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The Critical Role of Ocean Container Transport in Global Supply Chain Performance

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With supply chains distributed across global markets, ocean container transport now is a critical element of any such supply chain. We identify key characteristics of ocean container transport from a supply chain perspective. We find that unlike continental (road) transport, service offerings tend to be consolidated in few service providers, and a strong focus exists on maximization of capital intensive resources. Based on the characteristics of ocean container transport as part of global supply chains, we list a number of relevant and challenging research areas and associated questions.

Key words: supply chain management; transport; ocean containers; research agenda
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1. Introduction

As supply chains become more global and more operations are being outsourced and moved offshore, the impact of transportation on supply chain performance is increasing. Nearly all intercontinental transport of goods takes place by sea, and an increasing share of this transport is containerized. Containerized ocean transport has become the lifeline of almost any global supply chain. Since the early 1990s, world container traffic has been growing at almost three times world GDP growth (UN-ESCAP 2005).

Ocean container transport thus fulfills an essential role in today's global supply chains. Container transport has been heavily studied in the field of maritime economics. Containerization has been the main development in the maritime industry in the past 30 years, and its full effects are yet to be understood. Studies in the field of maritime economics typically either address strategic questions conceptually from the perspective of the port authority, terminal operator, or ocean liner company, or conduct empirical studies that describe certain aggregate trends or developments. In the operations research domain, a very particular stage of the container supply chain[1] has been heavily studied, namely the operation of the container terminal (see Steenken et al. [2004] and Stahlbock and [Voss 2008] for some recent reviews). These include for instance the scheduling of quay cranes, berths, and automated guided vehicle (AGV) carriers.

The impact of ocean container transport on supply chain performance and supply chain decision making remains significantly understudied compared to the impact of other aspects such as inventory management or road transport. However, typical supply chain management topics such as coordination across parties and contract definition; pricing policies; competition between ports, carriers, and terminals; and capacity management are extremely important problems in ocean container transport with such specific characteristics that they warrant further study. In this paper, we will present a number of interesting supply chain management challenges that the ocean container transport industry is faced with, discuss those challenges from a supply chain management research perspective, and also explain the specificities of these challenges. Typically, they are different from the problems studied in maritime economics for a number of reasons. First, we are interested in operational decision making: for instance to develop decision procedures such that the supply chain can maintain a certain service level, or decide on a certain trading contract. Second, we are explicitly interested in the operational variability of this supply chain: to what extent does variability exist and how does this impact decision making (under uncertainty). Our paper demonstrates that abundant opportunities for supply chain management research exist in ocean container transport with a major impact on the operations of the world's global supply chains.

The research issues we identified are based on an understanding of this industry that we developed over the past years in studying the literature, by extensively visiting a series of ports in Europe and Asia, by attending professional conferences that address the issues that the different parties in this supply chain are faced with, and by conducting a number of field projects to further increase our understanding of detailed processes. The paper hence has an extensive empirical basis but lacks a rigorous methodology due to the collected material from the visits being largely anecdotal. It however serves to initiate research in this field and help those not familiar with ocean container transport to acquire an understanding of the key issues from a supply chain management perspective. In this paper, we specifically focus on the decision and consequences of the *users* of the ocean transportation services: shippers and consignees. They are most affected by the lack of attention in research on operational decision making in container supply chains.

We have designed the structure of the paper as follows. In the next section, we give an overview of the main characteristics of current ocean container supply chains. In section 3, we discuss some major trends that affect the operation of these supply chains. In section 4, we present four new research themes that have emerged from our study. These research themes are in the supply chain management domain, and offer opportunities for both formal modeling research and empirical studies. We conclude in section 5.

2. Today's Global Container Supply Chains

Since the shipping of "fifty-eight aluminum truck bodies aboard an aging tanker ship moored in Newark, New Jersey," which "five days later […] sailed into Houston, where fifty-eight trucks waited to take on the metal boxes and haul them to their destinations" (Levinson 2006), the world of container shipping has moved to a global trade which involves containers standardized at 20 and 40 feet, with fixed dimensions and properties, to be shipped all over the world. The road was not easy, but its eventual impact is enormous, with substantial reductions in shipping costs over decades. For an excellent study on the history of the shipping container we refer to Levinson (2006), who conducted a historical study and presents both anecdotal and statistical evidence on the impact of this technological revolution in logistics.

In the last decade, the global container trade has been growing excessively, primarily because of the offshoring of manufacturing operations to Asia, in particular China. In the Chinese export supply chain only, we estimate based on 2010 data (Li and Fung 2011) that at least 65 billion USD is caught up in inventory during transport from China to destinations abroad.[2] This is more than the total inventory in all US department stores in the same year.[3] In 2007, China's mainland ports (thus excluding those of Hong Kong and Taiwan) handled more than 100 million twenty-foot equivalent container unit (TEU, the standard measure used in container trading) of products by sea. As reference, India's ports handled just over 7 million TEU in the same year (UNCTAD 2009). In 2006, more than 99% of the US' international cargo (by weight) was moved by sea cargo (Agarwal and Ergun 2008). Since the early 1990s, world container traffic has been growing at almost three times world GDP growth (UN-ESCAP 2005), while container port throughputs increased even faster due to an increase in the number of containers being transshipped. The worldwide containerized liner trade has risen from 11.4 million TEU in 1980 (Boile et al. 2006) to 137 million TEU in 2008 (UNCTAD 2009), with an almost 13 times increase. In 2008, world container throughput at ports amounted to 506 million TEU, an increase of 4% over the previous year, following multiple years of double-digit growth (UNCTAD 2009). These two numbers on container trade and container port throughput imply that on average, a container is handled about 3.7 times (up from 3.4 in 2007), inclusive of it being handled empty. Table 1 provides an overview of the largest containers ports.[4]

Table 1 shows strong growth in the Chinese ports, reflecting not only the actual growth in exports from China but also the fact that these ports take market share from regional hubs such as Busan. Another regional port, Kaohsiung in Taiwan, dropped completely from the top 10; Kaohsiung was the world's third largest container port in 2001.

Table 2 contains an overview of the largest container liner companies in the world. Substantial consolidation has taken place in this industry between 2005 and 2010. In 2010, the top-10 companies together had more than 50% market share. Consolidation thus moves much faster than in other logistics industries. For instance, in global contract logistics, only one company (DHL Exel) had a market share larger than 5% in 2006 (Datamonitor 2006). This is likely due to the high capital intensity of the container liner industry. This difference in level of consolidation potentially explains the dominant market power of the ocean carriers in this supply chain (see also section 4.2).

The overall container supply chain involves many different parties. A good overview of these is provided by Willis and Ortiz (2004). The shipper usually

Table 1 World Busiest Container Ports

Rank (2008)	Port	2008 (kTEU)	2007 (kTEU)	2006 (kTEU)	Rank (2002)
1	Singapore (SG)	29,918	27,932	24,792	2
2	Shanghai (CN)*	27,980	26,150	21,710	4
3	Hong Kong (HK)*	24,248	23,881	23,539	1
4	Shenzhen (CN)	21,413	21,099	18,469	6
5	Busan (KR)	13,425	13,270	12,039	3
6	Dubai (AE)	11,827	10,653	8923	–
7	Ningbo (CN)	11,226	9360	7068	–
8	Guangzhou (CN)	11,001	9200	6600	–
9	Rotterdam (NL)	10,800	10,791	9655	7
10	Qingdao (CN)	10,320	9462	7702	–

Source: UNCTAD (2009) and Port of Rotterdam (2007).
*Includes river transport.

contracts a third party to take care of the container shipment. This could be a third or fourth party logistics service provider, which in this industry is often (but not necessarily exclusively) denoted as Non-Vessel Operating Common Carrier (NVOCC). They serve primarily as wholesalers of ocean vessel capacity, booking large blocks of container space with the ocean liner companies, and sell these out in smaller quantities to shippers. The NVOCC thus holds a contract with the shipper on the one hand and the ocean liner company on the other. Very large shippers would contract the ocean liner companies directly, without intervention of an NVOCC. A crucial step in each container supply chain is the terminal operator, who handles the container and moves it between different modes of transportation and between different ocean vessels in the hub-and-spoke system. Terminals are generally contracted by the ocean liner company and in some cases by the NVOCC. A challenge in this contractual relationship is that the terminal operator in its daily operations also deals with the hinterland transport operators (truck, rail, or river barge), who deliver and pick up the containers but have no contractual relationship with the terminal operator. This implies that operational coordination of the container operations is a challenging task involving multiple decision makers. Some recent studies have addressed this problem using Multi-Agent Systems (see, e.g., Douma et al. 2009). We refer to section 4.2 for a further discussion on this topic and to Figure 2 for an overview of the contractual and operational relationships in this supply chain.

