vessel sharing, equity-sharing joint venture, and cargo sharing. The most prominent type of alliance is often referred to as strategic or global alliances, which aim at jointly operating containerships over specific routes. They cooperate on decisions related to ship type/size, number of ships, port selection and sequence, and ship sailing schedule. The cooperation among members of a strategic alliance is often limited to ship operations without involving marketing, pricing, revenue pooling, profit/loss sharing, and joint management and executive functions (Panayides and Wiedmer 2011).

Heaver et al. (2000) presented an overview of different cooperation agreements including alliances and mergers among shipping lines, conferences, vertical integration of shipping lines with terminal operators or inland transport companies. The main focus was on the competitive position of the ports in the new market structure. Panayides and Cullinane (2002) addressed the issue of competitive advantage in liner shipping by focusing on the themes such as vertical integration, strategic alliances, mergers and acquisition, and shipper relationships. They pointed out the need for empirical investigation of the strategy-performance relationship. Panayides (2003) conducted an empirical research and found the positive relationship between pursuing competitive strategies and company performance in ship management (e.g. by achieving economies of scale and offering a wider range of services). Cariou (2008) provided an overview of horizontal integration, vertical integration and investment of mega-vessels in liner shipping sector for the period from 1990 to 2005. Fremont (2009) discussed various levels of vertical integration that a shipping line can achieve, e.g. a shipping line can take on the functions of a shipping agent and a terminal operator. This implies that the shipping line no longer has to depend on an external agent who may also provide services to a competitor and ensure more efficient handling at container terminals. The shipping line can go further to integrate with inland transport operators, freight forwarders and/or logistics service providers, which would enable it to offer extended or even door-to-door services. Alexandrou et al. (2014) surveyed the shipping mergers and acquisitions from 1984 to 2011 and analysed the gains that the shareholders of both acquirers and targets realized. Caschili et al. (2014) performed a network analysis to examine how shipping companies integrate and coordinate their activities. It was confirmed that the main purpose of the cooperation is to reduce costs, compete against larger carriers, or increase their local and specialized market penetration.

The scale and scope of liner shipping alliances is quite unique compared to other transport industry sectors, and play a central role in the operations and long-term viability of liner shipping companies. With the announcement of the 2M Alliance (Maersk and MSC) and the Ocean Three Alliance (CMA CGM, CSCL, UASC) in 2014, every shipping line in the top 10 in the world is a member of one of the global alliances. According to the data from Alphaliner in November 2015, the CKYHE Alliance (Cosco, K-Line, Yang Ming, Hanjin, Evergreen) occupies 16.46% of the market; the G6 Alliance (Hapag-Lloyd, NYK, OOCL, APL, MOL and HMM) occupies 17.14%; the 2M Alliance occupies 27.94%; and the Ocean Three Alliance occupies 14.65%. These four alliances combined account for nearly 80% of the global container carrying capacity. Recently, there have been a number of major mergers occurred or planned, e.g. the merger of Cosco and CSCL in late 2015, the acquisition of NOL (the parent of APL) by CMA CGM in the summer 2016, the potential merger of Hapag-Lloyd and UASC revealed in April 2016. These mergers and acquisitions have triggered the re-organization of existing shipping alliances. For example, a new alliance, named as "Ocean Alliance" was announced on 20th April 2016, which consists of four ocean carriers: CMA CGM, COSCO Container Lines, Evergreen and OOCL, which are from three different existing alliances. The Ocean Alliance will become operational from April 2017 subject to regulatory approval. Its market share will be nearly 35% on Asia-Europe service and 38.9%

on Asia-North America routes, making it the largest on those routes. Because three existing alliances, Ocean Three, CKYHE, and G6 are to lose their key members, this will probably bring to an end to these three alliances in 2017. According to Alphaliner, a potential scenario is that the eight container carriers left out of the two major alliances, the 2M and Ocean Alliance, could team up to form a new mega-alliance. This potential new alliance would consist of Hapag-Lloyd (G6), UASC (Ocean Three), Yang Ming (CKYHE), NYK (G6), K Line (CKYHE) and MOL (G6), but may omit two South Korean ocean carriers, Hanjin (CKYHE) and HMM (G6), because they are experiencing serious financial problems.

Huang and Yoshida (2013) summarised the comments of several executives on the formation of liner shipping alliances during the recent economy recession as follows: (i) the market is turning into an oligopoly because of frequent mergers and acquisitions, lower market investment, and low return on equity; (ii) alliances create high barriers of entry; (iii) alliances are growing in scale and scope, and so cut-throat competition is inevitable; and (iv) service quality and reliability will be the key issues for alliances in the future.

From the modelling perspective, there are relatively limited number of studies on competition and cooperation between shipping lines. Lei et al. (2008) presented mixed integer programming models to evaluate non-collaborative, slot-sharing and total-sharing container-vessel policies. They indicated that the advantage of collaborative planning cannot be fully exploited without partner carriers' full commitment to share the demand and the resource.

Agarwal and Ergun (2008b) considered the container shipment assignment problem in a shipping alliance network, in which individual shipping lines own capacity on the arcs of the network and share this capacity to deliver shipments. Using cooperative game theory and the inverse optimization technique, they presented a mechanism of regulating interaction among the shipping lines in the alliance by computing capacity exchange costs, which motivates individual shipping lines to move towards the collaborative solution. Agarwal and Ergun (2010) extended the above model to address the alliance formation among shipping lines covering both tactical issues (such as shipping network design) and operational issues (such as capacity allocation among shipping lines in the alliance). Zheng et al. (2015a) further extended the above work to the network design and capacity exchange problem for liner alliances with fixed and variable container demands. They assumed that each shipping line only operates its own shipping routes with its own ships, and capacity exchange costs are determined for shared shipping routes (instead of for each link of the network as in Agarwal and Ergun (2008b; 2010)). Alvarez-SanJaime et al. (2013) modelled the competition between a road transport firm and two shipping lines, and investigated the impact of the horizontal integration of two shipping lines on their profitability and the social welfare.

Within a strategic alliance, the alliance member companies are still regarded as competitors. This is due to the fact that alliance members normally only cooperate at the operational level, e.g. slot exchange, vessel sharing, service route rationalisation. They are competing against each other in terms of marketing and sales, pricing, and organisation. Song and Panayides (2002) pointed out that alliance members may indeed pursue their own self-interest at the expense of the alliance and other members if opportunities arise.

Methodologically, Polak et al. (2004) proposed multi-agent-based simulation to model the competition between shipping lines, in which shipping lines compete for customer demand in a bottom-up bidding process. Song and Panayides (2002) argued that cooperative game theory is an applicable approach for modelling inter-organisational behaviour of shipping lines in a strategic alliance for two reasons: (i) it considers the underlying motivations for the formation of the strategic alliance; (ii) it aims to optimise the joint business objectives of all partners. However, the second reason may not always hold since alliance members may not always have a common goal and may act independently. Gelareh et al. (2010) presented a mixed-integer programming formulation and a Lagrangian method combined with a primal heuristic to address the hub-and-spoke network design problem, in which the competition between a newcomer liner service provider and an existing dominating operator is considered. Wang et al. (2014a) presented non-cooperative models to analyse the competition between two shipping lines in a new emerging container shipping market. The shipping lines' decisions include the freight rate, service frequency and ship capacity. The market share of each shipping line is determined by the logit-based discrete choice model.

2.2 Port and terminal competition and cooperation

Port authority traditionally has three types of functions: landlord, regulator and operator. Its job is to administrate and manage port infrastructure, and coordinate and control the activities of the different operators present in the port (Verhoeven 2010). With the socioeconomic changes in the port landscape in recent years, port authority is also developing a community manager function that aims to solve collective action problems in and outside the port area, such as hinterland bottlenecks, training and education, marketing and promotion, innovation and internationalisation (Verhoeven 2010). Port authority outsources the cargo-handling activities to private operators, i.e. terminal operators, who are responsible for providing expensive handling equipment (such as quay cranes, yard cranes) and other resources to handle ships and containers.

Heaver et al. (2001) discussed strategic measures in terms of the cooperation and competition relationships between port authorities and terminal operators, and between terminal operators within a port. Song (2003) proposed a concept 'co-opetition', the combination of competition and co-operation, to explain the relationships of the container ports in Hong Kong and South China. Notteboom (2004) discussed the challenges faced by container terminal operators, e.g. competition from new entrants including carrier, railway companies, logistics companies and investment groups. Based on the empirical data, he showed the emergence of international terminal networks and the integration along the supply chain. Mclaughlin and Fearon (2013) considered cooperation and competition through a new conceptual cooperation/competition matrix and evaluated the response strategies of ports to the changing maritime competitive dynamics with their competing ports. Notteboom and de Langen (2015) discussed container port competition in Europe at different levels. At the intra-port competition level, operators compete for cargo handling, and towage and bunkering business. At the level of inter-port competition within the same region, adjacent seaports compete for the same hinterland cargo flows. Port authorities focus on offering the best basic infrastructure and IT facilities, the best logistics facilities and the lowest port user costs, whereas terminal operators focus on price, handling time and productivity. Government policies can also have an impact on the conditions and level of competition among subgroups of ports. At the level of inter-port competition between different regions, hub ports compete for transhipments in hub-feeder relations. Lee and Lam (2015) evaluated the competitiveness of four major Asia container ports: Busan, Hong Kong, Shanghai and Singapore. They measured port competitiveness by cross-sectional, longitudinal and horizontal aspects including service quality, ICT, community environmental impact, port cluster, maritime cluster, logistics hub, inland and waterside.

From the methodological perspective, the literature on port competition may be classified into two groups. The first group employs empirically based approaches (such as case study, survey, data envelopment analysis, stochastic frontier analysis, analytical hierarchy process, structural equation models) to define a conceptual framework of port competition and competitiveness, measure port efficiency and performance, and identify key competitive factors. The second group develops mathematical models such as game-theoretic models to examine port competition.

Many studies on port competition were empirically based (Notteboom and Yap 2012). This is understandable since many factors could affect the strategic and operational decisions at ports. Some factors are qualitative in nature, e.g. reputation, skill and knowledge of employees, understanding customer needs, ease of communication, political stability, social stability, and availability of other supporting services. Other factors are quantifiable, e.g. terminal handling charges, port dues, pilotage and towage, storage costs, reliability, physical accessibility of hinterland, maritime access, terminal productivity, transit time for shipment, port maintenance charges, connectivity to other ports, and accident rate (Yap and Lam 2004). Some institutes are trying to rate terminal operators (like rating hotels) based on key performance indicators of efficiency, but none has succeeded so far because too many uncontrollable factors exist that are not easy to evaluate. A much broader scale for rating global logistics performance for more than one hundred countries has been developed by World Bank in 2007, 2010, 2012 and 2014, based on the following criteria: customs, infrastructure, international shipment, logistics quality and competence, tracking and tracing, and timeliness (World Bank 2014).

In the last decade, a number of game-theoretic models have been developed to address port competition in a quantitative way. According to the geographic distance between the players, port competition can be classified into three levels: intra-port competition between terminal operators at the same port (e.g. Saeed and Larsen 2010); inter-port competition between operators at neighbouring container ports (Song 2002; De Borger et al. 2008; Li and Oh 2010; Wang et al. 2012; Song et al. 2016); and inter-port competition between operators at different geographical areas (Bae et al. 2013; Wan et al. 2013). At the third level, port authorities and port policymakers are often involved either explicitly or implicitly. Their role is to offer good infrastructure in and around the port so that the port can compete with other ports in the region. Although most of these game theoretical models are relatively simple and based on rather restrictive assumptions, they represent a promising research stream since they are able to capture the nature of port competition in the container shipping industry.

Apart from the competition between ports, the cooperation between ports has also been discussed in the literature (e.g. Heaver et al. 2001; Song 2003; Mclaughlin and Fearon 2013; Asgari et al. 2013). Mclaughlin and Fearon (2013) argued that direct competition and preserving traditional inter-port rivalries is not a sustainable strategic response to globalized competitive dynamics, and increasing collaboration or partnerships is the way forward. However, collaboration between ports is seldom formalized in practice.

2.3 A game model of competition involving ports and carriers

In the following, we introduce a non-cooperative game-theoretical model based on Bae et al. (2013), which aims to examine port competition for transhipment containers in a duopoly market but involving multiple shipping lines. Consider a scenario with two transhipment ports competing for port calls from a number of shipping lines. Each port has to make pricing decisions on container handling (e.g. terminal handling charge), whereas each shipping line has to make decisions on transhipment port calls split over two ports. The following notation is used:

p: the index of two transhipment ports, p=1,2;
j: the index of shipping lines that call at both ports;
f_{jp}: the gateway containers that are imported and exported at the port p by liner j;
g_j: the total transhipment containers by liner j at the two ports;
p_j: the shipping line j's price (revenue) per container;
K_p: the port p's effective maximum capacity;
a_p: a positive coefficient related to port congestion cost;
c_j^l: the shipping line j's unit operating cost;
c_p: the port p's operation cost per unit;
m_p: the port p's capacity investment cost per unit;
q_{jp}: the decision variable indicating the fraction of transhipment port calls that shipping line j makes at port p such that $0 < q_{jp} < 1$ and $q_{j2} = 1 - q_{j1}$;
w_p: the decision variable indicating the container handling price at port p;

It is assumed that the transhipment container demand of each shipping line at one port is proportional to its fraction of transhipment port calls at the corresponding port in the given period of time. The gateway containers are not affected by the port call split decisions. Thus, the total number of containers that shipping line j handles at port p is denoted by F_{jp} and given by

$$F_{jp} = f_{jp} + g_j \cdot q_{jp}, \text{ for } p=1,2;$$

Port congestion is a very important factor for shipping lines when deciding how to split transhipment port calls over two ports. The following quadratic function describes the port congestion cost per unit (which can be regarded as container delay cost due to port congestion):

$$G_p = a_p \cdot (F_p / K_p)^2, \text{ for } p=1,2$$

where a_p is a positive parameter, K_p represents port p's effective maximum capacity, $F_p = \sum_j F_{jp}$, and $F_p \leq K_p$. It is easy to see that the congestion cost is increasing in the number of port calls, and decreasing in port capacity.

In a non-cooperative game, each player makes decisions independently. To apply the non-cooperative game theory, we define the profit functions for all players. Shipping lines' profit functions are given (for j=1,2,…,N) as follows:

$$\pi_j^l = \sum_p (p_j - c_j^l - w_p - G_p) \cdot F_{jp}$$

s.t.

$$0 < q_{j1}, q_{j2} < 1$$
$$q_{j2} = 1 - q_{j1}$$
$$F_p \leq K_p, \text{ for } p=1,2$$

where w_p represents the container handling cost paid to the port (i.e. port price per unit). Ports' profit functions (for p=1,2) are given as follows:

$$\pi_p = (w_p - c_p) \cdot F_p - m_p \cdot K_p, \text{ for } p=1,2$$

The non-cooperative game problem can then be formulated as a two-stage problem. At the first stage, each port makes port pricing decisions (w_p) to maximize its profit. At the second stage, each shipping line makes its port call decision (q_{jp}) to maximize its own profit by observing each port's capacities, prices, and transhipment levels.

To solve the problem, the backwards induction approach is used. For the second stage, the sub-game Nash equilibrium can be obtained. The port call decision variables can be represented as a function of port capacities, prices, and transhipment levels. For the first stage, by utilizing the port call decisions obtained at the second stage, the Nash equilibrium port prices can be derived. This then yields the shipping lines' port call decisions.

2.4 Research opportunities

We suggest the following areas for further research:

- Although a few studies have applied the non-cooperative game approach to model port competition, they are limited to specific contexts. The empirical research has shown a long list of factors that affect the competitiveness of a port or terminal (Notteboom and Yap 2012). Therefore, more sophisticated models should be developed so that the main factors can be appropriately incorporated.
- The concept of port co-opetition has existed for a decade, yet neither the empirical research nor the modelling research has given adequate attention to it (in particular to formalised cooperation like liner alliances). In addition, seaports are no longer regarded as isolated nodes but rather as crucial and integrated links within global value chains of primary and support activities. Thus, port competition may be extended to intermodal supply chain competition, or port-cluster competition (e.g. a hub port with a set of feeder ports).
- Horizontal integration: As pointed out by Caschili et al. (2014), although cooperative agreements and alliances are main trends in the shipping industry, scant analyses and models have been performed on this topical industrial strategy. In the past, the largest two shipping lines, Maersk and MSC did not participate in an alliance as they can achieve economies of scale individually with their large ship fleets. With the formation of the 2M Alliance and the Ocean Three Alliance in 2014, every shipping lines in the top ten in the world is a member of one of the global alliances. Note that members in a strategic alliance are independent in some business operations, and cooperative in other operations. There are three types of competition between in liner shipping industry: (i) competition between strategic alliances; (ii) competition between individual shipping lines in different alliances; (iii) competition and cooperation between individual shipping lines within the same alliance. There is a need of more operations management studies in the above three aspects. With the merger of Cosco and CSCL, and the acquisition of APL by CMA CGM, it is interesting to see how the existing shipping alliances would be re-organized and to what degree individual shipping lines could be affected. In addition, as the scale of strategic alliances in liner shipping reached an unprecedented level, shippers have raised some concerns on quality of service and freight rates since the consolidation of

the world's top 20 shipping lines into super alliances. Therefore, the impact of such large scale of alliances on shippers is worth investigating.

- Vertical integration: there has been clear evidence that some shipping lines are pursuing vertical integration to achieve integrated intermodal supply chain management. For example, a shipping line can take on the functions of a shipping agent and a terminal operator. This implies that the shipping line no longer has to depend on an external agent who may also provide services to a competitor and ensure more efficient handling at container terminals. The shipping line can go further to integrate with inland transport operators, freight forwarders and/or logistics service providers, which would enable it to offer extended or even door-to-door services (Fremont 2009). Therefore, it is important to explore the enhanced scope of logistics activities and the management issues under vertical integration, e.g. how to achieve optimal intermodal container transport on a global scale.
- Under either vertical or horizontal integration of global container supply chains, the question of how to incorporate operational-level uncertainties such as random demands and port congestion into tactical/strategic planning problems requires more research.
- The Container World project (Polak et al. 2004) proposed a multi-agent-based simulation approach and the concept of the complex adaptive system to model the global intermodal container supply chain systems. This approach is probably appropriate for the current container shipping practice given the fragmented nature of the industry. However, the main challenges remain largely unanswered: (i) how to appropriately capture individual agents' autonomous and coordination behaviours; (ii) how to collect consistent data for the global shipping networks and inland transport networks; (iii) how to forecast global trade demands; and (iv) how to balance between the complexity of the model and computational complexity.

3. Pricing and contracting

Container transport is a global activity involving multiple players. Managing these relationships is of strategic importance. One aspect of relationship management is pricing and contracting among players. Pricing is closely related to competition issue, whereas contracting is related to cooperation issue in the previous section. Fransoo and Lee (2013) has one section covering this issue. However, we did not find any specific survey paper that dedicated on the container shipping pricing and contracting. In this section, we will discuss the trade agreement between consignor and consignee, and the contracts among service providers, or between user and provider; describe the pricing problem; review the relevant literature; present a specific model on pricing and contracting, and then point out future research opportunities.

The complexity of container shipping does not arise only from border crossing issues and multimodal transport over long distances, but also from the fact that a large number of parties are involved, each with their own objectives. For example, the following players may be involved in a container shipping supply chain: a consignor, a consignee, an ocean carrier, freight forwarders, inland carriers, banks, legal experts, insurance brokers, customs, port/terminal operators, and inland depot operators. They can be roughly divided into service users and service providers. The consignor and the consignee are service users, and all other players are service providers.

A series of buy or sell transactions are conducted among the players, who must deal with the pricing and/or contracting issues. Unlike air freight, where rates are centrally negotiated and published by trade bodies, ocean freight has to be negotiated individually with ocean carriers in two forms: a contract rate agreed for a fixed period of time (normally a year), and a spot market rate at the time of booking. In the following, we will address the contracting and pricing issues in a typical container shipping supply chain consisting of a consignor, a consignee, an ocean carrier, a freight forwarder, and a terminal operator.

3.1 Trade agreement between consignor and consignee

International trade is generated by the buy-sell agreement between the consignor (seller) and consignee (buyer) and drives the demand for international logistics including maritime shipping. The contract between consignor and consignee must cover the terms of sale and terms of payment. The former specifies who is responsible for arranging the physical movement of the goods (and for paying the incurred charge), and when and where the legal title to the goods is transferred to the consignee. The latter specifies when and how the payment is to be made. Clearly, these terms must be appropriately coordinated to ensure that the buyer will receive the right goods and the seller will receive the right payment. The delivery terms (called Incoterms) used in international trade were standardised by the International Chamber of Commerce (ICC) in 1936. The most recent version was released in 2010 (ICC, 2010), which consists of 11 Incoterms ranging from EXW (ex works, i.e. handing over the ownership of the goods at the seller's premise) to DDP (delivery duty paid, i.e. handing over the ownership at the buyer's premise). Several Incoterms have been specifically designed for maritime transport, and all of them are in use today depending on the agreement between the seller and the buyer. However, the most commonly used Incoterms are FOB (free on board) and CIF (cost, insurance and freight). Under FOB (CIF), the seller is responsible for the delivery of goods on board a vessel (to a specified port), and the buyer is responsible for the rest of the delivery journey. Fransoo and Lee (2013) pointed out that there is little academic work (either theoretical or empirical) on decision making related to Incoterms. Recently, Del Rosal (2015) presented an econometric model to examine the relationship between the use of delivery terms and several factors such as the weight/value ratio, distance, and GDP per capita, based on empirical data on Spanish seaborne export and import operations in 2011.

3.2 Contract among service providers, or between user and provider

The shipper is the owner of the transported cargo. Depending on the terms of sale, either the seller or the buyer may be the shipper who negotiates with the ocean carrier for the seaborne transportation. The contract between shipper and ocean carrier is termed a bill of lading. Apart from serving as a contract of carriage, a bill of lading also serves as a document of title to the goods and a receipt for goods. In practice, ocean carriers often have long-term contracts (one year or more) with major shippers or large freight forwarders (i.e. non-vessel operating common carriers or NVOCCs), which can provide them with regular large volumes of full containers. For example, MSC and BMW have long-term shipment contracts at Antwerp port (Fremont, 2009). Signing these long-term contracts also helps shipping lines better control their container stocks as the origins and destinations of containers are fixed. However, the flat freight rate agreed in such long-term contracts could fall well below the spot market price because of the volatile freight rate market. For example, Maersk Line signed a long-term contract with Argos (a large retailer in the UK) at the agreed rate of US$930 per container, and later on unilaterally imposed an increased rate of $2,730 per container in response to high spot market price. Maersk Line eventually forked out US$14 million to settle the dispute with Argos according to Lloyd's List. On the other hand, when the spot freight rate tumbled, Maersk Line mentioned that some of its shippers may rip up the signed long-term contracts and go for the spot market (Brett 2014b). However, no specific cases have been reported on whether a penalty is imposed if shippers display opportunistic behaviour and violate the long-term contracts.

Container terminals provide services to ocean carriers such as berthing vessels, loading and unloading, container storage, and refuelling. There are formal contracts between ocean carriers and terminal operators. The contract and pricing may be highly related to the types of container terminals. According to their ownership, container terminals may be classified into five types: public or state-run terminals, carrier-leased dedicated terminals, operator-built and operated terminals, carrier-built and operated terminals, and terminals that are joint ventures between the carriers and terminal operators. For example, public or state-run terminals often operate on a first-come-first-served basis, which means the port service tariff is the same for all carriers, and normally no penalty is imposed for delays caused either by the carrier or the terminal. On the other hand, dedicated container terminals act as strategic hubs for the carrier, which may be used by the associated carrier solely or with priority. Maersk Line and APM Terminals reportedly entered into a formal agreement in 2013, which provide Maersk Line with dedicated capacity at certain key container terminals to ensure service efficiency (Brett 2014a). As mentioned in Fransoo and Lee (2013), though the consignor (consignee) has an operational relationship with the terminal operator as they need to deliver (pick up) containers to (from) the terminal, they do not in contractual relationships with the terminal operator.

Inland carriers such as rail operators or road hauliers may sign long-term contracts with ocean carriers. The development of intermodality and door-to-door service (i.e. carrier haulage) has meant that shipping lines could either extend their service to hinterland transport or subcontract to inland carriers (e.g. Maersk Line has a multi-year contract with the UK rail operator, Freightliner). Carrier haulage is popular in North America and the UK, but less popular in Europe and Asia (Fremont 2009). The proportion of inland transport that is directly controlled by shipping lines is estimated to be 30% (Notteboom, 2004). The organisational structure may affect the contractual relationship between ocean carrier and inland carrier. When a shipping line subsidiary and a logistics subsidiary both belong to a larger conglomerate group, the two subsidiaries can perform their activities independently with no direct association between them, e.g. Maersk Line and Maersk Logistics are subsidiaries of AP Moller-Maersk Group; APL and APL Logistics are subsidiaries of the NOL Group. However, shipping lines or their parent companies must often make a choice between reinforcing their core business activity and developing other activities along the transport chain to offer value-added services to their clients. For example, in early 2015 the NOL Group sold APL Logistics to Kintetsu for US$1.2 billion in order to deploy fresh capital in the container shipping division (Inagaki and Grant 2015).

The main activities that a freight forwarder undertakes are freight grouping/degrouping operations, documentation, and customs clearance. Large freight forwarders also play a role in managing flows of goods before and after the production processes including inland transportation of containers. Europe's top four ocean freight forwarders are: Kuehne+Nagel, Deutsche Post DHL, DB Schenker, and Panalpina. These large freight forwarders purchase slots from ocean carriers in advance in large quantities, and then act as NVOCCs to provide seaborne transport services to shippers. In that sense, the price between ocean carriers and NVOCCs can be regarded as a wholesale price, whereas the price between NVOCC and shippers can be regarded as a retail price.

As mentioned above, in the current practice, the carrier may sign a contract with the shipper stating a fixed price per container for the whole year or sell the slots in the spot market just before the shipping. The former case benefits the carrier by allowing it to lock in the market share and it is also good for capacity planning. Nevertheless, many executives representing shippers are reluctant to sign fixed-price contracts to avoid having to bear the responsibility when the spot market price drops below than the contract price. Lee and Tang, et al., (2015) addressed the issue by investigating whether carriers should bear some of the "price risk" by offering a "fractional" price matching contract in which the shipper pays a constant contracted freight rate in advance. If the realised spot price is below the regular price, the carrier will refund the shipper a "fraction" of the difference between the regular price and the realised spot price. They show that the carrier can generate a higher demand from the shippers for using the fractional price matching contract. Also, the carrier will not incur any revenue loss by optimally adopting this scheme, i.e. the optimal fractional price matching contract is "revenue neutral."

3.3 Shipping pricing in practice

Container shipping pricing has been a long debated topic. Historically, liner conferences have been used as a device by ocean carriers to agree a set of tariffs, and terms and conditions of carriage in certain trade routes. Since October 2008, liner conference activities and price fixing are no longer permitted on routes to and from Europe. However, liner conferences in other parts of the world are still acceptable, e.g. Transpacific Stabilisation Agreement (TSA) and the Canada Transpacific Stabilization Agreement (CTSA).

In the recent years, shipping lines have been using general rate increase (GRI) as a regular mechanism to increase freight rates. GRI refers to the average amount by which an ocean carrier will add to the current base freight rate. However, shipping lines were suspected to collusion on the freight rate using GRI as "pricing signals" to competitors intended to raise freight rates. In February 2016, Europe competition regulator announced a deal with 15 major shipping lines to end the public GRI announcements on European routes. The GRI announcement will be replaced by the total price announcement, which specifies the maximum prices for the announced period of validity, but carriers will remain free to offer prices below the announced maximum price. However, it is unclear when the new pricing rules will be implemented. Table 3.1 shows the regulatory rules concerning carrier pricing around the world.

Table 3.1 Regulatory rules concerning carrier pricing around the world (Source: Drewry 2016)

	Asia, Africa, Latin America and Oceania (except European route)	**US (except European route)**	**Europe now**	**Europe post-GRI ban**
Liner conference	Allowed	Allowed (but few operate)	Not since Oct. 2008	Not

Discussion agreements	Allowed	Allowed	Not	Not
GRI announcements by carriers	Allowed	Allowed	Allowed	15 carriers to stop publishing GRIs

Drewry (2016) summarized the main changes and no changes to shippers under the new pricing rules on European routes: (i) The post-GRI pricing rules will affect spot rates only and not affect contract rates; (ii) Individual carriers can set up maximum prices once a month for their commodity shippers, but no minimum prices will be set; (iii) Shippers will still be able to negotiate lower freight rates than the announced maximum rates. It is hoped that the new pricing rules would end the sudden huge GRIs (e.g. over $1,000) per 40ft container on the Asia-Europe route, which have happened 9 times in 2015.

3.4 Pricing and contracting literature

Academic literature on contracting and pricing in container shipping supply chains is scarce. Zhou and Lee (2009) addressed the transport service pricing decisions considering the ECR cost. In a monopoly market (with a single carrier), they characterized the pricing strategy analytically. In a duopoly market with symmetric carriers, they showed that there is a unique Bertrand Nash Equilibrium and derived its analytic properties. Yin and Kim (2012) examined shipping lines' optimal freight tariff to forwarders. Noting that the container transport service cannot be stored, they designed all-unit quantity discount schemes with multiple price-break points to maximize both the liner's profit and the forwarders' profit.

Fan et al. (2014) analysed the pricing strategies for fronthaul and backhaul shipping trips in liner shipping. They employed Johansen's vector error correction model to identify the critical trade imbalance ratios that disintegrate the freight rates for both directions. Lee, Boile et al. (2012) presented a three-level model to capture the interactions among oligopolistic ocean carriers, port terminal operators, and land carriers. A game theoretic approach is used to model these players who compete with each other in their pricing and routing decisions.