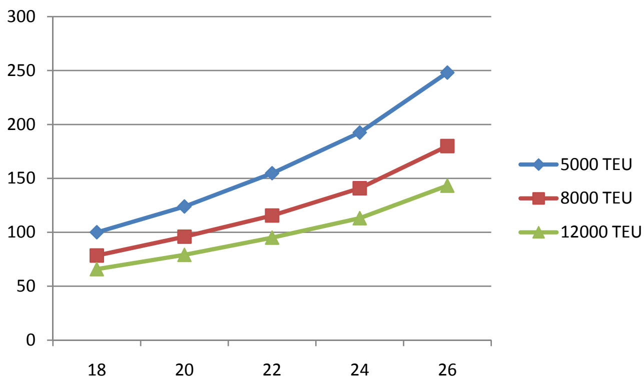
At the terminal itself, operations tend to be highly automated and/or mechanized, to ensure that vessels get loaded and discharged as quickly as possible. Consequently, investments in terminals are extremely high and tied up substantial amounts of (often government) capital. Due to the extensive capital cost, efficient operations of the terminals that maximize the throughput (terminals are paid by a handling charge per container) are essential for the terminal operators' profits. Terminals operations have been studied extensively in the field of Operations Research and many formal OR models are available and have been implemented. We refer to Vis and De Koster (2003), Steenken et al. (2004), Günther and Kim (2006), and Stahlbock and Voss (2008) for review papers of this extensive research area.

In every operational purchasing relationship, buyer and supplier agree on a split between them of the costs and risks of the transport of their goods. These trade agreements have been standardized by the International Chamber of Commerce. Depending on the specific trade agreement between buyer and supplier, relationship in the supply chain will be different. For instance, under a so-called *Ex Works* trade agreement, the buyer is responsible for arranging the pick-up of the goods from the supplier's warehouse and arranging the entire transportation to its own

Table 2 Largest Container Liner Companies in the World (in 1000 TEU) in January 2006 and January 2002 (original data on which this analysis is based can be found in BRS [2006] and Alphaliner [2010]), and their Compound Annual Growth Rate Over the Period 2000–2010.

February, 2010					January, 2000		
Rank	Liner	kTEU	Share (%)	CAGR (%)	Rank	kTEU	Share (%)
1	A.P. Möller-Maersk (DK)	2050	14.9	12.7	1	620	12.0
2	MSC (IT/CH)	1528	11.1	21.1	5	225	4.4
3	CMA CGM Group (FR)	1050	7.6	23.9	12	123	2.4
4	Evergreen Group (TW)	554	4.0	5.7	2	317	6.2
5	APL (US)	544	4.0	10.1	6	208	4.0
6	Hapag-Lloyd (DE)	491	3.6	16.9	14	103	2.0
7	COSCO Container L. (CN)	454	3.3	8.6	1	620	12.0
8	CSCL (CN)	438	3.2	17.6	18	86	1.7
9	Hanjin (KR)	428	3.1	5.8	4	245	4.8
10	NYK (JP)	407	3.0	9.4	5	225	4.4

Figure 1 Fuel Consumption Cost per Container per Nautical Mile, Indexed (18 knots and 5000 TEU vessel = 100), Based on Data in Table 3



incoming goods warehouse. On the other hand, in a popular trade agreement, called Free on Board, the point of title transferred occurs when the goods have passed over ship's rail. Namely, it is the shipper's responsibility for transporting goods to a vessel, loading aboard, and export clearance. Once the goods are loaded the risk of loss and costs of transport reverts to the buyer. We will discuss these trade agreements in further detail in section 4, when we will discuss the distribution of risk and cost in the supply chain, as this potentially affects decision-making behavior by each of the parties involved.

3. Main Developments in the Supply Chain: Insights from Previous Studies

The ocean container transport industry has been affected by a number of dominating trends over the past 5 years. We will briefly review the most important trends to get readers in the supply chain management field up to speed.

A very important development that drives a lot of decision making is the general move toward hub-and-spoke networks. Increasingly larger containers ships (now up to 14,000 TEU) are used to transport containers between large hubs such as Hong Kong, Shanghai, Shenzhen, and Rotterdam, while smaller feeder vessels are used to bring the containers to the hubs from smaller ports and again from the downstream hub to the port of destination. The main driver has been the cost per container, which is lower for larger vessels due to economies of scale in construction, manpower, and energy usage. It is unclear to what extent these hub-and-spoke networks will further develop. Due to the large volumes, also the number of direct scheduled services between many different ports has been increasing. The general expectation (UN-ESCAP 2005) is, however, that the share of total container transport that is transshipped in hub-and-spoke networks will increase slightly.

The entire industry is very much driven by economies of scale. Economies of scale can be obtained in ocean vessels due to fuel efficiencies. Alfred Marshall is quoted by Clark et al. (2004): "a ship's carrying power varies as the cube of her dimensions, while the resistance offered by the water increases only a little faster than the square of her dimensions." This drives the growth of container vessels and is the main driver behind the growth of the hub-and-spoke network. Obviously, further economies of scale exist in the building of the vessel and in its labor costs. Economies of scale also are present in container terminals, as investments for berths are substantial and concave in container throughput capacity (UN-ESCAP 2005).

Marine cargo is heavily affected by energy prices. To our knowledge, well-researched public sources are not available. It has been reported (Wellins 2008) that the price of bunker cost has grown significantly and has now exceeded 35% of total vessel cost. Though we need to take great care in using these figures, they do indicate a high share of energy costs. In our interviews (during 2007 and early 2008), energy cost shares of 30–50% were reported. UNCTAD (2008) reports various estimates for the last quarter of 2007, depending on vessel size, between 40% and 63%.

Table 3 and Figure 1 show the energy consumption of large container vessels dependent upon speed.

It is clear that further increases in energy prices will further affect this ratio. This will impact the choice of vessel size but also the cruising speed.[5] For the supply chain, it is quite impactful if speeds are reduced to save on fuel cost. During the economic recession in 2009, ocean liners reduced speeds and hence increased lead times in the supply chains of their customers. A decrease in speed does not only increase the lead times of transportation, but also the inventories will increase due to the longer transit times. Furthermore, it may decrease the overall capacity available for container transport, as fewer trips can be made within a certain timeframe. The ocean liner

Table 3 Fuel Consumption, Expressed in US Dollars Per Day at Sea at Various Speeds and for Three Different Vessel Sizes Based on July 2006 Bunker Price Levels (Germanischer Lloyd, cited in Dynamar 2007)

At knots	5000 TEU	8000 TEU	12,000 TEU
18	23,100	29,000	36,500
20	31,800	39,400	48,700
22	43,700	52,200	64,400
24	59,300	69,400	83,600
26	82,800	96,100	114,700

company may also decide to add an extra ship in the fleet on a particular route. For instance, a fleet between Asia and the US West Coast would usually need five vessels, but during periods of slow steaming, a sixth vessel may be added. Interestingly, after adding one vessel, it is still less costly than faster steaming with fewer vessels due to lower fuel consumption.

The important trend of manufacturing outsourcing and offshoring has direct consequences on the type of merchandise shipped via ocean transports. While ocean transport traditionally transported predominantly raw materials and agricultural product, this later shifted to consumer products but is now dominated by intermediate products, that is, products upon which additional value adding operations take place in the country of import (Feenstra 1998). This suggests a further increasing importance from a supply chain perspective, as not only consumer products, but also intermediates are shipped via ocean container transport, thus indicating even more than a single ocean link in the supply chain. An interesting example is the manufacturing and recycling of laser printer cartridges. After the cartridges have been used, they are collected for recycling. The recycling process is labor intensive, and one of the companies that one of the authors worked with, shipped the empty cartridges from Europe to China, and then returns them to Europe for a second sale as a remanufactured product. Within their closed-loop supply chain, two ocean shipments were included.

A final important issue that is often discussed and is actually an important problem in this industry is the issue of container imbalance. With the load device being standardized, this container is also not disposable but is meant for multiple usages. However, the transport of full container loads is very unbalanced, since Asia (in particular China) exports much more than it imports; the reverse is true in most other areas of the world, in particular Europe and North America. According to statistics and forecasts (Dynamar 2007), the trade imbalance in trans-Pacific liner trades is more than 10.6 million TEU in 2006, and expected to reach almost 11.9 million TEU in 2007 and 13.2 million TEU in 2008. For the Europe–Far East trade, the imbalance is about 6.5, 7.9, and 9.1 million TEU in 2006, 2007, and 2008, respectively. Furthermore, "60 percent of the containers that crossed the Pacific Ocean from Asia to North America and 41 percent of the containers on European routes came back to Asia empty in 2005" (Fuller 2006). As a result of strong seasonal dynamics and imbalanced trade, Asia is always an area where empty containers are in demand, whereas the United States and Europe are areas where empty containers are in surplus. Empty container movements reportedly cost more than USD 11 billion, which accounted for 20% of the total ocean container movement cost (Bonney 2004).

Extensive studies have been conducted regarding the empty equipment management problem. Quantitative analysis can be found in White (1972), Florez (1986), Dejax and Crainic (1987), Crainic et al. (1993a,1993b), Lai et al. (1995), Shen and Khoong (1995), Du and Hall (1997), and Cheung and Chen (1998). Recently, Song (2007) used a Markov decision process approach to characterize the optimal empty container repositioning policy, Zhou and Lee (2009) use a mathematical model to study the pricing policy and outcome of competition between two firms regarding empty container reposition. Ding and Lee (2007) use chance constrained programming to solve an empty container reposition problem for transshipment routes. Qualitative and statistical industry oriented reports and articles represent an interesting source of reference and information (e.g., Behenna 2001, Boile 2006, Boile et al. 2006, Crinks 2000, Drewry Shipping Consultants 2003, Dynamar 2007, Hanh 2003, and The Tioga Group 2002). While this kind of literature helps greatly to gain a broad understanding concerning empty container management, the quantitative models are still far from applicable for solving realistic large scale problems, and there are no closed form solutions of optimal container repositioning for the stochastic transportation problem. Furthermore, the models do not address the inherent issue of trade imbalance. As discussed in Notteboom and Rodrigue (2007), the major causes of empty container imbalance problem include trade imbalances, repositioning costs, container manufacturing and leasing costs, and usage preferences. Furthermore, many shipping lines use containers as a way of branding the company name and they are reluctant to share market information on container positions and quantities (Notteboom and Rodrigue 2007). This makes empty container management an extremely challenging issue, and a very important and emerging research topic for the supply chain community. For instance, the way carriers (who own most of the containers) decide on demurrage and detention fees has a strong impact on the behavior of the container users, as users are more or less forced to return empty containers early to the empty depot, before a potential load can be identified.

4. Container Shipments from a Supply Chain Perspective: New Issues

The issues mentioned above are interesting and have been widely studied and reported on. Moreover, in those areas substantial research questions remain to be answered. The objective of this paper is, however, to present and discuss a number of problems and related research questions that have been understudied in the literature (academic and industry), and yet appear to be challenging for the industry of container shipping. In this section, we will outline four of those industry problem areas, namely:

- The coordination of container shipments across the container supply chain.
- Pricing and risk management in the container supply chain.
- Competition between ports, carriers, and container terminals.
- Capacity management in the container supply chain.

Based on our analysis of the industry, we believe these four areas represent challenging problems in this industry, are related to very interesting research questions, and provide extensive opportunities for researchers in the field of operations management to contribute. The impact of such research will be substantial due to the enormous impact of ocean container transport on most of today's supply chains. Together, they therefore constitute a research agenda for supply chain management research in ocean container transport. The common characteristic of these research topics is that they affect the performance of the entire supply chain rather than addressing specific issues of the various entities that provide logistic services. Moreover, we have selected these specific topics because supply chain management researchers can contribute toward a better understanding and toward the development of decision support models. We will discuss each of these four topics in detail in this section.

4.1. Coordination Across the Container Supply Chain

Moving containers from source to destination requires many operational coordination decisions to be taken, especially addressing the moment of handover of the container from one player to the next. To do this, decision makers have a lot of decision variables to take into account, such as the sailing speed, the stacking sequence in the ocean vessel, the handling of containers in the ocean terminal, the routing of the ships, and the mode selection of the hinterland transportation.

Many different parties are involved, each making their own decisions. These include the buyer and the supplier, and multiple service providers such as a logistics service provider, an NVOCC, an ocean carrier, one or more terminals operators, and one or more hinterland transport operators. Willis and Ortiz (2004) provide an extensive description of the different parties involved. In this supply chain, there is generally not a party who really controls the end-to-end transport of the container. While this argument can be put forward for any supply chain, the fact that the load carrier (the container) and the transportation service provider have been decoupled substantially changes the problem. While this decoupling has been the primary driver for productivity increase (container cargo reduces handling costs as compared to break bulk cargo), this also causes coordination problems that are inherently different from traditional supply chains. NVOCCs and logistics service providers try to get into a position where they can exert sufficient influence to be the *de facto* director of transport in this supply chain. However, the high capital intensiveness of both the ocean liner industry and the terminal operators lead to generally poorly controlled systems with extensive queuing characteristics under complicated priority settings at each of the stages that the container needs to pass. Consequently, lead times in this supply chain tend to be very variable and poorly controlled.

Transit time has become more and more important, and has become one of the dominating factors in selecting the ocean liner company (Notteboom 2006). From a supply chain management perspective, the transit time is the most important variable determining the lead time in supply chain models. Roughly speaking, transit time consists of hinterland transportation (on the sending and receiving end), terminal dwell time (on both ends and on the transshipments points), and sailing time. In the sailing time, there are two types of reliability: schedule reliability and transit reliability (Notteboom 2006). A schedule is a published timing of a round-trip voyage of a specific ship. Liner companies may adjust schedules to increase transit time reliability while affecting schedule reliability. Notteboom (2006) mentions an example where a carrier reroutes ships to avoid congested ports, and then using inland transport to transport the cargo to the required destination to maintain transit time reliability. Obviously, substantial cost may be involved for the carrier. He mentions that—based on a survey among shipping lines—by far the most important cause for schedule unreliability is port and terminal congestion. Vernimmen et al. (2007) argue that schedule reliability is also heavily affected by the position that the port takes in the sequence of ports that the vessel calls. Schedule reliability is likely to be higher in those ports that are first port of call (for import cargo). On the other hand, schedule reliability in a port that is only fifth or sixth port of call in a certain loop is heavily dependent on time delays experienced in the previous four or five ports.

Saldanha et al. (2006) analyze the sailing time performance of ocean container carriers based on data from a large shipping movements database. The main purpose of their study is to show that substantial differences exist in sailing time performance between different carriers; and in fact substantially larger than is generally subsumed. From a supply chain perspective it is interesting that they have also explicitly measured the standard deviations of the sailing time, in addition to determining the averages. Their data suggest that in the estimated sailing time a standard deviation of up to 3 days exists, depending on the carrier and the route. Leachman (2008) in a study on California ports concludes that from a supply chain perspective reliability is important, but may not justify substantial additional costs. His study is one of the few in which he analyzes the costs of infrastructure and service providers and compares them to the costs that the shippers and consignees make in terms of keeping extra safety stock.

To our knowledge, Leachman's work is the single published study that models operational containers flows (including stochastic behavior) and takes the perspective of the container. He considers the trade-off between keeping more inventory at the shipper, vis-à-vis more investments in infrastructure to reduce the lead time. In the maritime economics literature, models exist that also take the container perspective, but these fail to take the operational coordination problems into account (see, e.g., Luo and Grigalunas 2003). The transit time of the container is relevant for the user of container transportation services, and as Notteboom (2006) indicates, it has developed to be one of the primary reasons for selecting a carrier. It is therefore even more remarkable that so little empirical and modeling research exists taking this perspective.

Empirical research could entail both qualitative and quantitative studies. While our understanding of the contractual relationships in the supply chain is based on a small and selective sample (see our discussion of contracts for some examples), there is a need for more systematic work. Some preliminary work has been conducted in this field by Lee and Wong (2007), who conducted a survey to better understand the actual decision makers deciding on the choice of ports in the Pearl River Delta. They conclude that the shipper decides on the port of export in Asia, while the consignee (receiver) decides on the port of import in Europe. A second interesting subject for empirical research is the duration of actual container transport and gaining understanding of variability in container lead times. Ratliff et al. (2006) announce a large-scale project in which they attempt to get access to data that enables them to build a database of transportation lead times, with specific attention on lead time variability. Their idea is that because of transshipments and delays at terminals, actual transit time delays from the container perspective are substantially larger than the relatively low standard deviation that the study of Saldanha et al. (2006) suggests. Both of these examples illustrate the different type of empirical questions that SCM researchers would be interested in, as compared to the maritime economists who have conducted extensive empirical research in this domain for decades.

Modeling research would address the traditional coordination and planning questions. The eventual research question to address would be how to coordinate a supply chain where both the carrier (ocean liner) and the handling agent (container terminal) are capacity constrained, which leads to substantial variability in lead times. Partial research questions are many, including operational coordination with stochastic lead times, operational coordination with lane, carrier, or terminal choice, etc. This research obviously has strong links to the inventory management literature, including literature on visibility, contracting, multi-echelon inventory theory with stochastic lead times (see De Kok and Graves [2003] for a recent overview of the state of the art in these fields). The inventory management literature, however, generally abstracts from the dominant problems in this industry, such as stochasticity in transportation lead times, delays in handling at terminals, and the absence of a contractual relationship between some parties. Some recent research (see, e.g., Douma et al. 2009) models some of these coordination problems as a multi-agent system.