Liu and Yang (2015) considered the joint slot allocation and dynamic pricing problem in a container sea-rail multimodal transport system with uncertain demands. A two-stage optimal model is presented. The first stage is formulated as a stochastic integer programming model to determine long-term slot allocation in contract market and empty container allocation. The second stage is formulated as a stochastic nonlinear programming model to determine dynamic pricing and slot allocation in each period of free market. The chance constrained programming and robust optimization methods are used to transform the stochastic models into deterministic models. Xu et al. (2015) extended the model in Zhou and Lee (2009) to a three-echelon supply chain consisting of one carrier, two forwarders, and shippers. They presented a Stackelberg game model and analysed the optimal joint pricing policy and the repositioning cost sharing policy from the perspective of the whole service chain. Chen et al. (2016) studied a two-port system in which the shipments can be classified into two categories: goods and waste. The trade imbalance, e.g., on the trans-Pacific route and the Asia-Europe route, motivates carriers to accept low-valued waste to be shipped at bargain rates. Of course, when the imbalance still exists, empty containers must be repositioned from a surplus location to a shortage location. A monopoly and a duopoly model were built to find the optimal pricing strategy for carriers. Sensitivity analysis was also provided to analyse how trade imbalance, cost structure, price and competition intensity affect the profit.

3.5 A pricing model involving shipping line and freight forwarders

In the following, we briefly introduce the pricing and contracting model in Xu et al. (2015). Consider a container shipping supply chain consisting of a single shipping line and two freight forwarders providing transportation services between two ports. The two freight forwarders are located at two ports and only providing services from their home port to the other port. The shipping line acts as the leader and sets wholesale prices to freight forwarders. The freight forwarders then set service prices to shippers to attract cargo. Due to the trade imbalance, the shipping line has to reposition empty containers between two ports to balance the contain flows. The following notation is used:

w_i: the shipping line's wholesale price per unit to freight forwarders, i=1,2;
p_i: the freight forwarder's price per unit to shippers, i=1,2;
d_i: the contract quantity from customers from port i to the other port, i=1,2;
c_i: the unit transportation cost of laden containers from port i to the other port, i=1,2;
e_i: the unit transportation cost of empty containers from port i to the other port, i=1,2;
α_i: the volume of potential demand from freight forwarder i from port i to the other port, i=1,2;
β_i: the price sensitivity factor, which measures the responsiveness of demand from port i to the other port to the price, i=1,2;

We assume a linear model for shippers' demand such as: $d_i = \alpha_i - \beta_i p_i$, for i=1,2. The freight forwarders' profits (π_i , i=1,2) and the shipping line's profit (π) can be expressed as

$$\pi_i = (p_i - w_i)\, d_i,\ i=A, B;$$
$$\pi = (w_1 - c_1)\, d_1 + (w_2 - c_2)\, d_2 - e_1\, (d_2 - d_1)^+ - e_2\, (d_1 - d_2)^+.$$

Note that the shipping line is the leader and sets wholesale prices first. The freight forwarders maximize their profits, leading to $p_i = (\alpha_i + \beta_i w_i)/(2\beta_i)$ and $d_i = (\alpha_i - \beta_i w_i)/2$ for i=1,2. Corresponding to the demand relationships of both ports (i.e. $d_2 > d_1$, $d_2 < d_1$ and $d_2 = d_1$), it is easy to derive the shipping line's optimal pricing policies under three cases as shown in the following Proposition 3.1 (using the first-order condition of the shipping line's profit function).

Proposition 3.1 (Xu et al. (2015)). The optimal pricing decisions are given by
(i) If $\alpha_2 - \alpha_1 > \Delta^U$, then $w_1 = (\alpha_1 + c_1\beta_1 - e_1\beta_1)/(2\beta_1)$; $w_2 = (\alpha_2 + c_2\beta_2 + e_1\beta_2)/(2\beta_2)$;
(ii) If $\alpha_2 - \alpha_1 < \Delta^L$, then $w_1 = (\alpha_1 + c_1\beta_1 + e_2\beta_1)/(2\beta_1)$; $w_2 = (\alpha_2 + c_2\beta_2 - e_2\beta_2)/(2\beta_2)$;
(iii) If $\Delta^L \le \alpha_2 - \alpha_1 \le \Delta^U$, then

$$w_1 = \frac{\alpha_1}{2\beta_1} + \frac{\beta_1\beta_2(c_1 + c_2) + \beta_1(\alpha_1 - \alpha_2)}{2\beta_1(\beta_1 + \beta_2)}$$
$$w_2 = \frac{\alpha_2}{2\beta_2} + \frac{\beta_1\beta_2(c_1 + c_2) + \beta_2(\alpha_2 - \alpha_1)}{2\beta_2(\beta_1 + \beta_2)}$$

where $\Delta^L = \beta_2(c_2 - e_2) - \beta_1(c_1 + e_2)$; $\Delta^U = \beta_2(c_2 + e_1) - \beta_1(c_1 - e_1)$.

In the above, case (iii) represents the scenario that $d_1 = d_2$. In other words, under the condition $\Delta^L \le \alpha_2 - \alpha_1 \le \Delta^U$, the optimal pricing decisions of the shipping line and the two freight forwarders will lead to a balanced trade demand between ports. This indicates that the shipping line seeks cargo balance by pricing policy. Case (i) represents the scenario that $d_2 > d_1$, i.e. under the condition $\alpha_2 - \alpha_1 > \Delta^U$, the optimal pricing decisions of the shipping line and the two freight forwarders will lead to an imbalanced trade demand with more demand for shipping from port 2 to port 1. Case (ii) can be interpreted similar to (ii). The implication is that seeking a balanced realized demand is not always appropriate for the ocean carrier as shown in Cases (ii) and (iii).

3.6 Research opportunities

Fransoo and Lee (2013) have pointed out a few research directions in the areas of contracting, pricing, and risk management along the container supply chain. We add a few more areas for further research.

- The first area is the contractual relationship between shipping lines and shippers. The lack of communication and mutual understanding between shippers and carriers may explain the fluctuating service levels. On the one hand, shippers are the victims of service unreliability; on the other hand, they could be the root cause of the problem. Drewry (2012) reported that the 'on-time shipment of cargo' (which involves loading a container onto the ship on time) was less than 70%, which implies that the container will arrive late at the final destination port even if the originally intended ship voyage is on schedule.
- The second area is the contractual relationship between shipping lines and port/terminal operators. Notteboom (2006) showed that over 90% of schedule unreliability is port-related. A better contractual relationship between carriers and ports with appropriate incentive mechanisms would improve the quality of services.
- The third area is the pricing strategy of shipping lines. In practice, shipping lines design different types of pricing strategies for shippers and freight forwarders with different time scales. Further research on the pricing strategies and their applications is required. Moreover, an interesting question is whether any relationships exist between the pricing strategies of individual shipping lines and the volatile freight market.
- The fourth area is the application of game theory or agent-based models to more realistic scenarios. Zhou and Lee (2009) and Xu et al. (2015) proposed the Stackelberg game models for the pricing decisions of carriers and forwarders considering ECR costs in relatively simple scenarios. It would be desirable to generalize these models (e.g. to multiple players).
- Fifth, setting spot market pricing has been a big challenge in the recent few years. Some well-known freight rate index, such as Shanghai Freight Index, is usually the average freight rate carriers have charged shippers. For setting the spot rate, the General Rate Increase (GRI) scheme is often used to increase the freight rate. However, GRI has been misused recently. In 2015, there were 10 announcement of GRIs, in which 9 of them were over $1000. This led to extremely high volatility of spot freight rate. The recent agreement between European Commission and 15 major shipping lines indicated that GRI will not be allowed in the European routes soon. The geographical difference in pricing regulations (cf. Table 1) and the emerging new regulations (e.g. GRI ban in European routes) would bring new challenges and opportunities for further research.
- Sixth, the pricing and contracting issue is often considered together with other planning issues such as horizontal competition and cooperation (e.g. Alvarez-

SanJaime et al. 2013), slot allocation (Liu and Yang, 2015), port pricing (e.g. Bae et al. 2013; Song et al. 2016), empty container repositioning (Zhou and Lee 2009; Fan et al. 2014; Xu et al. 2015; Chen et al. 2016). More research could be undertaken in this direction empirically and theoretically.

4. Network design and routing

Network design and routing is related to the competition and cooperation issue, and also the pricing and contracting issue from the channel relationship perspective. For example, within a strategic alliance, shipping line members have to coordinate their service networks; within a vertical channel, shipping line will design their service network taking into account the location of their dedicated container terminals; external and internal pricing/contracting strategies also affect the service network design and container routing. In this section, we take the organizational perspective to address the network design and routing issue.

4.1 Service network design

A container shipping network consists of a number of service routes. Each service route forms a round trip involving a fixed sequence of port of calls. Each port of call in a service route is served at a fixed frequency, normally on a weekly basis, by a set of vessels. The container network design problem aims to select ports, construct service routes and deploy a fleet of vessels so that service requests/customer demands can be served effectively. A number of survey papers have covered this topic, e.g. Christiansen et al. (2004); Christiansen et al. (2007); Christiansen et al. (2013); Brouer et al. (2014a); Meng et al. (2014); and Tran and Haasis (2015).

In a broad perspective, management decisions in service network design may include: how many service routes should be opened; how a service route should be structured in terms of port rotation and schedule; which frequency the service route should be; which type of vehicles and how many should be deployed in a service route; how to manage the container fleet, and how the customer demands should be assigned over the service network (e.g. Agarwal and Ergun 2008a; Alvarez 2009; Reinhardt and Pisinger 2012; Mulder and Dekker 2014; Plum et al. 2014; Wang and Meng 2014). In this view, service network design includes a number of sub-problems such as service route design, vessel fleet deployment, vessel scheduling, container fleet management, and container cargo routing. More often, these sub-problems may be treated separately, or in a simplified or aggregated format under the umbrella of service network design problem.

In a narrow perspective, service network design mainly focuses on determining the service route structures to better service customer demands. Service routes may be created from the given set of ports and optimized in a combinatorial optimization way (e.g. Shintani et al. 2007; Tran 2011; Song and Dong 2013; Plum et al. 2014; Brouer et al. 2014b), or selected from a set of candidate service routes that have been pre-specified based on industrial and/or historical experience (e.g. Mulder and Dekker 2014; Brouer et al. 2014a; Wang and Meng 2014; Liu et al. 2014; Dong et al. 2015).

A customer demand may be regarded as a requirement to transport a number of laden containers from a specified origin to a specified destination. In a multi-service network, transhipment operation represents an interaction among routes. The cost and profitability of the service network depend on the paths chosen to transport the cargo and the vessels deployed on service routes.

4.2 Container cargo routing

Container cargo routing concerns the assignment of customer demands over the shipping network in the most economical way. It can be regarded as a sub-problem of service network design to evaluate and feedback the performance of a given service network. On the other hand, container cargo routing implies which routes will be selected and utilized to transport the containers. In that sense, service network design may be regarded as an implicit sub-problem of container cargo routing problem, e.g. select and utilize a set of candidate service routes to serve a set of customer demands.

A large number of studies have been conducted on container cargo routing, e.g. the assignment of container shipments over global shipping networks provided by all existing shipping lines (Song et al. 2005); container routing using various link-based network flow models (Wang 2014); container routing with cabotage constraints (Wang et al. 2013); container routing with empty container repositioning (e.g. Brouer et al. 2011; Bell et al. 2011; Song and Dong 2012; Bell et al. 2013; Huang et al. 2015); container routing considering elastic demand on freight rate (Wang et al. 2015b); cargo routing with network design (essentially all network design studies involve cargo routing or demand assignment).

4.3 Complexity of the network design and container routing problem

Agarwal and Ergun (2008a) proved that the problem of designing a shipping network for liner containers is NP-hard by reducing the problem to a Knapsack problem. Brouer et al. (2014) further proved that the container shipping network design problem is strongly NP-hard by reducing it to a traveling salesman problem (TSP). In some cases, a set of service routes is pre-specified. The network design problem then becomes the selection of service routes to meet the given customer demands. Brouer et al. (2014a) showed that this problem can be reduced to a set-covering problem (e.g. choose the cheapest set of service routes to cover all ports), which is also strongly NP-hard. We state these results in the following proposition.

Proposition 4.1 (Brouer et al. 2014a): (i) The problem of designing a shipping network for liner containers is strongly NP-hard; (ii) solving the problem with a set of pre-specified service routes is also strongly NP-hard.

Since ship deployment and container routing are often part of the shipping network design problem, their computational complexity should be studied. We have the following results (which can be shown easily by reducing the Knapsack problem to our problems).

Proposition 4.2: Deploying a fleet of vessels over a given set of service routes is NP-hard.

Proposition 4.3: Container routing in a given shipping network is NP-hard if shipments are not splitable.
Proof: We reduce the problem to the Knapsack problem. Suppose given a set of service routes N with each route has a common leg and all demands have to be carried across this leg. The total capacity of the leg is denoted by M. Each demand (i.e. shipment) has a volume w_i

and revenue c_i. The selection of the demands to maximize the total revenue subject to service capacity is equivalent to the 0-1 Knapsack problem. This completes the proof.

In the following, we first introduce a container routing model for a given set of shipping service routes, then present the problem of designing a single service route including route generation. Finally, we discuss the relevant literature and the research opportunities.

4.4 A model of single service route design

The problem of designing a single service route include both tactical decisions (port rotation, ship deployment) and operational decisions (ship sailing speed, container loading/unloading, empty container repositioning). Here the main challenge lies in port rotation generation and selection.

In fact, single service route design is a combinatorial optimisation problem. For example, let us consider a seven-port service route in which five of these ports may be called twice on a single round-trip. This gives rise to a total of 12 port calls and nearly $12! \approx 10^8$ different port rotations. It is computationally difficult to evaluate all these port rotations. However, by observing the empirical shipping service routes, it is possible to narrow down the port rotations substantially, even to a manageable size.

Song and Dong (2013) introduced a new concept called *directed simple cycle*, which is defined as a graph in which all nodes are connected forming a single closed loop with all edges being oriented in the same direction. Empirical data showed that topologically almost all shipping service routes can be regarded as a series of such directed simple cycles, of which any two neighbouring directed simple cycles are joined by only one common port, as shown in Figure 4.1.

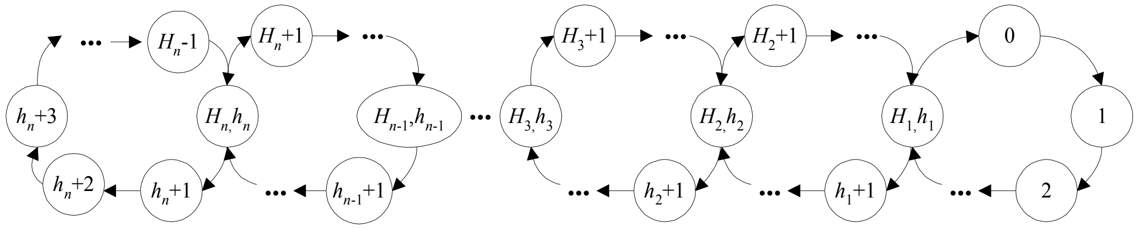

Figure 4.1. Generic shipping service route (Song and Dong 2013)
Note: (i) h_i and H_i refer to the same port; (ii) $h_i < H_i$ in the port call sequence

It is observed that in practice the number of directed simple cycles within a shipping service route is very small. Of the 154 service routes in 2008 on three major trade lanes (Asia-North America, Asia-Europe, Europe-North America), 45% have only one directed simple cycle, 20% have two directed cycles and 16% have three directed cycles (Song and Dong 2013). This implies that the problem of designing a single service route can be greatly simplified by limiting the number of directed cycles when designing its route structure.