Research addressing these coordination problems would specifically need to address the fact that multiple players in this supply chain are primarily focused on optimizing the utilization of their expensive resources. For instance, both ocean carriers and terminal operator are aiming at very high utilization of their investment, which—under stochastic demand—may lead to substantial variance in performance.

In conclusion, these are some examples of research questions in supply chain coordination:

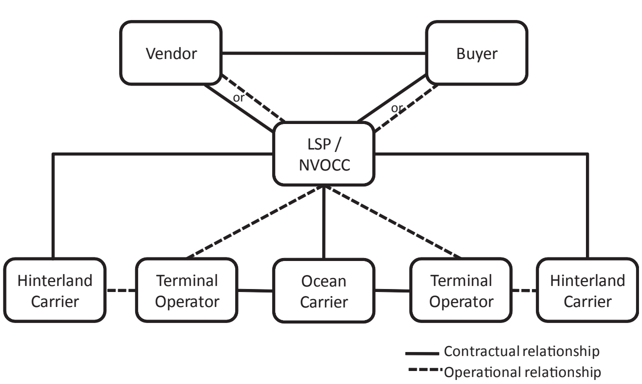
- What is the actual decision-making process on routing, terminal, and carrier selection in this industry? To what extent is there a party that may control this end-to-end?
- What are actual distributions of transit times? Can the variance in travel times be empirically explained, for instance due to transshipments or routing changes? What is the structure of the reliability-cost trade-off?
- How to allocate containers optimally to various carriers, given their operational characteristics? How to take travel time variability into account in the selection process?
- What is the good control mechanism to reduce transit time variability, for instance by advancing or delaying specific containers based on information tracking, or by using multi-agent approaches?

4.2. Contracting, Pricing, and Risk Management Along the Container Supply Chain

This supply chain is an excellent example of a supply chain in which contractual and operational relationships are not aligned. Let us take the example of the logistics service provider, ocean carrier, terminal operator, and hinterland carrier (see Figure 2). The logistics service provider contracts the ocean carrier and the hinterland carrier, the ocean carrier contracts the terminal operator. The terminal operator and the hinterland carrier have no contractual relationship, but their operational coordination impact both the waiting times of the hinterland carrier and the efficiency at the terminal. The operational coordination between the terminal operator and the hinterland carrier is important for the overall performance of this supply chain, and will affect the lead time reliability of a container that the logistics service provider can offer to its customers.

All contracts that are operational in this supply chain contain provisions on price setting and risk sharing. Carriers are paid a transport charge dependent on the specific route that they operate. Carriers then typically have the freedom to choose the detailed execution of the route, such as choosing whether to operate this on a direct liner or via the hub-and-spoke network (see Agarwal and Ergun [2008] for an interesting algorithm that combines scheduling and network design for container cargo). This latter choice obviously affects the overall transportation lead time from the container perspective. Based on our observations across several continents, and discussions with various parties in the industry, we are led to conclude that the transportation lead time from the container perspective is typically not a part of the contract, or—alternatively but with the same impact—penalties for late delivery do not exist or are not executed in the contract between the shipper (or freight forwarder as the case may be) and the ocean liner. It is not clear from the literature nor from our empirical work why this is the case. A potential explanation is that due to the fragmentation along the supply chain, there is no party willing to accept such responsibility. The results by Notteboom (2006) about the causes of delays also suggest that delays are closely intertwined: a delay by an ocean vessel may lead to a different allocation of berth places on the quay, which again may lead to delays at other ocean vessels having to reroute. It then becomes not very easy to assign the cause of a particular delay to one of the parties in the supply chain. The impact for the shipper is eventually that he is unable to obtain a reliable lead time (or even transit time) for his shipments. There is a need to design a pricing and penalty system between the various parties that would lead to more reliable lead times. Apart from the contracted prices, there are also published prices for many routes, but some argue that these prices are hardly ever paid due to most prices being negotiated in specific contracts (Levinson 2006).

Figure 2 Contractual Relationships and Operational Relationships Without Contract in the Ocean Container Supply Chain



Contracts regarding timing are much more stringent between the ocean liners and the terminal operators. Ocean liners usually have a contract with terminal operators in which they agree on a terminal charge per container handled. Note that a handling movement in the contract usually involves a single move, that is, from a vessel to the quay or *vice versa*. Furthermore, an operational contract is designed if an ocean liner books a slot at the quay for a specific time. Vessels announce their expected time of arrival about a week ahead of time, and provide the terminal with daily updates regarding their expected arrival time at the quay. From about 24 hours before arrival, the predictions tend to be accurate. Penalties exist both ways, both for the ocean liner not showing up (due to diverting its route) and delaying its arrival, and for the terminal if the quay is not available or the loading or unloading takes too long; however, these penalties are generally not executed to maintain the relationship between the terminal operator and the powerful ocean carriers. If an ocean carrier decides to change its route, and use a rival terminal or port, the ocean carrier is generally responsible for arranging the hinterland transport to ensure that the container ends up at the terminal for which it was originally intended.

An ocean carrier that owns a container charges detention fees if an empty container is not returned on time, or demurrage fees if the full (import) container is not collected on time from the quay. Under merchant haulage, the shipper will need to pay for the transport of the container to and from the seaport. Depending on its anticipated exports, it may want to retain the container to avoid the transportation charges, but then he will risk the detention charges. Alternatively, under carrier haulage, the carrier is responsible for the hinterland transport and hence may want to set detention fees differently for the shipper to avoid having to ship a container back to the seaport and then back out again to the shipper. Containers are also effectively used as warehousing capacity, which further increases the complexity of interactions. A consignee, faced by a certain structure of detention charges, may want to make a trade-off whether to use the container as additional warehouse capacity. For the ocean carrier, they may want to decide on specific incentives for the consignee to return the container. It is not clear what the policies are on setting the detention fees, and research opportunities exist for modeling research on optimal pricing strategies for carriers and optimal strategies for shippers to respond to certain pricing schemes. Furthermore, the pricing strategies have an effect on the overall efficiency of the system, in particular relating to the repositioning of empty containers in the hinterland, so also a societal (or system-encompassing) objective of transport minimization may be taken into account when developing pricing strategies.

The main contract between the buyer and the supplier is standardized according to the so-called Incoterms™ (ICC 2000). Incoterms™ specify the division of cost and risk between the buyer and the supplier. They specify when the product changes ownership and who is responsible for arranging and paying the transportation. Especially due to the long lead times in ocean container transport, negotiation of the right Incoterms™ is very important for a company's cash flow position, as well as for its risk position. Consequently, dependent on the Incoterms™ agreed, the seller and buyer may display certain strategic behavior. For instance, under Cost–Insurance–Freight, the seller is responsible for cost and freight until the port of destination, while the buyer is responsible for the risk during the ocean transport. Hence, the selection of the carrier is with the seller, while the associated risk is with the buyer. Furthermore, the Incoterms™ could also be linked to research on supply chain finance. To our knowledge, there is no academic work (neither theoretical nor empirical) on decision making related to Incoterms™, while these are actually very dominant in international trade.

The Incoterms™ clearly define the liability across international trade, the ownership of goods across international trade, and the responsibility for transport. Associated with ownership is cost associated with inventory holding such as cost of capital and obsolescence risk. Associated with liability is the risk of disruption occurring along the supply chain that may harm or lose the product. Associated with responsibility is the hiring of carriers, and negotiating rates (probably strongly related to buying power and volume). It is not very clear how these costs and risks interact, especially under assumption of strategic behavior by others in the supply chain. Under which conditions are which terms most favorable? And how does this impact the pricing?

The supply chain contracting literature (Cachon 2003) does not appear to have researched any of the problems discussed here. Most of the literature involves contracts with an inventory risk, while this is not the case here. In case of capacity contracts, the literature involves contracts in which one party buys capacity from a supplier. There is some literature studying the shipping contracts between shipper and transportation companies. Koekebakker et al. (2007) study the freight derivatives market. They propose a formula and show that their formula gives very accurate prices, in particular of forward-starting freight options. Garrido (2007) studies an electronic bidding system for the shippers to contract each shipment to a single carrier through an open auction and selects the carrier based on the best bidding price. Since the carrier will usually need to reposition the empty containers, they thus try to offer substantially lower shipping prices to the shippers to *generate* demand for these empty trips. The newly generated demand thus transforms shippers into bidders for the available capacity at discounted price. The paper shows that under a certain policy a spot price can trigger a demand generation for transportation services in the shippers' pool. Lim et al. (2008) study a shipper's transportation procurement model that involves an auction process, in which the transportation companies bid for routes to procure freight services from the companies, which minimizes its total transportation costs. The shipper gives assurances that shipments made in non-peak periods will be commensurate with shipments in peak periods. They formulate the model as an integer programming problem and develop a solution approach to solve it and also demonstrate the practical usefulness of the model.