In addition, the knowledge of the port geographic locations is also very useful in designing the service route structure and planning ship deployment from the practical perspective. For example, if a service route connects only two continents (e.g. trans-Pacific or trans-Atlantic service routes), it is practical for a vessel to visit each continent only once on a single round trip. This means we can split the ports into two sub-groups according to their geographic locations, which will simplify route design.

For a given port rotation, the shipping company may further need to deploy ships on the service route, meet shipment demand, reposition empty containers, and determine the sailing speed in order to minimize the total operating cost. To simplify the narrative, we assume that the same type of ship will be deployed on the service route and the sailing speed is constant on all sea legs. We also assume that the weekly demand between pairs of ports is constant. The following notation is introduced (based on Song and Dong 2013):

Given parameters:

P: the set of ports on the service route;

N: the number of port calls on the route. The port calls are indexed from 0 to $N-1$;

D_{ij}: the weekly demand from port call i to port call j;

$p(i)$: the port to which the ith port call refers on the service route;

d_i: the distance in nautical miles from port call i to the next port call on the route;

h_i: the handling rate at port i in TEUs per hour, which represents the number of lifts (including both lifting-on and lifting-off activities) in TEUs per hour.

t_i^a: the ship approach and docking time (in hours) on port call i when it arrives.

t_i^d: the ship exit time (in hours) from port call i when it departs.

t^p: the total time (in hours) that a ship spends at the ports on a round-trip, including approach and docking and exit times. Let $t^p(i)$ denote the time that a ship spends on port call i.

t^s: the total time (in hours) that a ship spends at sea on a round-trip.

t_{ij}: the transit time in hours from port call i to port call j.

C_i^l: unit cost of loading containers at port $p(i) \in P$;

C_i^u: unit cost of unloading containers at port $p(i) \in P$;

C_{ij}^p: unit penalty cost for lost-sales from demand from port call i to port call j;

C^f: the fuel cost (USD/tonne);

C^{LI}: the average laden container inventory holding cost per TEU per day (USD/TEU/day).

C^{EI}: the average empty container inventory holding cost per TEU per day (USD/TEU/day).

V: the set of ship types;

Cap_v: the vessel capacity of vessel type v;

$G^s(v)$: the daily cost of owning a ship of type v (USD/day), which includes all the costs incurred even when the ship is not sailing. For a time-chartered ship it refers to the daily charter hire.

$F(v, s)$: the daily bunker fuel consumption (tonnes/day) for a ship of type v sailing at speed s at the sea;

$F^p(v)$: the daily bunker fuel consumption (tonnes/day) for a ship of type v at a port.

$G^p(i, v)$: the fixed ship berthing cost per call at port i for a ship of type v (USD/per call).

Decision Variables:

y_{ij}: the weekly laden containers that are loaded on a ship from port call i to port call j;

x_{ij}: the weekly empty containers that are loaded on a ship from port call *i* to port call *j*;

v: the ship (or vessel) type to be selected for the service route ($v \in V$). Here a ship type can be regarded as a combination of ship attributes such as carrying capacity, economic and environmental efficiency indexes.

n_v: the number of ships (of the selected ship type *v*) to be deployed on the service route.

s: the sailing speed of ships at sea in nautical miles per hour, which takes a value between the minimum speed S_{min} and the maximum speed S_{max}.

Mathematically, for a given port rotation, the problem is to find the optimal solution $\{y_{ij}, x_{ij}, v, n_v, s\}$ by minimizing the average total daily cost of operating the shipping service, denoted by *J*. The average total daily operating cost of the shipping service route can be defined as the number of deployed ships (i.e. n_v) multiplied by the total operating cost incurred by a single ship on a round-trip divided by the journey time in days (Ronen 2011). Note that the journey time on a round-trip is equal to $7 \cdot n_v$ days in order to maintain the weekly service. Therefore, the daily total operating cost is equal to the total operating cost incurred by a single ship on a round-trip divided by 7. The mathematical programme is given as follows:

$$
\begin{aligned}
\text{Minimize } J = {} & n_v \cdot G^s(v) + C^f \cdot [F(v,s) \cdot t^s / 24 + F^p(v) \cdot t^p / 24] / 7 \\
& + \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} C_i^l (y_{ij} + x_{ij}) / 7 \; + \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} C_i^u (y_{ji} + x_{ji}) / 7 \; + \sum_{i=0}^{N-1} G^p(i,v) / 7 \\
& + C^{LI} \cdot \sum_{i=0}^{N-1}\sum_{j=}^{N-1} t_{ij} \cdot y_{ij} / 24 / 7 \; + C^{EI} \cdot \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} t_{ij} \cdot x_{ij} / 24 / 7 \\
& + \sum_{i=0}^{N-1}\sum_{j=}^{N-1} C_{ij}^p (D_{ij} - y_{ij}) / 7 \qquad (4.1)
\end{aligned}
$$

subject to

$$y_{ij} \le D_{ij} \text{ for any } i, j \qquad (4.2)$$

$$\sum_j \sum_{i, p(i)=p} (x_{ij} + y_{ij}) = \sum_i \sum_{j, p(j)=p} (x_{ij} + y_{ij}) \text{ for any } p \in P \qquad (4.3)$$

$$\sum_{k=2}^{N} \sum_{j=1}^{k} (x_{i+k, i+j} + y_{i+k, i+j}) \le Cap_v \text{ for any } i \qquad (4.4)$$

$$t^p(i) = t_i^a + t_i^d + \sum_{j=0}^{N-1} (y_{ij} + y_{ji} + x_{ij} + x_{ji}) / h_i \text{ for any } i \qquad (4.5)$$

$$t^p = \sum_i t^p(i) \qquad (4.6)$$

$$t^s = 7 \cdot 24 \cdot n_v - t^p \qquad (4.7)$$

$$S_{min} \le s \le S_{max} \qquad (4.8)$$

$$s = \sum_i d_i / t^s \qquad (4.9)$$

$$t_{ij} = \sum_{k=i}^{j} (t^p(k) + \frac{d_k}{s}), \text{ if } j>i \qquad (4.10)$$

$$t_{ij} = \sum_{k=i}^{j+N} (t^p(k \bmod N) + \frac{d_k}{s}), \text{ if } j<i \qquad (4.11)$$

$$x_{ij} \geq 0,\ y_{ij} \geq 0, \text{ for any } i, j;\ v \in V;\ n_v \text{ is positive integer.} \tag{4.12}$$

In Eq. (4.1), the first term represents the ship cost including crew, repair and maintenance, insurance, administration, possibly capital costs etc. The second and third terms represent fuel consumption costs at sea and ports respectively. The fourth and fifth terms represent the container handling costs at ports for loading and unloading respectively. The sixth term represents the port access cost. The seventh term represents the cargo (laden container) inventory holding costs. The eighth term represents the empty container inventory in-transition costs. The last term represents the lost-sales penalty costs. Constraint (4.3) is to ensure the flow balance for each port. Constraint (4.4) is to ensure the total number of containers (laden and empty) not exceeding the ship capacity in each leg. Here the subscript should be understood as the remainder with the mode *N* when it equals or is greater than *N*. Other constraints are relatively straightforward according to their definitions.

It should be noted that the decision on the vessel type (v) affects not only the vessel capacity, but also the ship daily operating cost, the ship bunker fuel consumption, and the ship berthing cost. The above formulation aims to minimize the total cost subject to a set of constraints such as flow balance, vessel capacity, and speed range. A two-stage approach can be used to solve the above problem of designing a single service route:

Stage 1: By limiting the number of directed cycles on the service route and grouping the ports according to knowledge of the port geographic locations, we can identify a set of candidate port rotations.

Stage 2: For each candidate port rotation, we solve the optimisation problem in (4.1)–(4.12).

Two- or three-stage approaches are quite common in tackling the problem of designing liner shipping networks, due mainly to the different planning levels/tasks involved such as strategic/tactical level and operational level, but also to technique requirements in order to simplify the solution procedure or reduce the computational complexity.

4.5 A link-based network flow model for container cargo routing

For a given set of shipping service routes, the container routing problem concerns the assignment of customer demands across the shipping network in the most economical way, which implies the selection of service routes. Link-based (e.g. Agarwal and Ergun 2008a; Brouer et al. 2011; Wang 2014), or path-based (e.g. Brouer et al. 2011; Song and Dong 2012) network flow models are often used to tackle this problem.

We present an origin-destination (O-D)-link-based model below. To simplify the formulation, we assume that container shipment is splitable. In other word, the customer demands for a specific O-D pair can be regarded as an aggregated volume that may be fulfilled partially. This would enable us to formulate a linear programming model instead of an integer programming model. We introduce the notation for the model.

Given parameters:

P: the set of ports;

od: an index to represent the O-D pair from port $o \in P$ to port $d \in P$;

D_{od}: the weekly demand from $o \in P$ to $d \in P$;

C^l_p: the unit cost of loading containers at port $p \in P$;

C^u_p: the unit cost of unloading containers at port $p \in P$;

C^t_p: the unit cost of transhipping containers at port $p \in P$;

C^p_{od}: the unit penalty cost for lost-sales from od;

R: the set of shipping routes;

R_p: the set of routes that call at port $p \in P$;

N_r: the number of port calls on the route $r \in R$;

I_r: the set of port call indices on the route $r \in R$, i.e. $I_r := \{1, 2, \ldots, N_r\}$;

p_{ri}: the port that corresponds to the ith port call on route r;

$I_{r,p}$: the set of port call indices corresponding to port p on the route $r \in R$, i.e. $I_{r,p} := \{i \in I_r \mid p_{ri} = p\}$;

Cap_r: the vessel capacity on route $r \in R$;

C_{ri}: unit cost of transporting laden containers on vessel on leg i on route $r \in R$;

Decision variables:

$y^l_{od,ri}$: the number of containers from od that are loaded on the ith port call on route r;

$y^u_{od,ri}$: the number of containers from od that are unloaded on the ith port call on route r;

$y^f_{od,ri}$: the number of containers from od that are carried on board on leg i (from the ith port call to the i+1th port call) on route r;

y_{od}: the fulfilled demand from od;

The objective is to minimize the total cost including i) the laden and empty container loading (lifting-on) cost, ii) the laden and empty container unloading (lifting-off) cost, iii) the laden and empty container transhipment cost, iv) the lost-sale penalty cost, v) the laden container transportation cost on vessel, and vi) the empty container transportation cost on vessel.

To simplify the narrative, we introduce a few intermediate variables. Let y^l_p, y^u_p, and y^t_p denote the total number of container loading operations (including export and transshipment), the total number of container unloading operations (including import and transshipment), and the number of container transhipment operations at port p, respectively. The container routing problem can be formulated as a linear programming model:

$$\min_{\substack{y_{od}, y^l_{od,ri}, y^u_{od,ri}, \\ y^f_{od,ri}, y^l_p, y^u_p, y^t_p}} \{\sum_{p \in P}(C^l_p y^l_p + C^u_p y^u_p + C^t_p y^t_p) + \sum_{r \in R}\sum_{i \in I_r}(C_{ri} \sum_{o,d \in P} y^f_{od,ri}) + \sum_{o \in P}\sum_{d \in P} C^p_{od}(D_{od} - y_{od})\} \quad (4.13)$$

subject to

$$y^l_p = \sum_{r \in R_p}\sum_{i \in I_{r,p}}\sum_{o,d \in P} y^l_{od,ri}, \text{ for any } p \in P; \quad (4.14)$$

$$y^u_p = \sum_{r \in R_p}\sum_{i \in I_{r,p}}\sum_{o,d \in P} y^u_{od,ri}, \text{ for any } p \in P; \quad (4.15)$$

$$y^t_p = y^l_p - \sum_{d \in P} y_{pd} = y^u_p - \sum_{o \in P} y_{op}, \text{ for any } p \in P; \quad (4.16)$$

$$y^f_{od,ri} = y^f_{od,ri-1} - y^u_{od,ri} + y^l_{od,ri}, \text{ for any } o,d \in P, r \in R, i \in I_r; \quad (4.17)$$

$$\sum_{r\in R_o}\sum_{i\in I_{r,o}} y^l_{od,ri} = y_{od}\text{, for any } o,d\in P; \tag{4.18}$$

$$\sum_{r\in R_d}\sum_{i\in I_{r,d}} y^u_{od,ri} = y_{od}\text{, for any } o,d\in P; \tag{4.19}$$

$$\sum_{r\in R_p}\sum_{i\in I_{r,p}} (y^u_{od,ri} - y^l_{od,ri}) = 0\text{, for any } o,d,\ p\in P,\ o\neq p,\ d\neq p; \tag{4.20}$$

$$\sum_{o,d\in P} y^f_{od,ri} \leq Cap_r\text{, for any } r\in R,\ i\in I_r; \tag{4.21}$$

$$y_{od} \leq D_{od}\text{, for any } o,\ d\in P; \tag{4.22}$$

$$y^l_{od,ri} \geq 0,\ y^u_{od,ri} \geq 0,\ y^f_{od,ri} \geq 0,\ y_{od} \geq 0,\ y^l_p \geq 0,\ y^u_p \geq 0,\ y^t_p \geq 0. \tag{4.23}$$

Eqs. (4.14)–(4.16) represent the total containers that are loaded, unloaded, and transhipped at port p. Eq. (4.17) represents the flow balancing for containers at each port for each service route. Eqs. (4.18) and (4.19) indicate the total fulfilled demand from *od* that must be loaded at port o and unloaded at port d. Eq. (4.20) states that the number of containers unloaded and loaded for each *od* at a transhipment port must be balanced. Constraint (4.21) represents the vessel capacity constraints on each leg for each route. Constraint (4.22) states that the fulfilled demand does not exceed the customer demand. Constraint (4.23) represents the non-negative of the relevant decision variables.

The majority of general shipping network design models in the literature take the tactical planning perspective (often assuming demand is given and constant). They focus on decisions such as port rotations, service route selection, ship deployment, and container assignment. When operational decisions such as vessel sailing speed and container loading/unloading times are included, the research is often narrowed down to a specific network structure or a single service route.

In practice, a shipping line cannot reshuffle its shipping service routes overnight because shipping schedules are fixed months in advance. More practically, a shipping line may adjust its service routes and ship deployment on a small scale from time to time, e.g. in response to changes in demand volume and pattern, and to delivery of new ordered vessels. Therefore, the design of a single service route is also practically important.