Apart from the contracting relationship between vendor and buyer, the contracting relationship between shipper and service provider is also interesting. A recent survey by Merge Global (2008) indicated that in the container shipping industry the largest cost (50%) is related to ocean liners (carriers) and 17% (the second) is related to terminal operators. Hence, the contracts between shippers and carriers are very important and have a potentially large impact on the efficiency of the supply chain. Direct customers (shippers) can purchase freight services with carriers through long-term contracts (usually 1 year). On the other hand, the contracts between freight forwarders (NVOCC) and carriers are usually much shorter (1–3 months). In current practice, an NVOCC may even not make a binding commitment to the contract price if the spot market price is lower. In the Asia-Europe container trade, around 70% is contracted with carriers through freight-forwarders (NVOCC), while in the Asia-North America container trade, around 70% is contracted with carriers by the customers (shippers) directly. There is no clear (empirical or theoretical) explanation for this difference. Potentially this is related to the abolition of the so-called "conferences" in 2008 on the Asia-Europe route, following a decision of the European Commission under anti-trust law. Under the conference scheme, ocean liners build alliances and decide on prices jointly. Other regions, including North America and Asia are now considering abolishing the conference scheme. In fact, in September 2010 a new bill was introduced to the House of Representatives in the United States, which aims to eliminate anti-trust immunity for ocean carriers. All these developments make the contract arrangement between shipping liners on one hand and shippers and NVOCCs on the other, even more challenging, and hence an important and interesting research topic.

As mentioned above, in the supply chain literature the contract usually relates to inventory issues. Furthermore, it mostly deals with two different echelons. However, in ocean container transport, we may need to consider multi-echelon and/or multi-agent contracts. For example, the contract between freight forwarder and shipping liners may involve intermodal transportation, that is, not only the ocean transport but also inland transport. In such a case, the shipping liners need to arrange the contract not only with the shipper but also with the hinterland transportation service providers. Similarly, the terminal operator may sign contracts not only with shipping liners including terminal handling charges and related loading and unloading of containers, but also with consignees regarding over-duration storage charge. Furthermore, though the conference scheme is likely to be abolished soon, the alliance contract among shipping liners is still popular. The contracts among alliance members will affect the contract between shipping liner and shippers, and will certainly affect the global supply chain.

Based on our knowledge, there is no literature directly dealing with contracts issues between different parties in ocean container transport, though some literature has studied the aggregated contract impact. For example, Kavussanos et al. (2004) investigates the impact of Forward Freight Agreement trading on spot market price volatility in two panamax Atlantic and two panamax Pacific trading routes of the dry-bulk shipping industry. Literature also exists in other industries related to logistics, including, for example, airline ticket contracts for large corporations (Pachon et al. 2007), bus service contracts (Hensher and Houghton 2004, Hensher and Stanley 2003), and contracts and regulations for road franchising (Tan et al. 2010).

In conclusion, these are some examples of interesting research questions in contracting:

- How to selects the optimal Incoterms, taking into account a strategic response from the customer or supplier, to maximize expected profits or to control certain risks?
- How to design contracts such that the contracted party demonstrates certain behavior toward other contracting parties of the principal, without a contractual relationship between the two contracted parties? For instance, referring to Figure 2, how should an LSP design its contracts with the ocean carrier and the hinterland carrier, such that lead time variability in the transfer from ocean carrier, via terminal operator, to hinterland carrier is reduced?
- How should the ocean carrier contract with the LSP, or price its demurrage or detention fees such that the movements of empty containers are minimized?
- What are good pricing strategies for ocean carriers once conference schemes are abolished?
- Should an ocean carrier contract differently with NVOCCs then they would contract with a shipper directly?

4.3. Competition Between Ports, Carriers, and Terminals in the Container Supply Chain

Competition in this industry is fierce and is present in many parts of the supply chain. First, ports compete to attract terminal operators and obtain a place into the schedule of the ocean liners. In the Pearl River Delta in Southern China, the ports of Hong Kong, Shenzhen, and Guangzhou compete to attract containers for the Guangdong hinterland; in the Yangtze River Delta, Shanghai and Ningbo compete for business out of the vast Yangtze hinterland; in Northwest Europe, the ports of Le Havre, Antwerp, Rotterdam, and Hamburg compete to serve the majority of the European industrial heartland along the Rhine, Scheldt, and Elbe. Ports compete by investing in new quays, by ensuring good access from the sea, or by moving new quays closer to the sea. Furthermore, port authorities (who are mostly public bodies or publicly held companies) and national governments try to improve the strategic advantages of ports by improving the hinterland infrastructure, to ensure that shipments can reach the port and the hinterland without delay, and by ensuring deep-sea access (see, e.g., Cullinane et al. 2004, 2005, Robinson 1998, for various qualitative case studies; Malchow and Kanafani 2001, Nir et al. 2003, Veldman and Bückmann 2003, for econometric studies based on multinomial logit models; note that similar models have been developed and applied in the competition between airports, e.g., Pels et al. 2003). Competition between ports is generally seen as a field of public policy, but taking a supply chain view on these matters may seriously affect the port's strategy. Many ports deliberate whether they should maintain their traditional role of landlord and infrastructure provider, to allow terminal operators to conduct their business as well as possible, or to take more of a supply chain perspective and hence deliberately and proactively analyze goods flow developments and adapt an infrastructure with partners in the hinterland and at other ports that could better serve the container supply chain as a whole (Notteboom 2004, Robinson 2002).

Since there are many factors that affect the strategic and operational decisions of the port, it is hard to study port competition quantitatively. So, research on pure port competition models is scarce. Recently, Luo et al. (2010) used a two stage duopoly model to study the market power transition and the evolution of Hong Kong and Shenzhen ports. They investigated the competition game between the two ports in two steps: the pricing subgame and the capacity expansion subgame. Qiu and Lu (2008) considered models of static and dynamic seaports competition games and tested these models through a study of Dalian and Yingkou, two neighboring ports in northern China. Wang et al. (2008) analyzed the situation of two-port competition, Dalian and Yingkou, by means of the Stackelberg model and the hub-and-spoke system. Anderson et al. (2008) develop a game-theoretic best response framework to analyze the current investment and competition between the ports of Busan and Shanghai.

We believe that future developments need to address more the full integration of container ports in supply chains and treat the container port as an element of a supply chain. For the port competition research, to maximize the welfare for the whole system, besides purely competition, we can take into account the possible co-operation and competition between regional ports at the same time and the coordination of the container supply chain which includes the port as an important element. Furthermore, the utilization of economic models from competition theory may help to mathematically analyze port competition and gain some useful managerial insights.

To a certain extent, and definitely when it concerns more long-term strategic choices, the competition between terminal operators is similar to the competition between ports. However, in the shorter term competition between terminals holds different characteristics. Terminals compete for business from ocean carriers. They want ocean carriers to have their cargo discharged at their terminal. Availability of the quay is important, as ocean liners may decide to reroute ships to other terminals (within the same port or at other nearby ports) if the quay is not available and waiting time would be too long. This problem is similar to the one studied by Hall and Porteus (2000), who model shifting behavior of customers between service providers based on service achieved; service is related to capacity in previous periods. Terminals need to anticipate future arrivals of vessels, assess the number of containers that would need to be loaded and discharged, and decide on actual requests of vessel operators to load and discharge containers. They are thus faced with an online order acceptance and scheduling problem. In the operations research literature, the berth allocation problem has been studied extensively (Steenken et al. 2004), but these papers study this problem with a given set of vessels to be processed, and without considering strategic behavior of either the vessel operator or the terminal operator. For river transport, it is known that barge captains display strongly strategic behavior (Douma et al. 2009). Our findings suggest that to allow for flexibility, ocean liners are restrictive on sharing information. Information regarding the number of containers to be loaded and discharged is often revealed at a late stage, leading to poorly controlled stacks of containers on the quay. For instance, despite substantial increases in throughput, one of the terminals in a major European port reported to us that the average dwelling time of a container on the quay is still increasing.

It is the general impression in the industry, based on our interviews, that the ocean liners are the most powerful party in this supply chain. Also in the literature (Robinson 1998, 2002), this is suggested. Clear theoretical explanations for this dominance, apart from the strong consolidation that has taken place in this industry, are not available and hence strategies for how to deal with this dominance by the other parties in the supply chain have not been developed. This is a very interesting area of research. A potential explanation for the dominance of the ocean liners is that over the past years, they have formed alliances that effectively operate more or less closed networks. These alliances have some similarity to the alliances in the airlines industry, and the concept of "code sharing" in the airline industry. Agarwal (2007) is a recent work and the first one that addresses the problem of alliance formation in container liner shipping using formal modeling. There is, however, still a need for research that explains the dominant position of ocean liner companies.

In summary, interesting research questions in the area of competition relate to competition between ports, competition between container terminals, and competition between the ocean carriers and the terminals operators to fulfill certain roles:

- How should ports compete to strengthen their position in relation to specific supply chain characteristics, such as the extent of their hinterland connections and the reliability of their customs operations? Are specific strategies likely to prevail, for instance competing on hinterland connections compared to competing on low labor costs in the port?
- How should terminals compete to obtain visits of major ocean carriers? How should they trade off berth availability and short waiting and handling times with low operational costs with high equipment utilization?
- What are theoretical explanations for the apparent dominance of the ocean carriers in the competitive relationship with terminal operators? Do they have an incentive not to share information to maintain this position? What can other parties do to improve their competitive position?

4.4. Capacity Management in the Container Supply Chain

Due to the high capital intensity in this supply chain, the management of this capacity is a dominant trait. The capacity orientation in container terminals explains to a large extent the extensive amount of operations research work that has been conducted to optimize terminals operations. This is not limited to theoretical work, as many OR applications are actually used daily in these terminals. In this section, we would like to address the management of capacity from a supply chain perspective, both from a tactical level and from a more operational level.

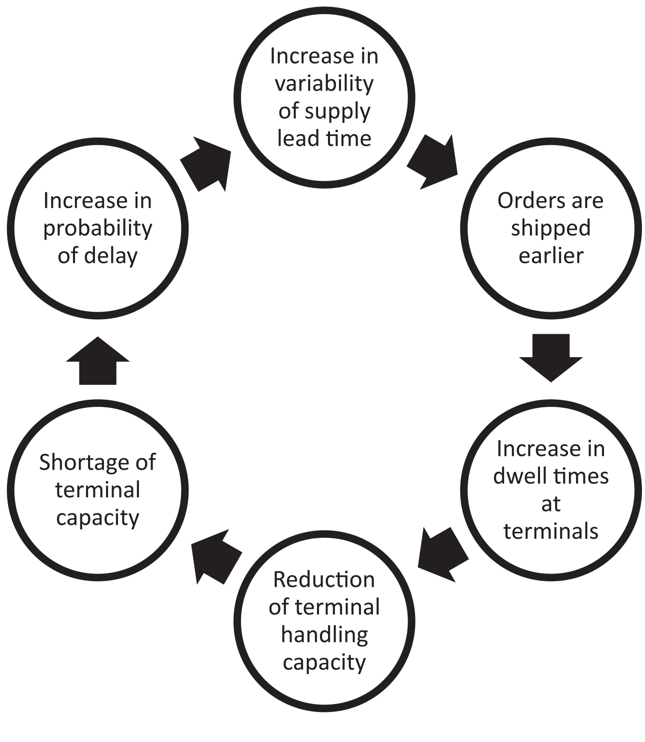
At the tactical level, decisions need to be made upon investments in capacity. Investments in ports and terminals can largely be based on some of the competitive econometric models that we have discussed in the previous section, some of which aim to predict demand for container traffic at certain ports or terminals in a region. An example is the work by Veldman and Bückmann (2003) who, using a competitive model, predict the demand for terminal handling capacity in the port of Rotterdam to support investments leading to new quays. Competing ports will, however, make similar analyses and decisions on port expansions. This has some similarities to investment decision in highly capital intensive industries, such as the semiconductor industry and the machine tool industry. In these industries, it has been demonstrated that a significant bullwhip effect occurs as a consequence of cyclic investment patterns (Anderson and Fine 1998). The enormous and continuous growth in container transport in the past decade and the relatively slow expansion procedures in Europe may have dampened the bullwhip effect, as capacity utilization at terminals is still high. However, it is unclear what will happen when growth slows down. There is a need for models—similar to those in the semiconductor industry—that analyze and optimize the capacity expansion decision in ports and terminals, and are validated on real-life data.

At the operational level, decision making is more complicated due to the high levels of capacity utilization in container vessels and terminals, as well as in some of the hinterland connections. Increased utilization leads to increased variability, and strategies for decision making are only few. The decisions are actually complicated by the fact that not all parties have a contractual relationship, as discussed above. Variability in lead times is high. According to Drewry (reported in Dynamar 2007), "the share of ships arriving on the advertised date" was "Transpacific 63%, Europe-Far East 49%," and "Transatlantic 46%." We hypothesize that the increased dwell times that have been reported to us in European and North American ports are related to the high levels of capacity utilization both on vessels and in terminals. Taking a system dynamics perspective, increased utilization leads to increased lead times (due to waiting at the port of export) with increased variability, which causes the shippers to have their products sent early. However, they will not pick up their orders earlier than needed and leave them on the quay. Increased storage of containers on the quay reduces the efficiency of the handling operations on the quay and could effectively cause further capacity problems, this time at the quay. This line of thinking has been summarized in Figure 3.

This problem has similarities to production control problems in highly utilized systems and consequently variable lead times, relating to issues such as the lead time syndrome (Mather and Plossl 1978, Selcuk et al. 2009). In the production control literature, various approaches have been developed to manage production departments with variable lead times (see, e.g., Pahl et al. [2005] and Missbauer [2006] for recent overviews of this work), and this could be a potential theoretical basis for addressing the problems in this industry characterized by high levels of utilization.

An alternative theoretical basis to relate these dynamics to is the bullwhip effect (Forrester 1958, Lee et al. 1997), to which a whole series of modeling papers is related addressing the countering of this effect, covering issues such as information sharing (value of information), and the countering of shortage gaming behavior. The focus of these papers is very much on the management of inventory. The reasoning above implies that capacity issues may be more dominant than inventory issues in this supply chain, albeit the variability in lead times does have immediate con-

Figure 3 Relationship Between Delays and Capacity Usage



sequences on inventory policies and related inventory holding cost at the shipper.

Strategies need to be developed for the various players in this supply chain, addressing research questions such as:

- What are optimal capacity investment strategies for port authorities expanding quays and terminal operators investing in handling capacity?
- What are optimal ordering policies for shippers (especially *when* to place the order in order to obtain a reliable delivery), taking into account the dynamics in the container supply chain as described above?
- What is the value of sharing information between the various parties in the container supply chain? For instance, the deepsea terminal operator typically does not know the final destination of the container, and only gets informed relatively late by the hinterland carrier about collection of the container. This leads to queuing of hinterland carrier vehicles at the terminal, and simultaneously drops in efficiency in the sea terminal. Sharing information may improve capacity utilization.
- What should prices be for containers dwelling on the quay, bearing in mind that too high prices would turn shippers and liners away to competing terminals, but too low prices would transfer the quay into cheap warehouse space and reduce terminal efficiency?

Operations management studies addressing these and similar questions are few and far between.

5. Conclusions, Managerial Insights, and Research Agenda

In this paper, we have outlined the key characteristics of ocean container shipping, an essential part of today's global supply chains, and the primary link between manufacturing sources in developing economies and the markets in the developed world. We have noted that the supply chain impact of this mode of transport is significantly understudied, and we have identified four areas of research that can contribute to a better understanding and improved performance of the worldwide container supply chains. The four identified research areas are:

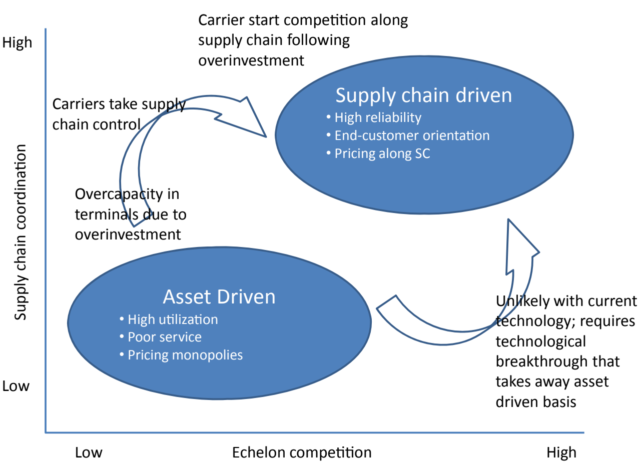
- The coordination of container shipments across the container supply chain.
- Pricing and risk management in the container supply chain.
- Competition between ports, carriers, and container terminals.
- Capacity management in the container supply chain.

While discussing this segment of transportation and the related industries, we have demonstrated that it is heavily capacity oriented, with a particular dominance of the ocean liner companies that operate the still scarce capacity of vessels. While vessel capacity has been increasing and it will be only a matter of years until the overall capacity will have exceeded the worldwide demand for ocean transportation capacity, the substantial consolidation in this industry may serve to consolidate the relative power of the ocean liner operators in this supply chain as outlined above.