4.6 Research opportunities

Earlier research on shipping network design (before 2000) seldom considered a regular service frequency. Nowadays, a weekly service has become almost the industry standard in container shipping. Such regularity simplifies the supply chain operations for shippers, ocean carriers, and terminal operators. Therefore, recent research (e.g. Agarwal and Ergun 2008a, and the relevant literature onwards) has generally adopted the weekly service frequency in container network design. Although a number of interesting studies have been conducted (see the review papers by Tran and Haasis 2015, Brouer et al. 2014a, and Meng et al. 2014), container shipping network design is still a young topic. Since the network design and container routing problem consists of a few sub-problems, which are by themselves NP-hard, the topic is challenging overall. Brouer et al. (2014a) provided a benchmark suite of data instances (termed LINER-LIB-2012), which may facilitate the research development in container shipping network design. We suggest the following areas for further research:

- General network design and container routing: a realistic shipping network for most global shipping lines includes multiple routes with multiple butterfly ports and multiple transhipments. Therefore, port rotation generation and container routing in general networks deserve more research. Recently Plum et al. (2014) made an attempt in this direction. But their mixed-integer programing model was only able to solve two of the smallest instances of LINER-LIB-2012 due to the large number of variables and constraints. On the other hand, Meng et al. (2014) pointed out that most of the existing literature in the design of liner container shipping networks is devoted to itinerary design and ship deployment assuming a fixed sailing speed and without considering schedules. Two research directions can be pursued: One is to develop more efficient solution methods; the other is to incorporate some operational decisions such as vessel sailing speed and port handling activities.
- Specific/single-route design and container scheduling: specific route structure design includes the hub-and-spoke network (e.g. Imai et al. 2009; Meng and Wang 2011), and single-route design (e.g. Shintani et al. 2007; Song and Dong 2013). This type of research models the operational decisions in great detail together with route structure creation and ship deployment. Thus, the interaction between the strategic/tactical decisions and the operational decisions could be more appropriately modelled. Further research includes identifying other types of route design problems based on empirical data and practical requirements, and extending the research to multiple service routes or more general networks. Brouer et al. (2014b) and Plum et al. (2014) have made some attempts in this direction.
- Design of intermodal container transport networks: Container transport is a typical example of intermodal transportation. Note that the origins and destinations of laden containers are usually inland locations, although some containers are unpacked at sea ports. From the supply chain management perspective, it would be desirable to design intermodal transport networks for both seaborne transport and inland transport. Only a couple of studies have taken the global intermodal perspective. For example, Tran (2011) considered a single-route design problem including decisions such as port choice, sequence of selected ports, and loading/unloading ports for each shipment by minimizing the total cost consisting of ship cost, port tariff, inland transport cost, and inventory cost. Meng et al. (2012) developed a model for the design of a large-scale intermodal liner shipping service network. Laden container routing in the inland transportation network is combined with maritime network design. Empty container flows in the hinterland and maritime networks were also discussed. More research is still required in this area.
- Dynamic and uncertain factors: Almost all shipping network design models in the literature have assumed that all demands are deterministic, and even fixed on a weekly basis. In reality, container demand fluctuates significantly from season to season. Both long-term contractual demand and spot-market demand contribute to the fluctuations. Future research should incorporate dynamic and uncertain factors including customer demand, port operations, and sea conditions into shipping network design and container routing.
- Alliance factor: on some shipping routes, especially on trans-Pacific and Asia-Europe routes, most shipping lines have formed alliances to provide shipping services jointly. This brings up another challenging issue for global shipping lines, i.e. how to design an integrated shipping network, in which some services are operated solely by the company, whereas other services are operated under the alliance. Existing literature on shipping network design has focused either on a single company or an alliance,

with little attention on the coordination of the two. On the other hand, the problem of designing networks for multiple shipping lines simultaneously in a competition context has not been studied.

5. Ship scheduling and slow steaming

Ship scheduling brings the time dimension into shipping service planning. In a broad viewpoint, ship scheduling covers ship deployment, schedule design, speed selection, and dynamic routing and scheduling. This implies that both tactical and operational decisions may be involved in ship scheduling. For example, some of them may be included in service network design problem whereas others may be incorporated into disruption management problem. In a narrow viewpoint, ship scheduling concerns the development of vessel arrival and departure timetables, and the selection of planned sailing speed. Slow steaming refers to the practice that a ship is planned to sail at a speed significantly less than its designed speeds, which can be regarded as a component of ship scheduling. This section takes the narrow viewpoint of ship scheduling and focuses on ship schedule design and planned speed selection.

5.1 Ship scheduling

The ship scheduling problem (not limited with container shipping) has been covered in a few survey papers, e.g. Ronen 1983; Ronen 1993; Christiansen et al. (2004); Christiansen et al. (2007); Psaraftis and Kontovas (2013); Christiansen et al. (2013); Brouer et al. (2014a); Meng et al. (2014); and Tran and Haasis (2015).

In container shipping, ship scheduling involves determining the planned arrival and departure times on each port call for service routes, where the port rotations of the service routes are often given. The schedules essentially specify the container transit times for each pair of ports. Once the schedule is designed, the speeds of the containerships are largely determined. Therefore, the ship scheduling problems always include speed selection/optimization either explicitly or implicitly.

An important characteristic of container shipping is the presence of various uncertainties. This causes ships to arrive at ports out of the planned time windows, which is called schedule unreliability. Due to the cascading effect, once a ship is delayed at one port, it is likely to be delayed at subsequent ports. An empirical survey showed that over 93% of schedule delays were caused by port-related uncertainty factors such as port access and terminal operations (Notteboom 2006). Recent statistics shows that the actual arrival for all vessel calls deviated from the schedule by about 0.6 days (Drewry 2012). The causes of schedule unreliability and its impact on the stakeholders in the container shipping supply chain were further illustrated in Vernimmen et al. (2007).

Very few studies have addressed the container ship scheduling problem taking into account the uncertainty at ports and/or at sea. Wang and Meng (2012b) developed a mixed-integer non-linear stochastic model for the liner ship route scheduling problem with sea contingency and uncertain port times in order to minimize the ship cost and bunker cost, while fulfilling the port-to-port transit time constraints. Ship delays are not allowed. Wang and Meng (2012a) considered the robust schedule design problem for a liner ship route. The objective is to achieve the optimal trade-off between buffer time allocation and schedule robustness in terms of reliability, integrity, and stability. Qi and Song (2012) designed an optimal containership schedule on a service route with uncertain port times by minimizing an expected objective function consisting of fuel consumption and delay penalty. They showed that the shortest leg is the most problematic leg on a round-trip when designing the optimal schedule to achieve 100% service level and minimizing the fuel consumption. In Wang and Meng (2012a) and Qi and Song (2012), the vessel speed is determined implicitly with the aim to catch up with the schedule as much as possible if the vessel has been delayed. Song et al. (2015) considered a joint tactical planning problem for the number of ships, the planned maximum sailing speed, and the liner service schedule in order to simultaneously optimize the expected cost, the service reliability and the shipping emission in the presence of port time uncertainty. A multi-objective genetic algorithm was applied to obtain Pareto-optimal solutions.

Wang et al. (2014b) formulated the ship route schedule design problem into a mixed integer nonlinear nonconvex optimization problem. The model is deterministic but the availability of port in a week (defined as port time window) is considered. A similar deterministic schedule design problem using dynamic programming method was addressed in Wang et al. (2015a).

5.2 Slow steaming

Slow steaming may be defined as the practice of sailing cargo ships at speeds significantly lower than their design speed. Slow steaming in the container shipping industry started around 2008, when the market began experiencing significant overcapacity, decreasing trade demands, declining freight rates, and increasing fuel prices. Slow steaming acted as one of the effective cost-cutting strategies to mitigate the impact of the global economic crisis in 2008 on the container shipping industry. The designed speed of a containership is usually in the range between 23 knots and 26 knots. Slow steaming is classified into three levels: normal slow steaming (~21 knots); extra slow steaming (~18 knots), and super slow steaming (~15 knots). Nowadays, almost every shipping line has adopted slow steaming to a large degree.

The vessel sailing speed has a significant impact on the total operating cost (Notteboom and Vernimmen 2009). The bunker fuel consumption of vessels increases approximately cubically with the speed of the vessel (Ronen 1983; Wang and Meng 2012c). When the bunker fuel price is around $500 per tonne, the fuel consumption cost constitutes about 75% of the ship operating costs for a large containership, and reducing the sailing speed by 20% from its designed speed can reduce daily bunker consumption by 50% (Ronen 2011).

The steep increase in oil prices in 2009 drove containership operators to reduce the sailing speed of their vessels in order to reduce bunker fuel consumption and the operational cost. Slower sailing speed leads to a longer transit time of the shipping service loop, which requires adding one or more vessels to the service loop in order to maintain the weekly service frequency. Research showed that the resulting bunker cost savings from slower sailing speed are sufficient to compensate the cost of chartering in and operating the additional vessels for a given service route (Vernimmen et al. 2007). The benefit would be more obvious if the shipping line has already had spare vessels in the fleet. In that sense, slowing down the vessel speed could absorb more vessels and overcome the overcapacity issue. Drewry Shipping Consultant estimated that about 7% of the world's containership fleet has been absorbed via slow steaming.

Ronen (2011) presented a cost model to analyze the trade-off between reducing ship speed and adding extra ships to a container service route by minimizing the annual operating cost of the route. Wang and Meng (2012c) optimized vessel speed on each leg of each ship route in a shipping network considering container routing. A mixed integer nonlinear programming model is formulated and solved using an approximation method. Psaraftis and Kontovas (2013) comprehensively reviewed the models in which ship speed is one of the decision variables in maritime transportation. They classified the models according to a set of parameters: optimization criterion, shipping market, decision maker, fuel price, freight rate, fuel consumption function, ship fleet, cargo inventory costs, port-related variables, and emissions. The ship sailing speed and the number of deployed ships are two critical decisions in the slow steaming practice. Psaraftis and Kontovas (2014) raised the awareness of various factors such as payload, weather conditions, hull conditions, fuel price, state of the market, inventory in-transit, mixed chartering, which may affect the ship speed decisions.

Ferrari et al. (2015) claimed that slow steaming induces narrowing of the sample of the direct call ports per service, which increases inter-port competition. They discussed the impact of slow steaming on finance, service differentiation, environment, and inter-port competition. Wong et al. (2015) presented a slow steaming decision support sustainability model to balance the operation decision on speed reduction with the factors on bunker cost, shipment delay, and carbon emission. Song et al. (2015) analysed the relationships between multiple objectives and decision variables, and presented a simulation-based non-dominated sorting genetic algorithm to simultaneously optimize the expected cost, service reliability and shipping emissions in the presence of port time uncertainty. Mansouri et al. (2015) provided a comprehensive review to examine the potential of multi-objective optimization as a decision support tool to achieve the trade-off between environmental objectives and economic objectives.

Cariou (2011) discussed the sustainability of slow steaming. He stated that slow steaming can only be sustained given a bunker fuel price of at least \$350 per tonne for the main container trades. However, since the fuel price has dropped from over \$500 per tonne in 2014 to less than \$350 per tonne in 2015, to less than \$200 per tonne in early 2016, there is a lot debate and requires a revisit about the viability of slow steaming. We will present two formulations below to address the sustainability of the slow steaming practice in a more comprehensive way.

5.3 Two models for slow steaming

As a vessel's planned sailing speed depends on the number of total vessels deployed (due to the weekly frequency requirement), the slow steaming problem is essentially to determine the optimal number of vessels to be deployed on a single service route. In this section we assume that vessels are homogeneous because our focus is on a specific service route. Before we present the slow steaming models, the following notation is introduced:

N: the number of port calls on the route. The port calls are indexed from 0; and the Nth port call refers to the vessel sailing back to the first port;

D_{ij}: the weekly demands in TEUs from port call i to port call j;

d_{ij}: the distance in nautical miles from port call i to port call j on the route;

n: the number of ships to be deployed on the service route;

s: the sailing speed of ships in nautical miles per hour, which takes a value between the minimum speed S_{min} and the vessel design speed S_0;

t^p : the total time (in hours) that a ship spends at the ports on a round-trip;

t_{ij}^p : the time that a ship spends on port calls i, i+1, …, j; hence t_{ii}^p refers to the port time on port call i; and $t^p = t_{0N-1}^p$;

t^s : the total time (in hours) that a ship spends at sea on a round-trip;

t_{ij} : the transit time (in hours) from port call i to port call j;

C_i^l : the unit cost of loading containers on port call i;

C_i^u : the unit cost of unloading containers on port call i;

C^f : the fuel price (USD/tonne);

C^{LI} : the average laden container inventory holding cost per TEU per day (USD/TEU/day);

r_{ij} : the revenue from satisfying the demand (USD/TEU) from port call i to port call j;

G^s : the daily cost of owning a ship (USD/day), which includes all the costs incurred even when the ship is not sailing. For a time-chartered ship it refers to the daily charter hire;

F_0^s : the daily fuel consumption (tonnes/day) for a ship sailing at the vessel design speed S_0 at sea;

$F^s(s)$: the daily fuel consumption (tonnes/day) for a ship sailing at speed s at sea, which is given by $F^s(s) = F_0^s \cdot (s / S_0)^3$ (e.g. Ronen 2011).

F^p : the daily bunker fuel consumption (tonnes/day) for a ship at a port.

G_i^p : the fixed ship berthing cost per port call i for a ship (USD/call).

Note that the journey time in a round-trip is equal to $7 \cdot n$ days in order to maintain the weekly service. The total profit of the service route with n vessels over a round-tip period is given by

$$n \cdot \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} r_{ij} D_{ij} - n \cdot 7 \cdot n \cdot G^s - n \cdot C^f \cdot [F^s(s) \cdot t^s / 24 + F^p \cdot t^p / 24] - n \cdot \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} C_i^l D_{ij}$$
$$- n \cdot \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} C_i^u D_{ji} - n \cdot \sum_{i=0}^{N-1} G_i^p - n \cdot C^{LI} \cdot \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} t_{ij} \cdot D_{ij} / 24 \qquad (5.1)$$

Therefore, the daily profit of the service route with n vessels can be obtained by dividing (5.1) by $7n$. Note that, $t^s = 7 \cdot 24 \cdot n - t^p$; $s = d_{0N} / t^s$; $t_{ij} = t_{ij}^p + d_{ij} / s$ subject to $S_{min} \le s \le S_0$. Moreover, $F^s(s) = F_0^s \cdot (s / S_0)^3$, where S_0 is the designed speed of the vessel. Eq. (5.1) can be rewritten as,

$$\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} r_{ij} D_{ij} / 7 - n \cdot G^s - C^f \cdot \left(\frac{F_0^s d_{0N}^3}{168 S_0^3 (168n - t^p)^2} + \frac{F^p t^p}{168}\right) - \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} C_i^l D_{ij} / 7$$
$$- \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} C_i^u D_{ji} / 7 - \sum_{i=0}^{N-1} G_i^p / 7 - C^{LI} \cdot \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} \left(\frac{t_{ij}^p}{168} + \frac{d_{ij}(168n - t^p)}{168 d_{0N}}\right) D_{ij} \qquad (5.2)$$

Note that the number of vessels, n, and the sailing speed, s, are decision variables. With the assumption that other system parameters are fixed, we have the following result.

Proposition 5.1. Suppose a shipping line has a flexible homogeneous vessel fleet. The optimal number of vessels to be deployed on the single shipping route is determined by

$$n^* = \arg\min_n (nG^s + n\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\frac{C^{LI} d_{ij} D_{ij}}{d_{0N}} + \frac{C^f F_0^s d_{0N}^3}{168 S_0^3 (168n - t^p)^2}) \qquad (5.3)$$

subject to $S_{min} \le d_{0N}/(168n - t^p) \le S_0$ and n is a positive integer.