Also at the terminals, operations are primarily aimed at the optimization of expensive resources, leading to queuing effects at other places in the supply chain, notably in the hinterland transportation. Current operations are primarily driven by utilizing the scarce assets, while there appears to be little or no attention to an end-to-end supply chain focus. From a supply chain perspective, it would be logical to evaluate the performance of this container supply chain to the actual "delivery reliability" of a particular container at the final point of delivery, at the customer, against a certain total cost toward this customer.

While both modeling and empirical research will need to provide us with the actual insights, we believe that actually only two drivers will enable a true change in focus and performance of this supply chain (see Figure 4). One potential driver could be the per-

Figure 4 Industry Dynamics that May Drive the Global Container Shipment Industry from an Asset Driven Focus to a Supply Chain Driven Focus



iod when terminal capacity will be in oversupply, following the extremely high growth in investments in terminals. On the export side, especially in China, there appear to be increasing signals of overcapacity. On the import side in Europe and the United States, on the contrary, the growth in capacity has still not been able to keep up with the growth in volume. Also for the ocean liner capacity, the consolidation and alliance formation, coupled with the fact that effectively capacity can be regulated via the speed of the vessels, it is not obvious when this would be the case. An alternative breakthrough could be realized if technology would develop in such a way that scale would be much less important. While this conceptual model could forecast future competitive developments in this supply chain, more formal analysis is needed, coupled with additional empirical data, to truly understand the competition dynamics.

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Notes

[1]In this paper, we use the term "(ocean) container supply chain" to denote a supply chain of any arbitrary product that is transported using ocean containers.

[2]For this calculation, we assume conservatively that 50% of the value of Chinese exports is transported via ocean containers, and that the average lead time in transportation, including dwelling time and hinterland transport, is 1 month.

[3]Data from US Census.

[4]While the numbers indicate a strong growth trend, substantial caution should be taken in interpreting these numbers. There are several reasons for this. First, container traffic is generally measured as the number of containers handled in ports, rather than shipped end-to-end. This implies that in case of a direct shipment, the container is already counted twice: once at the port of export and once at the port of import. As networks develop further toward a hub-and-spoke system that is similar to the global passenger airline industry, every individual container tends to be handled several times within a single container terminal, for instance when it is transshipped from a feeder vessel onto a large long-distance ocean liner vessel. This means the container is counted twice more in port statistics. For instance, the port of Singapore is primarily dependent on transshipments (UN-ESCAP 2005), while for instance in Rotterdam this is 27% (Port of Rotterdam 2007). Second, handling of empty containers is also included in port statistics. Furthermore, different definitions apply, since for instance the ports of Hong Kong and Shanghai include river transport into their figures (implying that a single container coming from the hinterland by barge would also be double-counted), while the other ports do not. From the port of Rotterdam, for instance, more than 30% of the containers coming from or going to the hinterland are transferred by barge (Port of Rotterdam 2007). These interpretations of statistics make it very hard to compare data from various sources and one should be careful in making too specific conclusions. However, the general conclusion that world trade is growing at more than double the growth pace of the world economy, that trade using containers is growing at about triple the pace of world GDP growth, and that container terminal throughput is growing at an even higher pace, appears to be a valid conclusion given the various studies that we have cited.

[5]By way of illustration, we calculated the estimate fuel costs for a round trip from Hong Kong to Los Angeles. For a 5000 TEU vessel, at 18 knots, this is about USD 682,000 (USD 136 per container), while at 22 knots, it results in a cost of about USD 1,056,000 (USD 211 per container). For a 12,000 TEU vessel, these numbers are respectively 1,077,000 (90) and 1,556,000 (129).

References

Agarwal, R. 2007. *Network Design and Alliance Formation for Liner Shipping*. Ph.D. dissertation, Georgia Institute of Technology, Atlanta.

Agarwal, R., Ö. Ergun. 2008. Ship scheduling and network design for cargo routing in liner shipping. *Transp. Sci.* **42**(2): 175–196.

Alphaliner. 2010. Alphaliner Top 100. Available at: http://www.axs-alphaliner.com/top100/ (accessed date February 15, 2010).

Anderson, C. M., Y.-A. Park, Y.-T. Chang, C.-H. Yang, T.-W. Lee, L. Meifeng. 2008. A game-theoretic analysis of competition among container port hubs: The case of Busan and Shanghai. *Marit. Policy Manage.* **35**(1): 5–26.

Anderson, E., C. Fine. 1998. Business cycles and productivity in capital equipment supply chains. Tayur, S., R. Ganeshan, M. Magazine, eds. *Quantitative Methods for Supply Chain Management*, Chapter 13. Kluwer Academic Publishers, Norwell, MA, 381–416.

Behenna, P. 2001. *Container Asset Visibility: The Key to Reducing Ocean Carrier Operating Costs*. International Asset Systems. Available at: http://www.interasset.com (accessed date February 14, 2010).

Boile, M. P. 2006. Empty Intermodal Container Management. Final report, CAIT/Rutgers University Organization, Report No. FHWA-NJ-2006-005, Washington, DC.

Boile, M., S. Theofanis, M. Golias, N. Mittal. 2006. Empty Marine Container Management: Addressing Locally a Global Problem. Proceedings of the Transportation Research Board 85th Annual Meeting.

Bonney, J. 2004. Changing the landscape. *Journal of Commerce*, April 26.

Cachon, G. 2003. Supply chain coordination with contracts. de Kok, A. G., S. C. Graves, eds. *Supply Chain Management: Design, Operation, and Coordination*. Elsevier, Amsterdam, 233–257.

Cheung, R. K., C. Y. Chen. 1998. A two-stage stochastic network model and solution methods for the dynamic empty container allocation problem. *Transp. Sci.* **32**(2): 142–162.

Clark, X., D. Dollar, A. Micco. 2004. Port efficiency, maritime transport costs, and bilateral trade. *J. Dev. Econ.* **75**: 417–450.

Crainic, T. G., M. Gendreau, P. Dejax. 1993a. Dynamic and stochastic models for the allocation of empty containers. *Oper. Res.* **41**: 102–126.

Crainic, T. G., M. Gendreau, P. Soriano, M. Toulouse. 1993b. A tabu search procedure for multicommodity location/ allocation with balancing requirements. *Ann. Oper. Res.* **41**: 359–384.

Crinks, P. 2000. *Asset Management in the Global Container Logistics Chain*. International Asset Systems. Available at: http://www. interasset.com (accessed date February 14, 2010).

Cullinane, K., W. T. Fei, S. Cullinane. 2004. Container terminal development in Mainland China and its impact on the competitiveness of the port of Hong Kong. *Transp. Rev.* **24**(1): 33–56.

Cullinane, K., Y. Teng, T.-F. Wang. 2005. Port competition between Shanghai and Ningbo. *Marit. Policy Manage.* **32**(4): 331–346.

Datamonitor. 2006. Logistics Benchmarking and Profiler. Cited in: Transport News Network, Wincanton: Continental Europe Still Not Bringing Home The Bacon. Available at: http:// www.tnn.co.uk/IndustryNews/plonearticle.2006-11-10.853404 3500 (accessed date January 18, 2008).

De Kok, G., S. C. Graves, eds. 2003. *Supply Chain Management: Design, Operation, and Coordinaton*. Elsevier, Amsterdam.

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

Ding, Y., C.-Y. Lee. 2007. Empty Container Reposition Problem for Transhipment Routes in a Random Setting. Working paper, Department of Industrial Engineering and Logistics Management, Hong Kong University of Science and Technology, Hong Kong.

Douma, A., M. Schutten, P. Schuur. 2009. Waiting profiles: An efficient protocol for enabling distributed planning of container barge rotations along terminals in the port of Rotterdam. *Transp. Res. Part C* **17**(2): 133–148.

Drewry Shipping Consultants. 2003. *Annual Review of Global Container Terminal Operators*. Drewry, London.

Du, Y. F., R. Hall. 1997. Fleet sizing and empty equipment redistribution for center-terminal transportation networks. *Manage. Sci.* **43**: 145–157.

Dynamar, V. 2007. *Dyna Liners Trades Review January 2007*. Alkmaar, The Netherlands.

Feenstra, R. C. 1998. Integration of trade and disintegration of production in the global economy. *J. Econ. Perspect.* **12**(4): 31–50.

Florez, H. 1986. Empty-Container Repositioning and Leasing: An Optimization Model. Ph.D. dissertation, Polytechnic Institute of New York, Brooklyn, NY.

Forrester, J. W. 1958. Industrial dynamics: A major breakthrough for decision makers. *Harv. Bus. Rev.* **36**(4): 37–66.

Fuller, T. 2006. China trade unbalances shipping. *New York Times*, January 29.

Garrido, R. A. 2007. Procurement of transportation services in spot markets under a double-auction scheme with elastic demand. *Transp. Res. Part B* **41**: 1067–1078.

Günther, H. O., K. H. Kim. 2006. Container terminals and terminal operations. *OR Spectrum* **28**: 437–445.

Hall, J., E. Porteus. 2000. Customer service competition in capacitated systems. *Manuf. Serv. Oper. Manage.* **2**(2): 144–165.

Hanh, L. D. 2003. The Logistics of Empty Cargo Containers in the Southern California Region: Are Current International Logistics Practices a Barrier to Rationalizing the Regional Movement of Empty Containers. Project Final Report, Department of Civil and Environmental Engineering, University of Southern California, Los Angeles.

Hensher, D. A., E. Houghton. 2004. Performance-based quality contracts for the bus sector: Delivering social and commercial value for money. *Transp. Res. Part B* **38**: 123–146.

Hensher, A., J. Stanley. 2003. Performance-based quality contracts in bus service provision. *Transp. Res. Part A* **37**: 519–538.

Kavussanos, M. G., I. D. Visvikes, R. A. Batchelor. 2004. Over-the-counter forward contracts and spot price volatility in shipping. *Transp. Res. Part E* **40**: 272–296.

ICC (International Chamber of Commerce). 2000. Incoterms 2000. Available at: http://www.iccwbo.org/incoterms/id3037/ index.html (accessed date January 23, 2008).

Koekebakker, S., R. Adland, S. Sodal. 2007. Pricing freight rate options. *Transp. Res. Part E* **43**: 535–548.

Lai, K. K., K. Lam, W. K. Chan. 1995. Shipping container logistics and allocation. *J. Oper. Res. Soc.* **46**: 687–697.

Leachman, R. C. 2008. Port and modal allocation of waterborne containerized imports from Asia to the United States. *Transp. Res. Part E* **44**(2): 313–331.

Lee, C.-Y., M.-C. Wong. 2007. Current and Future Prospective of the Hong Kong Logistics Industry. Working paper. Department of Industrial Engineering and Logistics Management, Hong Kong University of Science and Technology, Hong Kong.

Lee, H. L., P. Padmanabhan, S. Whang. 1997. Information distortion in a supply chain: The bullwhip effect. *Manage. Sci.* **43**(4): 516–558.

Levinson, M. 2006. *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*. Princeton University Press, Princeton, NJ.

Li and Fung. 2011. China Trade Quarterly – Domestic and Foreign, January.

Lim, A., B. Rodrigues, Z. Xu. 2008. Transportation procurement with seasonally varying shipper demand and volume guarantees. *Oper. Res.* **56**(3): 758–771.

Luo, M., T. A. Grigalunas. 2003. A spatial-economic multimodal transportation simulation model for US coastal container ports. *Marit. Econ. Logist.* **5**(2): 158–178.

Luo, M., L. Liu, F. Gao. 2010. A two-stage game theory model for market power transition and evolution. Working paper, Hong Kong Polytechnic University, Hong Kong.

Malchow, M., A. Kanafani. 2001. A disaggregate analysis of factors influencing port selection. *Marit. Policy Manage.* **28**(3): 265–277.

Mather, H., G. W. Plossl. 1978. Priority fixation versus throughput planning. *Prod. Inv. Manage.* **14**: 27–51.

Merge Global. 2008. Insomnia: Why challenges facing the world container industry make for more nightmares than they should. *American Shipper*, July, 68–85.

Missbauer, H. 2006. Models of the transient behavior of production units to optimize the aggregate material flow. Working paper, University of Innsbruck, Austria.

Nir, A.-S, K. Lin, G.-S. Liang. 2003. Port choice behavior – from the perspective of the shipper. *Marit. Policy Manage.* **30**(2): 165–173.

Notteboom, T. E. 2004. Container shipping and ports: An overview. *Rev. Network Econ.* **3**(2): 86–106.

Notteboom, T. E. 2006. The time factor in liner shipping services. *Marit. Econ. Logist.* **8**(1): 19–39.

Notteboom, T., J.-P. Rodrigue. 2007. Reassessing port-hinterland relationships in the context of global supply chains. Wang, J., T. Notteboom, D. Olivier, B. Slack, eds. *Ports, Cities, and Global Supply Chains*. Aldershot, Ashgate, 51–68.

Pachon, J., M. Erkoc, E. Iakovou. 2007. Contract optimization with front-end fare discounts for airline corporate deals. *Transp. Res. Part E* **43**: 425–441.

Pahl, J., S. Voß, L. Woodruff. 2005. Production planning with load dependent lead times. *4OR* **3**: 257–302.

Pels, E., P. Nijkamp, P. Rietveld. 2003. Access to and competition between airports: A case study for the San Francisco Bay area. *Transp. Res. Part A: Policy Pract.* **37**(1): 71–83.

Port of Rotterdam. 2007. *Port Statistics 2006*. Port of Rotterdam, Rotterdam.

Qiu, Y., H. Lu. 2008. Competition Game Model of Regional Seaport Logistics Terminals: Case Study of Seaports in China. The Eighth International Conference of Chinese Logistics and Transportation Professionals, Chengdu.

Ratliff, H. D., J. Langley, H. Donaldson. 2006. Global Shipment Network Database. Supply Chain and Logistics Institute, Georgia Institute of Technology. Available at: http://www.scl.gatech.edu/industry/global-db/ (accessed date January 23, 2008).

Robinson, R. 1998. Asian hub/feeder nets: The dynamics of restructuring. *Marit. Policy Manage.* **25**(1): 21–40.

Robinson, R. 2002. Ports as elements in value-driven chain systems: The new paradigm. *Marit. Policy Manage.* **29**(3): 241–255.

Saldanha, J. P., D. M. Russell, J. E. Tyworth. 2006. A disaggregate analysis of ocean carriers' transit time performance. *Transp. J.* **45**(2): 39–60.

Selcuk, B., I. J. B. F. Adan, T. G. De Kok, J. C. Fransoo. 2009. An explicit analysis of the lead time syndrome: Stability condition and performance evaluation. *Int. J. Prod. Res.* **47**(9): 2507–2529.

Shen, W. S., C. M. Khoong. 1995. A DSS for empty container distribution planning. *Decis. Support Syst.* **15**: 75–82.

Song, D. P. 2007. Characterizing optimal empty container reposition policy in periodic-review shuttle service systems. *J. Oper. Res. Soc.* **58**: 122–133.

Stahlbock, R., S. Voss. 2008. Operations research at container terminals: A literature update. *OR Spectrum* **30**: 1–52.

Steenken, D., S. Voss, R. Stahlbock. 2004. Container terminal operation and operations research – a classification and literature review. *OR Spectrum* **26**: 3–49.

Tan, Z., H. Yang, X. Guo. 2010. Properties of Pareto-efficient contracts and regulations for road franchising. *Transp. Res. Part B* **44**: 123–146.

The Tioga Group. 2002. Empty Ocean Logistics Study, Technical Report, Submitted to the Gateway Cities Council of Governments, CA, 2002.

UNCTAD (United Nations Conference on Trade and Development). 2008. *Review of Maritime Transport 2008*. United Nations, New York and Geneva.

UNCTAD (United Nations Conference on Trade and Development). 2009. *Review of Maritime Transport 2009*. United Nations, New York and Geneva.

UN-ESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 2005. *Regional Shipping and Port Development Strategies (Container Traffic Forecast)*, Report ST/ESCAP/2398. United Nations, New York.

Veldman, S. J., E. H. Bückmann. 2003. Model on container port competition: An application for the West European container hub-ports. *Marit. Econ. Logist.* **5**: 3–22.

Vernimmen, B., W. Dullaert, S. Engelen. 2007. Schedule unreliability in liner shipping: Origins and consequences for the hinterland supply chain. *Marit. Econ. Logist.* **9**: 193–213.

Vis, I. F. A., R. De Koster. 2003. Transshipment of containers at a container terminal: An overview. *Eur. J. Oper. Res.* **147**: 1–16.

Wang, J., H. Zhang, Z. Yang. 2008. The Analysis on the Oligarch Game in the Competition of the Regional Hub Port. IEEE International Conference on Service Operations, Beijing.

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

Wellins, C. 2008. Shipping in the age of the $100 barrel. *Shippers Today*, February.

Willis, H. H., D. S. Ortiz. 2004. *Evaluating the Security of the Global Containerized Supply Chain*. Report TR-214. RAND Corporation, Santa Monica, CA.

Zhou, W., C.-Y. Lee. 2009. Pricing and competition in a transportation market with empty equipment repositioning. *Transp. Res. Part B* **43**(6): 677–691.