Note that the first term and the third term in Eq. (5.3) are costs directly incurred to the shipping line, whereas the second term (the inventory cost) is normally incurred to the shippers. Therefore, the optimal number of vessels, n^*, from the shipping line's perspective (under $C^{LI} = 0$) will be greater than that from the supply chain's perspective (under $C^{LI} > 0$).

Proposition 5.1 assumes that the shipping line has a flexible vessel fleet, i.e. it has the flexibility to charter vessels if needed. In practice, a charter contract often runs for several years and therefore a shipping line's vessel fleet may be fixed in the planning horizon. Therefore, it is also interesting to examine the vessel sailing speed for a given vessel fleet from the viewpoint of the daily profit per vessel. Here we assume that all vessels are deployed on the same trade route (not necessarily on a single service route) and each vessel earns the same daily profit. The purpose is to investigate how the shipping line balances between making more revenue by sailing at higher sailing speeds (implying higher operational costs) and making less revenue by sailing at lower speeds (implying lower operational costs) for a fixed vessel fleet.

By considering each vessel's daily profit, i.e. dividing (5.2) by n, we have the following result.

Proposition 5.2. Under a fixed vessel fleet, the optimal number of vessels to be deployed on a single shipping route is determined by

$$\begin{aligned} n^* = \arg\max_n \{ &\frac{1}{n}[\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\frac{r_{ij}D_{ij}}{7} - \frac{C^f F^p t^p}{168} - \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\frac{C_i^l D_{ij}}{7} - \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\frac{C_i^u D_{ji}}{7} \\ &- \sum_{i=0}^{N-1}\frac{G_i^p}{7} - \frac{C^{LI}}{168}\cdot\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(t_{ij}^p - \frac{d_{ij}t^p}{d_{0N}})D_{ij}] - \frac{C^f F_0^s d_{0N}^3}{168 S_0^3 \cdot n(168n - t^p)^2}\} \end{aligned} \qquad (5.4)$$

subject to $S_{min} \le d_{0N}/(168n - t^p) \le S_0$, and n is a positive integer and not greater than the fleet size. Since n is usually not large, the optimal n^* may be found from the interior point from the minimum feasible n to the maximum feasible n.

From Proposition 5.2, it is clear that the optimal n^* depends on many factors including the freight rate, bunker fuel cost, port fixed and variable costs, and cargo inventory cost (associated with cargo value and interest rate). An interesting point is that the optimal vessel deployment (slow steaming) in Proposition 5.1 differs substantially from that in Proposition 5.2. The main reasons are that two models take different perspectives based on different assumptions. The first model is to minimize the daily cost of the service route with a flexible vessel fleet. It is assumed that vessels can be chartered in or out as an additional decision variable. The second model is to maximize the daily profit of each individual vessel for a fixed vessel fleet. Therefore, their application context is different.

The direct result of slow steaming is a reduction in fuel consumption, which implies a reduction in pollutant emissions from shipping. Due to the general public's increasing concerns about climate change and shipping emissions from the International Maritime Organization (IMO), it is not surprising to see that one of the most cited reasons for slow steaming is to reduce pollutant emissions and bring about more environmentally-friendly shipping operations. However, more fundamental causes are probably to absorb excess shipping tonnage and to cut back on bunker fuel costs.

Cariou (2011) stated that slow steaming can only be sustained if the bunker fuel price is at least \$350–\$400 per tonne for the main container trades. However, his argument is based on a cost model consisting of three components: the fuel consumption cost, the vessel operating cost, and the in-transit inventory cost as shown in Eq. (5.3). Note that a low freight rate and vessel fleet overcapacity can significantly affect ocean carriers' ship deployment as shown in Eq. (5.4). Therefore, model (5.4) can better explain why slow steaming is still immensely popular among ocean carriers even though the bunker fuel price has been below \$350/tonne in most months in 2015.

5.4 Research opportunities

We suggest the following areas for further research:

- Evidence has shown that slow steaming enables shipping lines to absorb excess tonnage and reduce fuel consumption. However, the benefit to shippers and other stakeholders in the supply chain has not been adequately demonstrated. For example, although it is claimed that slow steaming offers opportunities to catch up with delays and improve schedule reliability, there is insufficient statistics supporting this claim. How to spread the benefits along the container shipping supply chains requires more research.
- Schedule unreliability has been a long outstanding issue in container shipping. It has a huge impact on the downstream supply chain operations. Firstly, the ship schedule should be better designed considering the uncertainty explicitly. Secondly, although port uncertainty is shown to be the dominant source of schedule unreliability, this factor is believed to be highly related to shipping lines' and shippers' operations that are beyond the control of port/terminal operations. Therefore, a better coordination between shipping lines, port/terminal operators, and shippers is required for ship scheduling and operations. Lee, Lee and Zhang (2015) analysed three years' worth of historical data on a leading shipping liner to estimate the port duration time and then used mathematical modelling to identify a quantitative relationship between service reliability, port time uncertainty and bunker cost. They showed an example of using data from industry to identify modelling and calibration parameters. In the literature, most of the scientific discussion is based on modelling, and there is a lack of support from historical data.
- Slow steaming, ship scheduling and speed selection are closely related to operating cost, shipping emissions, and service reliability. It is desirable to model these decisions as a multi-objective optimization problem (e.g. Wong et al. 2015; Song et al. 2015; Mansouri et al. 2015). More research and application in this direction could be done.

- Slow steaming provides more opportunities for shipping lines to differentiate their services, e.g. express service versus slow services; fast headhaul versus slow backhal; slowing down speed by fewer direct call ports versus slowing down speed by adding vessels; etc. On the other hand, slow steaming may lead to competition between hub ports as pointed out by Ferrari et al. (2015). Very little analytical work has been done in this direction.
- Fuel consumption is one of the largest ship operational costs. This is the main reason that shipping lines have adopted slow steaming widely since 2008. However, with the fuel price fell down substantially in 2015, it poses strategic questions for carriers, e.g. whether to consider laying up vessels, speeding up vessels to differentiate services, changing routes (e.g. taking the longer routes by avoiding canal passage charges or piracy areas), and revisiting the concept of economy of scale for mega-vessels.

6. Empty container repositioning

Empty container repositioning (ECR) may be considered within the shipping pricing strategy so that empty flows can be intentionally reduced by decreasing the degree of demand imbalance through appropriate pricing in two directions. ECR can also be mitigated by horizontal cooperation (e.g. slot exchange or container exchange) and vertical cooperation (e.g. improving visibility of container flows in the transport chain). Service network design and routing may also include ECR as a sub-problem because both laden and empty containers are moving over the same shipping network. Braekers et al. (2011) provided a literature review on empty container repositioning models at different planning levels, i.e. strategic, tactical, and operational levels. Khakbaz and Bhattacharjya (2014) reviewed the maritime ECR literature published between 1994 and 2013 in the fields of engineering, management, transport and logistics. Song and Dong (2015) gave a survey on ECR problems from the supply chain perspective and as well as from the modelling technique perspective.

ECR has been an important issue for the shipping industry in the last two decades, partially due to the rapid growth of container shipping and the severe imbalance of trade demands. A number of studies have been conducted to estimate the economic burden of empty container movements. For example, Rodrigue et al. (2013) found that shipping companies spent about US$110 billion per year to manage their container fleets (e.g. purchases, maintenance, repairs), of which US$16 billion (or 15 percent) were spent on repositioning empty containers. ECR (particularly by trucks inland) could result in significant environmental and social impacts such as additional emissions and congestions. However, based on the literature and our interviews with industries, shipping companies rarely make use of operational tools or models to assist them in their decisions related to ECR.

In this section, we will first discuss the commonality and differences between ECR and traditional inventory management. We will then classify the ECR problems into two broad types: quantity decision and cost estimation. We focus on the quantity decision type in this section. Relevant literature will be reviewed and an example of inventory control models will be introduced.

6.1 Relationship between empty container repositioning and inventory management

Although both inventory in production-inventory systems and empty containers in ocean transport serve the same function of satisfying external customer demand, they differ in several aspects:

i) In production-inventory systems, inventory is the real product itself and is purchased from producers. The incremental cost is the product price. The holding cost, which is usually lower than the capital cost, and salvage cost can be high. In ECR, the container is equipment that is usually owned by the carrier. The major cost consists of the moving cost, and the holding cost is mainly the storage cost.

ii) In production-inventory systems, most inventories are purchased directly from producers, though some may be transferred from the focal company's own warehouses. In ECR, most of the empty containers come from other ports (either as empty containers, or as laden containers but unloaded to become empty containers at these ports). Hence, a) the interaction among ports is critical, b) lead time (mainly seaborne transportation time) is usually known and can be controlled internally though the amount to be transported is constrained by available vessel capacity and the available empty containers at other ports (this is further complicated by inland demurrage and detention cost issues), and c) the seaborne transportation cost mainly consists of the loading and unloading handling cost paid to terminal operators since empty containers are usually carried by shipping lines' own vessels.

iii) In ocean transport, the shipping is two-way with the same capacity while the demand (laden containers) can be different each way. Thus, it involves: a) where to store the empty containers, b) when to ship the empty containers from one port to another port, and c) how to charge the shipper for implicit cost.

iv) ECR is in some ways similar to reverse logistics and packaging logistics. However, in reverse and packaging logistics, the reusable materials are sold to and owned by the consumers, whereas in container shipping the empty containers and laden containers are interwoven as the containers become empty and loaded repeatedly in the container's life cycle, and the containers are normally owned by the ocean carriers rather than by the customers.

Nevertheless, from the operation management perspective, it is interesting to contrast the shipping container logistics with the traditional manufacturing logistics. Regarding empty containers as inventories that are used to meet customer demands, a similarity emerges between the ECR problem and the production-inventory system. The similarity is that both inventories and empty containers are moved and stored from one location to another to meet external customer demand with a goal to minimizing the incurred total cost. Thus inventory-based control policies may be used to reposition empty containers. Our interview with a European shipping consultant revealed that many shipping lines are using inventory-based policies to reposition empty containers from Europe to Asia (e.g. storing empty containers at European ports up to a certain volume or a certain amount of time before repositioning them to Asian ports, or immediately repositioning an empty container to Asia whenever possible). This implies that in practice shipping lines are indeed explicitly or implicitly applying the concept of inventory control to manage empty container logistics.

6.2 ECR problem classification

There are two broad types of ECR problems: *quantity decision* and *cost estimation*. In quantity decision, carriers need to decide how many empty containers to keep at each port, and when and how many to move from one port to another. In cost estimation, the underlying idea is that moving empty containers only generates income when the containers become laden with shippers' products. Hence, an interesting and important question is how much cost is incurred in repositioning empty containers so that they would be ready for the next shipment.

For quantity decision, according to the modelling techniques and the form of the proposed solutions, ECR models may be classified into two streams (Song and Dong 2015). The first stream adopts network flow models and often applies mathematical programming to produce a set of arc-based (or origin-destination based) matrices, which specify the quantity of empty containers to be moved on an arc (i.e. from one node to another) in the network. The underlying concept is flow balancing, i.e. the container flows out of a node should be equal to the flows into the same node. The second stream adopts inventory control models to produce decision-making rules, which are able to determine the amount of empty containers to be repositioned into/out of a node dynamically by utilizing the information of how many empty containers are available and/or to be available across the system.

For cost estimation, ECR is combined with the shipment pricing decision. Different from the quantity decision which responds to uncontrollable demands, cost estimation tends to actively associate the flow balancing with shipping contracts which influence customer demands (e.g. Zhou and Lee 2009). In other words, the shipment price is determined after considering the cost of repositioning empty containers. This type of problem has been discussed in the section on pricing and contracting. In the rest of this section, we focus on models for quantity decision.

6.3 Network flow models for empty container repositioning

As the fundamental reason that causes empty container repositioning is the trade imbalance, it is natural to use network flow models to balance the flow in the shipping networks. Network flow mathematics models can generate tactical decision plans. At the operational level, due to the dynamic operations and uncertainty, the tactical plan for ECR may not be implemented exactly, e.g. there may be a lack of empty containers to be repositioned out, or a lack of available space on the vessel to carry the empty containers. Nevertheless, the generated plan could still be applied to stochastic situations with the help of simple operational rules, e.g. if not enough empty containers or spare vessel capacity is available, then the repositioned-out empty containers can be split among destination ports proportionally according to the plan, and the unfulfilled amount could be satisfied later on.

Major shipping lines operate global service networks consisting of multiple shipping service routes. In the literature many sophisticated network flow models have been developed for ECR on multiple service routes. These include time-space network models (e.g. Erera et al. 2005; Brouer et al. 2011; Song and Dong 2012; Epstein et al. 2012; Chao and Yu 2012; Chao and Chen 2015), a stochastic programming model (Cheung and Chen 1998; Erera et al. 2009), scenario-based linear programming (Di Francesco et al. 2009), a sample average approximation-based linear programming model (Long et al. 2012), and a multi-scenario mixed-integer programming model (Di Francesco et al. 2013); profit-based container assignment models (Wang et al. 2015b); a two-stage empty container coordination model among ocean carriers (Zheng et al. 2015b).

Network flow models were also developed for ECR at the regional level between port terminals and inland depots (cf. the references in Braekers et al. 2011; Braekers et al. 2013; Furio et al. 2013; Olivo et al. 2013; Sterzik et al. 2015).

Many of these network flow models are able to capture some important characteristics of the underlying ECR problem such as trade imbalance, dynamic operations and uncertainty. Depending on the scale and complexity of the problem, the network flow models may be solved exactly or approximately.

Challenging issues facing the network flow models include determining an appropriate planning horizon, ensuring computational tractability and ensuring robustness of the policy to uncertainties. In addition, mathematical programming models often require accurate data, timely communication, and centralised management, which are practically difficult. More importantly, the underlying logic of such models is hidden from the operations managers, which affects their application in practice.

6.4 Inventory control models for empty container repositioning

A number of studies have taken the inventory control perspective to tackle the ECR problem. At the regional level, Du and Hall (1997) proposed a threshold control policy to allocate empty equipment in a hub-and-spoke transport network. Li et al. (2004) and Song and Zhang (2010) established the optimality of the threshold-type inventory-based control policy in a single port subject to uncertain demands. Yun et al. (2011) applied the (s, S)-type inventory control policy to reposition empty containers between customers and terminals in an inland area with random demands for empty containers. A simulation-based optimization tool is applied to find the near optimal (s, S) policy. Dang et al. (2012) and Dang et al. (2013) extended the (s, S)-type inventory policy to a port area with multiple depots considering three types of decisions: repositioning empties from overseas ports, inland repositioning between depots, and leasing from lessors or other companies. Parameterized threshold policies are adopted for ECR and a simulation-based genetic algorithm is developed to optimize the threshold parameters.

At the global level, Song (2007), Lam et al. (2007) and Shi and Xu (2011) investigated the structure of the optimal ECR policies in two-port systems. Song and Dong (2008) developed threshold-type policies to reposition empties on cyclic service routes with uncertain demands. Li et al. (2007) and Zhang et al. (2014) extended the threshold control policy to multi-port systems. Dong and Song (2009) employed the simulation-based optimization method and an inventory control-based policy to deal with the joint optimization problem of container fleet sizing and ECR. They presented Kanban and base-stock type of control policies for ECR in cyclic shipping services and evaluated their performance. Lee et al. (2012) considered the joint ECR and container fleet sizing problem in a multi-port system, in which a single-threshold policy is used to control the inventory and flow of empty containers among ports. The infinitesimal perturbation analysis method is applied to improve the computational efficiency. Because the formulation assumes that the travel time for each pair of ports is less than one period and the shipping service routes are not explicitly considered, the model may be more appropriately regarded as a regional (inland or intermodal) network.

Most of the inventory control models also capture the important characteristics of the underlying ECR problem including trade imbalance, dynamic operations and uncertainty. The prominent advantage of these models is the easy-to-understand and easy-to-operate nature of the proposed repositioning policies. Often only a modest amount of real-time data is required. At the port-to-port global level, most of the literature has focused on a simplified structure of the service route or a single service route. This offers opportunities to design optimal or near-optimal repositioning policies in stochastic situations. However, a specific structure or a single service route overly simplifies the routing decisions and excludes the transhipment operations, which is an important phenomenon in container shipping operations.

Recently, a couple of attempts have been made to combine the inventory model and the network flow model to deal with the ECR problems at the global level. Chou et al. (2010) considered the empty container allocation problem on a single service route. A two-stage model is formulated. At stage one, an inventory decision-making model with a fuzzy backorder quantity is proposed to determine the optimal quantity of empty containers at a port. At stage two, a mathematical programming network model is proposed to determine the optimal number of empty containers to be allocated between two ports based on the results in stage one. The use of the proposed model is demonstrated through a case involving a trans-Pacific liner route in the real world. However, the authors focused on a single service route. Epstein et al. (2012) initially planned to develop a single, integrated, and robust optimization model that would address the ECR optimization problem with uncertainties, but realised that the time required for finding an optimal solution was too long even for small instances. They then opted for developing a two-stage solution approach, which combines a network flow model and an inventory model, named the empty container optimization (ECO) tool. The ECO tool is based on two decision models supported by a forecasting system. At stage one, an inventory model takes into account the uncertainty in container supply and demand and determines the safety stock for each node in the network. At stage two, a multi-commodity multi-period network flow model addresses the imbalance problem and supports daily empty container repositioning and inventory levels. The service level is managed by imposing the safety stock as a constraint in the network flow model with the assumption that the forecast demand is normally distributed. In addition, the ECO tool uses a collaborative web-based optimization framework to address the coordination problem among multiple agents with local objectives. However, both Chou et al. (2010) and Epstein et al. (2012) only focused on empty container logistics. The movements and routing of laden containers were not considered.

6.5 A specific inventory control model for ECR

We present an inventory control model for a regional ECR problem. The model is based on Ng et al. (2012), which is able to characterize the optimal empty container transfer policy between two ports/depots in stochastic dynamic situations. Consider a shipping company operating a container transport system involving two depots that are located nearby. It is assumed that: (i) the company receives random demand for empty containers and random supply of laden containers that are returned as empty containers; (ii) unfulfilled demands are backlogged; (iii) a single type of containers is considered; and (iv) the transfer lead times between the two depots are negligible. The following notation is introduced:

n: a discrete decision period;

N: the length of the planning horizon;

z_i : the net number of containers in a period flowing into depot i (random supply minus random demand);
x_i: the level of inventory at depot i;
u_n: the quantity of empty containers transferred from depot 1 to depot 2 in period n;
c_{ij}: the cost of transporting a unit of inventory from depot i to depot j;
h_i: the cost of holding one unit of inventory (empty container) for one period at depot i;
b_i: the cost of backlogging one unit of demand for one period at depot i.

In order to describe the system dynamics, let $x_{i,n-1}$ denote the on-hand inventory level of empty containers at depot i at the beginning of period n; and $z_{i,n}$ represent the net number of containers into depot i in period n. Then, the system state, i.e., the inventory levels at the two depots, in period n is determined by

$$x_{1,n} = x_{1,n-1} + z_{1,n} - u_n, \text{ and } x_{2,n} = x_{2,n-1} + z_{2,n} + u_n.$$

The problem is to find the optimal dynamic repositioning policy $\{u_n \mid 1 \le n \le N\}$ that minimizes the expected cost consisting of inventory holding cost, empty container transferring cost, and demand backlogging cost in the planning horizon (with the initial state $(x_{1,0}, x_{2,0})$).

$$\sum_{n=1}^{N} \alpha^n \, \mathrm{E}[c_{12}u_n^+ + c_{21}u_n^- + h_1(x_{1,n})^+ + b_1(x_{1,n})^- + h_2(x_{2,n})^+ + b_2(x_{2,n})^- \mid (x_{1,0}, x_{2,0})]$$

where α is a discount factor ($0 < \alpha \le 1$) and $x^- = \max\{0, -x\}$. Let $V_n(x_{1,n-1}, x_{2,n-1})$ be the expected discounted cost from period n to N. The problem can be formulated into a Bellman dynamic equation. We drop the subscript n in the system state and control decision, and define the state variable $\mathbf{x} := (x_1, x_2)$. Then, the Bellman dynamic equation is given as follows (Ng et al. 2012),

$$V_n(\mathbf{x}) = \min_u \{G_n(\mathbf{x}, u) : -x_2^+ \le u \le x_1^+\} \tag{3.1}$$

$$G_n(\mathbf{x}, u) = c_{12}u^+ + c_{21}u^- + L_n(\mathbf{x}, u), \text{ and} \tag{3.2}$$

$$\begin{aligned} L_n(\mathbf{x}, u) &= h_1\mathrm{E}(x_1 + z_1 - u)^+ + b_1 \,\mathrm{E}(x_1 + z_1 - u)^- + h_2 \,\mathrm{E}(x_2 + z_2 + u)^+ \\ &+ b_2 \,\mathrm{E}(x_2 + z_2 + u)^- + \alpha\mathrm{E}V_{n+1}(x_1 + z_1 - u, x_2 + z_2 + u). \end{aligned} \tag{3.3}$$

Define two switching surfaces $D_n(\mathbf{x})$ and $U_n(\mathbf{x})$ as follows:
$D_n(\mathbf{x}) = \min\{u \mid \partial L_n(\mathbf{x}, u)/\partial u \ge -c_{12}\}$ and $U_n(\mathbf{x}) = \max\{u \mid \partial L_n(\mathbf{x}, u)/\partial u \le c_{21}\}$.

Then we are able to characterize the optimal control policy $u^*_n(\mathbf{x})$ in the state space shown in Figure 6.1.

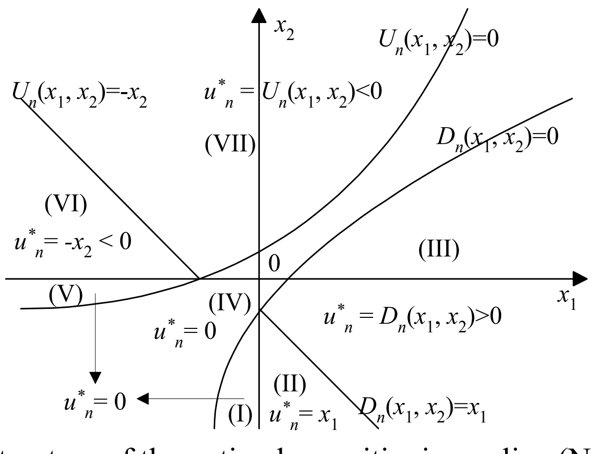

Figure 6.1. Structure of the optimal repositioning policy (Ng et al. 2012)

It can be seen that the monotonic switching curves $D_n(\mathbf{x}) = 0$, $D_n(\mathbf{x}) = x_1$, $x_1 = 0$, $x_2 = 0$, $U_n(\mathbf{x}) = -x_2$, and $U_n(\mathbf{x}) = 0$ divide the entire state space into seven control regions (I) – (VII). In fact, the switching curves $D_n(\mathbf{x}) = x_1$ and $U_n(\mathbf{x}) = -x_2$ are in parallel with $x_1 + x_2 = 0$; the former passes through the intersection point of $D_n(\mathbf{x}) = 0$ and $x_1 = 0$, while the latter passes through the intersection point of $U_n(\mathbf{x}) = 0$ and $x_2 = 0$. Although the switching curves may slightly change shape in different periods n, the division of the seven control regions and the monotonic properties of the switching curves remain the same.

From the practical perspective, the optimal repositioning policy in Figure 6.1 provides operations managers with insights for making decisions on ECR between depots. It not only provides easy-to-understand qualitative managerial knowledge, but also quantitative instructions on when and how many empty containers to reposition. How the system state affects the repositioning decisions is also revealed. For example, when the system state (x_1, x_2) is located under the line $x_1 + x_2 = -1$ with $x_1>0$, the optimal decision $u_n^* = x_1$; when the state (x_1, x_2) is moving from the curve $D_n(x_1, x_2) = x_1$ towards the line $x_1 + x_2 = -1$, the optimal decision u_n^* is increasing from 0 to x_1; when the state (x_1, x_2) is moving from the curve $D_n(x_1, x_2) = x_1$ towards the right-hand side (i.e. an increasing x_1), the optimal decision u_n^* is increasing from 0. Moreover, the structural properties of the optimal policy in Figure 6.1 such as monotonicity and region-switching form are useful for constructing easy-to-implement and near-optimal policies (cf. Ng et al. 2012 for more details), because the optimal repositioning policy may be too complicated and difficult to implement. This idea is similar to using threshold policies (e.g. Kanban, base-stock, or hybrid threshold policies) to approximate the optimal policy in two-stage stochastic production-inventory systems.

6.6 Research opportunities

Although a large number of studies have emerged in the last decade or so to address ECR, it remains a challenging problem in the container shipping industry. Note that empty containers are moved for reasons related to trade imbalance, dynamic operations, uncertainties, size and type of containers, lack of visibility and collaboration across the transport chain, and transport companies' operational and strategic practices (Song and Dong 2015). From the operations management's viewpoint, we point out the following research opportunities:

- The most realistic model of ECR would capture characteristics such as trade imbalance (by including both laden and empty containers), stochastic factors, dynamic operations, multiple types of containers, information sharing and coordinated management across the container transport chain. While formulating and solving such models is extremely challenging partially due to the fragmented nature of the shipping industry, it is still desirable to develop appropriate models incorporating some key elements and produce applicable solutions.
- In the stream of research on network flow models for global container management, very few studies (Erera et al. 2005; Brouer et al. 2011; Song and Dong 2012) have explicitly considered both laden containers and empty containers at the operational level. Even fewer have further taken into account the uncertainty nature of the problem. Here the main challenge is the computational complexity arising from three factors. Firstly, a fairly long planning horizon is required to incorporate the effect of empty container movements because it often takes about a month to reposition an empty container from one continent to another, whereas the decisions are often made

on a daily basis. Secondly, global shipping lines often operate large-scale shipping networks consisting of many interconnected service routes. This incurs the difficulty of shipment routing and empty container scheduling. Thirdly, although uncertainty may be represented and approximated by multiple samples/scenarios, doing so increases the computational complexity.

- In the stream of research on inventory control models, at either the regional or global level of ECR, the majority of studies are limited with a simplified structure of the service network or a single service route. The optimality of the repositioning policies and the structure of the optimal policies have only been established for rather simple systems (e.g. a single port, or two depot/port shuttle services). On the one hand, optimal inventory-based repositioning policies for more complicated networks require more research. On the other hand, more sophisticated inventory-based policies could be developed, e.g. by borrowing the concepts of Kanban and echelon base stock.
- There has been lack of simulation models for container logistics management in the literature. Lai et al. (1995) developed a simulation model to optimize a type of heuristic allocation policy for a shipping company to transport empty containers from the Middle East to ports in the Far East. Rensburg and He (2005) described a generic simulation model of ocean container carrier operations including transporting containers from depots to customers according to requirements and from port to port according to vessels' schedules. However, their focus was not on the performance evaluation of ECR policies. Dong et al. (2008) developed an event-driven simulation tool to evaluate and optimize inventory control-based ECR policies taking into account the stochastic nature and dynamic operations of the container shipping industry. Simulation offers great flexibility in handling dynamic and stochastic situations in a more realistic way. It could serve as a good alternative in situations when other modelling approaches are infeasible.
- As the ECR problem is closely related to other issues in container shipping such as network design, fleet deployment, vessel scheduling and shipment routing (Shintani et al. 2007; Meng and Wang 2011), more research should be conducted to integrate them appropriately with ECR. In addition, vertical and horizontal integration with other supply chain members to facilitate empty container management is another important area that requires further development both empirically and theoretically.
- Research on cost estimation should be extended in the following two directions: i) assess the practical difficulty and additional cost of tracing and extracting data on containers in order to implement ECR solutions and evaluate the potential benefits of the implementation; ii) calculate the ECR cost implicit in a laden container business, so that a carrier can decide whether to accept or pursue that shipping business. Note that the cost will affect the number of laden containers to ship.
- A couple of practical issues have not been addressed in the regional ECR problems. Firstly, ocean carriers charge shippers demurrage and detention costs for holding container equipment longer than the agreed period inside and outside the terminal. Secondly, regional container movements may be operated by a number of different freight forwarders or shippers, which are often beyond the control of ocean carriers and difficult to coordinate. Both issues would affect the regional empty container management and require further research.

7. Safety and disruption management

Safety and disruption management is related to strategic elements such as policies, regulations and other parties' behaviours, which affect contracting issues. As the insurance fee for the shipping routes across piracy area is much higher, the safety issue is normally factored into the pricing strategy. Service network design and cargo routing may also take into account the safety and disruption issue, e.g. design a longer service route to avoid piracy area. The safety and disruption also has operational element such as how to respond to unexpected factors and disruptive events. International Maritime Organization (IMO) is the United Nations' specialized agency responsible for improving maritime safety and preventing pollution from ships. Wang and Foinikis (2001) offered an overview of the formal safety assessment of containerships from multiple aspects. Sergi and Morabito (2016) provided a survey on quantitative economics of maritime piracy. Qi (2015) summarized the disruption management issue in liner shipping industry.

In this section we first discuss the general issues concerning safety and security in container shipping, and then explain the disruption management problem. A schedule recovery model will be introduced to describe how vessel operators could respond to disruptive events and improve supply chain resilience.

7.1 Safety and security management

Maritime safety and security has always been a priority concern to the shipping industry and the governing bodies such as IMO. This is reflected by IMO's slogan "*Safe, secure and efficient shipping on clean oceans*". The objective of safety management is to ensure safety, to prevent human injury or loss of life, and to avoid damage to the environment and to property.

Maritime safety and security may be addressed from different perspectives, e.g. the human aspect factors, the technological factors pertaining to ships, and the shipping operational factors. Wang and Foinikis (2001) discussed the formal safety assessment of containerships from four aspects: operational environment (physical, commercial, regulatory); organizational managerial infrastructure; personnel subsystem; and technical & engineering system. Yang et al. (2013) reviewed the challenges of maritime safety and the approaches to quantify the risks in maritime transportation.

From the container shipping operations' perspective, Chang et al. (2014) provided an empirical analysis of the safety and security risks based on a case study. Through a literature review and interviews, they identified 35 risk factors in container shipping operations that may cause maritime safety and security related damage. The risk factors are categorized into three groups according to the three logistic flows in shipping operations, i.e. information flow, physical flow and finance flow. It is shown that risk factors associated with the physical flow generally lead to more serious damages than risk factors associated with the information or finance flow.

Attack from pirates, as an important risk factor in the physical flow, is worth particular mention. Firstly, the pirate risk factor is unique to maritime transport. Secondly, the economic impact of piracy is becoming enormous to both shippers and ship-owners. Maersk Line expected its own piracy-related costs to double in 2011 to at least US$200 million. These costs include insurance premiums, hardship allowances, and the costs of rerouting vessels (Leach 2011). According to a report on April 12, 2013 by CNN, piracy off the Horn of Africa costs the world economy US$18 billion a year. Note that Maersk line's cost estimation is for their own company, whereas CNN's estimation is for the overall international trade plus the economic impact on neighbouring East African countries, including the pillar sectors of tourism and fishing. Sergi and Morabito (2016) reviewed the literature on quantitative economics of maritime piracy, and stated that Somali piracy's impact on the global economy was in the range of $7 to $12 billion in 2010. Jones (2014) provided a breakdown of the costs caused by maritime piracy including ransoms, insurance premiums, ship rerouting, security equipment, naval forces, prosecutions of pirates, anti-piracy organizations, and cost to regional economy.

IMO has suggested a number of best management practices for protection against maritime piracy attacks (BMP4, 2011). These situational measures can be grouped into two categories: pre-boarding and post-boarding measures. Pre-boarding measures aim to prevent boarding or securing physical access to the ship, including anti-piracy watch, private security, raising alarms, increasing lighting, evasive manoeuvring, increasing speed, and using guards. Post-boarding measures aim to delay or stop pirates from seizing the ship or crew once boarded, including enhanced bridge protection, control of access to bridge, closed circuit television, protection of equipment stored on the upper deck, safe muster points, and guards. Bryant et al. (2014) conducted an empirical research based on 452 cases from 2010–2011, and the result strongly supported the adoption of ship protection measures recommended by IMO to prevent piracy.

Fu et al. (2010) took the Far East-Europe container liner shipping service as an example, and investigated the economic welfare loss (due to competitiveness) and the efficiency loss (due to geographical rerouting) caused by Somali piracy. Marchione et al. (2014) developed an agent-based model to simulate pirate, vessel and naval forces behaviours. A case study of the Gulf of Aden is used to build the model.

7.2 Disruption management

Disruption is defined as disturbance or problems which interrupt an event, activity, or process (Oxford dictionary). Disruption management refers to dynamically recovering from various disruption events that prevent the original operational plan from being executed smoothly (Yu and Qi, 2004). In the last decade, disruption management has attracted much attention in various areas, e.g. airlines, machine scheduling, logistics scheduling, production planning, project scheduling, and supply chain coordination (Clausen et al. 2010; Yu and Qi, 2004).

However, disruption management in container shipping was rarely studied. Only recently have a few works emerged that look at this issue (Brouer et al. 2013; Li et al. 2015; Qi 2015; Li et al. 2016). Disruption is closely related to uncertainty, which is a more generic term. Two types of uncertainties may be classified in liner shipping operations: *regular uncertainties* which refer to recurring probabilistic activities or events in shipping operations; and *disruption events* which refer to occasional or one-off events occurring in shipping operations (Li et al. 2016). The nature of disruption events indicates that they are not planned in the tactical schedule design stage, but should be responded to appropriately after their occurrence on a real-time basis and sometimes may be forecasted just before their occurrence.

Common types of disruption events in container shipping include: port closure due to high wind, port congestion due to industry actions (labour strikes), port closure due to hurricane or flooding, terminal unavailability due to quay crane failures, and poor weather such as fog and wind. It can be seen that some disruption events are sudden and unpredictable while others may be somewhat known in advance. Therefore, disruption management may involve both reactive actions and proactive actions to mitigate the impact of disruption events.

Qi (2015) contrasted the similarity and differences in disruption management between liner shipping and the airline industry. Both transport modes have pre-specified schedules and the consequence of a disruption often leads to delay in arrival at or departure from ports/airports. However, the management strategies are quite different: (i) for airlines, it is common to swap and re-assign aircraft to scheduled flights after a disruptive situation; for line shipping, swapping vessels is impractical because container vessels operate on continuous voyages and the vessels are never empty in normal situations; (ii) for airlines, crew recovery is an important issue because (cabin) crew are subject to legal and contractual constraints regarding their working hours, administrative ground activity, training, and leave. The objective of crew recovery is to repair disrupted roster lines while making sure all flights have the crew needed to operate them and return the airline back to normal operations as quickly and efficiently as possible. Therefore, both crew recovery and flight schedule recovery must be tackled in airline disruptive situations, whereas in line shipping, crew scheduling is less relevant; (iii) for airlines, speeding up an aircraft is generally not regarded as a feasible measure to recover from a delayed schedule because flight schedules are designed based on high speeds and there is little room to speed up physically; in liner shipping speeding up vessels could be an effective measure to catch up with a delayed schedule especially on the longest inter-continent legs. This has become an even more powerful strategy in the current shipping practice where most shipping lines have adopted slow steaming (17-22 knots) or even super-slow steaming (14-16 knots) while the vessel speed is designed to be about 23-26 knots; (iv) for liner shipping, a deep-sea service route often consists of a few port calls in one region. This offers an additional option for the disrupted vessel to skip port calls or swap port call sequences for recovery; for airlines, this is not applicable.

Brouer et al. (2013) were the first to model the optimal recovery action under a given disruptive scenario in container shipping. The recovery measures include speeding up, port omission, and swapping port calls. A mixed-integer programming model was formulated to balance the increased fuel consumption and the impact on cargo flows in the shipping network and the service level. They applied the model to four real-life disruptive cases (including bad weather, port closure due to labour strike, lack of berth space, and port maintenance), and reported that the suggested solutions could reduce costs by up to 58%.

Li et al. (2015) presented nonlinear programming models and dynamic programming algorithms to determine the optimal operational action to catch up with a delayed journey in liner shipping. Several typical disruption recovery strategies (including vessel speeding up, port skipping, and port swapping) were analysed. It was revealed that speeding up is effective when experiencing small delays, but major disruptions require skipping and swapping ports to recover from the delayed schedule. Both Brouer et al. (2013) and Li et al. (2015) focused on schedule recovery after a disruptive event. They used deterministic models and did not consider future new delays. Li et al. (2016) formulated stochastic models considering multiple regular uncertainties along the service route. In addition, both proactive actions in response to updated forecasts of the disruptive event and reactive actions after the disruptive event are modelled on a real-time basis.

7.3 A model for schedule recovery from disruption

In the following, we introduce an operational model for the reactive strategy of speeding up a vessel based on Li et al. (2015). Here the focus is on how a disrupted vessel schedule could be recovered by speeding up the vessel taking into account the fuel and delay costs in the dynamic system. We introduce the following notation:

N: the number of port calls on the route. The port calls are indexed from 0; and the Nth port call refers to the vessel sailing back to the first port.

d_i: the distance in nautical miles from port call i to the next port call;

s: the planned constant sailing speed of ships at sea in nautical miles per hour;

t_i: the planned arrive time on port call i according to the schedule;

t_i^p: the time that a ship spends on port call i;

x_i: the amount of delay experienced by the ship before it departs from port call i, where x_0 refers to the initial delay on the journey;

s_i: the sailing speed in knots from port call i to the next port call under the recovery strategy, which takes a value between the minimum speed S_{min} and the vessel design speed S_{max}.;

t_i^a: the arrival time on port call i under the recovery strategy;

C_i: the ship delay penalty cost per unit time on port call i;

$f_i(s_i)$: the fuel consumption cost on leg i for the ship sailing at speed s_i at sea;

It is assumed that: (i) the fuel consumption cost function $f_i(s_i)$ is convex and increasing in s_i; (ii) the ship will not be handled if it arrives at the port earlier than the planned arrival time; (iii) the planned schedule is optimal if there is no delay in the system. The problem can then be formulated as follows:

$$\min_{s_i} \sum_{i=0}^{N-1} (d_i \cdot f_i(s_i) + C_i \cdot x_i) \tag{7.1}$$

subject to

$$s_i \cdot (t_{i+1}^a - t_i^a - t_i^p) = d_i, \ i=0, 1, \ldots, N\text{-}1; \tag{7.2}$$

$$t_i = \sum_{j=0}^{i-1} (t_j^p + \frac{d_j}{s}), \ i=0, 1, \ldots, N\text{-}1; \tag{7.3}$$

$$x_i = t_i^a - t_i, \ i=0, 1, \ldots, N\text{-}1; \tag{7.4}$$

$$S_{min} \le s_i \le S_{max}, \ i=0, 1, \ldots, N\text{-}1; \tag{7.5}$$

$$x_i \ge 0, \ i=0, 1, \ldots, N\text{-}1; \tag{7.6}$$

Li et al. (2015) showed that the above non-linear programming problem is a convex programme, which implies that a local minimum is also the global minimum.

The problem can be re-formulated into a dynamic programming problem so that a more in-depth analysis can be performed on the impact of delay on system performance. Let $G(i, x)$ be the minimum total cost incurred from leg i to leg N-1, given that the delay is x when arriving at port i. It follows that

$$G(i,x) = \min_t \{ g(i,x,t) \mid \frac{d_i}{S_{\max}} \le t \le t_i \} \qquad (7.7)$$

where

$$g(i,x,t) = d_i \cdot f_i(\frac{d_i}{t}) + C_i \cdot (x+t-t_i)^+ + G(i+1,(x+t-t_i)^+) \qquad (7.8)$$

with the boundary condition $G(N, x) = 0$.

It is easy to show that $G(i, x)$ is convex and increasing in x (Li et al. 2015). This indicates the disproportionality of the marginal cost of speeding up to catch up with different levels of delays. In other words, smaller delays can be recovered more economically. It can also be shown that when the delay exceeds a certain level, the vessel should not try to speed up further even if it is able to because the increased fuel cost would exceed the potential savings from catching up with the delay.

7.4 Research opportunities

We suggest the following areas for further research:

- The research on safety and security management should be expanded to cover more risk factors. Change et al. (2014) identified a variety of risk factors that may lead to safety and security issues in container shipping operations. Among a total of 35 risk factors, the most important five are: "shippers hiding cargo information (non-declaration)", "damage caused by transporting dangerous goods", "attack from pirates or terrorists", "damage to frozen cargo/reefer containers due to electricity failure", and "unstable weather". Some of them have rarely been addressed in the literature. However, because each of these factors has its unique characteristics, they should be tackled individually or in small groups;
- The IMO's Maritime Safety Committee at its 93rd session (May 2014) approved changes to the Safety of Life at Sea (SOLAS) convention regarding a mandatory container weight verification requirement on shippers. The requirement making container weight verification a condition for vessel loading will become legally binding on July 1, 2016. It would be interesting to examine the scope and scale of the potential impacts and disruptions to the global container transport supply chain (e.g. shippers, ports and shipping lines individually and collectively) when the new SOLAS regulations comes into force. In addition, the impact of the 100% container scanning requirement on the stakeholders in maritime transport chain deserves more research.
- Classifying the uncertainties into two groups such as regular uncertainty and disruption event may help to develop appropriate solution measures. Regular uncertainty can be tackled at both tactical and operational levels, whereas disruption events are often tackled at the operational level and in real time. It is therefore believed that a variety of strategies at different levels, e.g. policy and regulation, supply chain collaboration, robust design, and real-time control policy, should be developed. In particular, vertical integration strategies between shipping lines, terminal operators, freight forwarders and shippers, and horizontal integration strategies among shipping lines could achieve win-win results in safety and disruption management;
- Disruption management has been well studied and applied in the airline industry, but it is a new concept in the container shipping industry. Little research has been conducted on how disruption events in shipping operations would impact on the entire

supply chain. For example, disruption events may result in missing connections in container transhipment. Given the importance of transhipment in container shipping, there is a need to quantify the economic and environmental impacts of such connection misses and to investigate how to appropriately incorporate transhipment into the disruption management;

- Disruption events not only affect ship operations, but also the movements of cargoes and empty containers. The emerging concept of synchromodal transportation (Steadie Seifi et al. 2014) promoted the idea that carriers or customers could select the best mode based on the operational circumstances and/or customer requirements independently at any time. Appropriate application of such concept in practice would greatly improve the resilience of container transport chain and ensure the on-time delivery of cargoes even under disruptive events. Di Francesco et al. (2013) addressed the empty container repositioning problem in a shipping network subject to port disruptions. They adopted a stochastic programming approach to mitigate the risks of not meeting empty container demand.

8. Conclusions

This paper treats the whole value chain of the container shipping industry into five segments, e.g. shipment routing and capacity procurement, container fleet and repositioning, vessel fleet and operations, terminal operations and container handling, and inland transport vehicle and container handling. A wide range of strategic planning, tactical planning and operations management issues are identified across the entire value chain. We have reviewed the relevant literature on each of the identified issues and also suggested future research opportunities bearing in mind the emerging phenomena in the current shipping practice. The strategic planning issues studied include competition and cooperation between carriers, ports, and terminals; and pricing and contracting. The tactical planning issues covered in this paper include network design and routing, ship scheduling and slow steaming. The operations management issues include empty container repositioning, safety and disruption management. Representative models are introduced to address some of the problems in each of the above areas. For example, we presented two models of slow steaming reflecting different perspectives. One of these models can explain why ocean carriers are still widely adopting slow steaming although the bunker fuel price has dropped below the tipping point. This complements the claims made in the literature (Cariou 2011; Brett 2015) that slow steaming might become unsustainable to the container shipping industry when the fuel price is lower than US$350 per ton.

Some areas have been well studied yet remain challenging and important, including for example, service network design (how to solve an integrated model) and empty container repositioning (how to estimate the real repositioning cost). Some areas are understudied in ocean transport applications, including for example, contracting and pricing, disruption management, and information sharing (Zhang et al, 2016), although contracting and information sharing have been well studied in the field of manufacturing supply chains.

It is hoped that this study will stimulate more research into and application of operations management techniques and tools in container transport chains. For example, it is well known that big data and business analytics have been applied in airline industry to study customer preference. Hence revenue management and dynamic pricing have been widely used to setting flight ticket price. However, given that the cost of ocean container transport is relatively low (as a fraction of the product shelf price), it is an open question whether it is worth committing the effort and investment to apply big data techniques in ocean container transport. In short term, the cost of the collection and storage of data may be greater than the benefit obtained. Nevertheless, given the exponential progress in information technologies and fast dropping of the corresponding cost, the answer may soon become positive. Furthermore, it is a trend that government keeps tighter security policy, including for example, 100% scan rate policy proposed by US Government in 2010 (though it was not really implemented due to the cost issue and the strong against from Asia and Europe (Bakshi et al. 2011)) as well as the Safety of Life at Sea Convention (SOLAS) required by the International Maritime Organization, to be legally effective on July 1, 2016. It would be interesting to examine whether advanced IT tools, especially big data, can be applied in ocean transport business as well as help to fulfill the security policy.

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