Chapter 17
Hinterland Transportation in Container Supply Chains

Yann Bouchery, Stefano Fazi and Jan C. Fransoo

Abstract The increase in traded container volumes worldwide puts pressure on the hinterland road network, leading congestion and emission problems. This leads to a requirement to develop intermodal transportation systems. In this chapter, we analyze the most important features of such container transportation systems for the hinterland supply chain. At the network design level, we review the current state of the art and we identify avenues for future research. Among others, we highlight that the coordination of container shipments across the container supply chain is a particularly relevant issue as hinterland networks involve several actors. At the operational level, we characterize the most important factors influencing the trade-off between intermodal transportation and truck-only deliveries. In addition, we provide a case study of coordination at an intermodal barge terminal in the Netherlands. We highlight that the exchange of information is the key enabler for efficient hinterland intermodal transportation and we show that a better information system can be of crucial importance.

17.1 Introduction

Over the last decades, traffic of containers has increased substantially. Growth in international trade leads to increased growth in transport, and due to extensive containerization of an ever-increasing number of commodities, container transport has grown substantially (Fransoo and Lee 2013). Apart from the growth in intercontinental maritime transport, also the container traffic in the associated hinterland has grown substantially. Transportation means such as barges, trains and trucks have been adapted to be able to transport containers to and from the deep sea ports.

The transport of containers involved many actors and activities along the supply chains. If we consider an intercontinental shipment of a container that includes an ocean leg, the process is usually initiated by a company (such as a manufacturer) that orders a container. As the empty container is received, it is loaded and then transported

---

J. C. Fransoo (✉) · Y. Bouchery · S. Fazi
School of Industrial Engineering, Technische Universiteit Eindhoven,
Eindhoven, The Netherlands
e-mail: J.C.Fransoo@tue.nl

C.-Y. Lee, Q. Meng (eds.), *Handbook of Ocean Container Transport Logistics*,
International Series in Operations Research & Management Science 220,
DOI 10.1007/978-3-319-11891-8_17

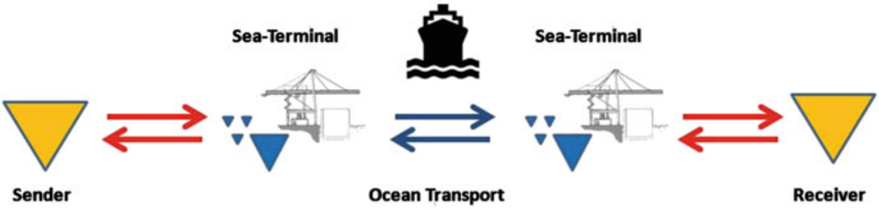

Fig. 17.1 A generic intercontinental shipment of a container. The *red* flows represent the hinterland transportation

to a terminal in a deep sea port, where it is handled and loaded onto a vessel. The container is then shipped to another seaport (potentially being transshipped along the way), discharged and delivered to a receiver (consignee), who unloads it. Finally, the container is delivered either to a depot for empties or to a deep sea terminal. Figure 17.1 contains a visual description of this cycle.

From this description we can identify 3 generic elements in this supply chain, namely:

- Ocean transport
- Terminal operations
- Hinterland transport

Each of these stages has been affected to a large extent by the increase of containerized transport.

In ocean transport, naval engineering pushed the physical limits of the ships remarkably. The latest ships provide capacity for more than 18,000 TEU (Kohr et al. 2013). Also civil engineering contributed to the ability to create economies of scale. As the size of the ships increased, also the infrastructures like canals, locks and docks had to be adapted. Artificial canals and expansions of current waterways have been made to allow more and larger ships to sail through. The case of the Panama Canal is one of the most well-known engineering processes of the artificial expansion of intercontinental waterways.

Deep sea terminals have generally been seen as the major element in the container transport chain affected by increasing container traffic, due to limited capacity in terms of storage spaces and handling equipment (Roso et al. 2009). A vast literature addressing this topic treats remedies for such limitations; from the optimization of crane scheduling to berth and yard allocation, see Vis and De Koster (2003), Kim (2005), Stahlbock and Voss (2008), and Bierwirth and Meisel (2010) for recent overviews. Besides making the best use of the available capacity, recently some deep sea ports are also expanding their premises; this requires certainly a bigger effort in terms of costs and time (Roso et al. 2009; Jarzemskis and Vasiliauskas 2010). For instance, in the Port of Rotterdam (Netherlands), a new extension of the Maasvlakte area, Maasvlakte 2, has been developed recently to allow more deep-water access. Approximately 2000 ha have been reclaimed behind a 4 km dike and approximately 1000 ha will be used by port related industries. Also with the latest larger vessels,

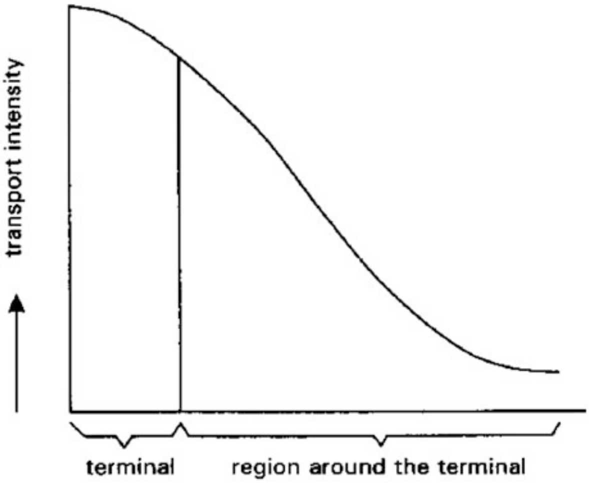

Fig. 17.2 Transport intensity. (Source: Konings 1996)

deep sea terminals have to catch up with the pace of technologies and global demands and face the challenge of handling more containers per time unit (Roso et al. 2009).

In recent years, hinterland transport has been receiving increased attention due to problems of road congestion, environmental concerns and traffic safety (Van Schijndel and Dinwoodie 2000). As the amount of containers handled by sea ports has been increasing substantially, the hinterland has been facing problems of congestion, especially in the area close to the sea port where the flows do not scatter yet (see Fig. 17.2).

The problem is very noticeable when the majority of containers are transported by truck. In Europe—especially in the North-Western area between Le Havre and Hamburg, where the flow of containers is the highest—the problem has become very relevant. Traffic congestion at the sea port and in the areas nearby is becoming unsustainable, and has drawn the attention of policy makers, shippers, and freight forwarders. Using different modalities than trucks is one of these (Van Schijndel and Dinwoodie 2000). Public authorities are pressing for the use of high capacity means of transport, in order to push large bundles far into the hinterland. Therefore, the use of trains and barges is favored by transport providers and policy makers alike, but criticized for the lack of flexibility (as compared to the high level of flexibility offered by trucks) and unfavorable cost structures. The so-called regionalization (Notteboom and Rodrigue 2005) of the sea ports is crucial in the success of multimodality. The idea is that connections between the deep sea port and the hinterland are strengthened, by means of inland terminals, strategically located in the region in order to ease the change of modality and the access of trains and barges (Parola and Sciomachen 2005). As the use of these means of transport can relieve congestion, regionalization is seen as alternative to sea port expansion as well. Moreover, the terminals should provide additional logistic services to make those alternative modes more profitable and competitive (Jarzemskis and Vasiliauskas 2010; Roso 2007; Notteboom 2007).

The design and coordination of these systems that connect deep sea ports and inland terminals is the topic of this chapter. In our description and analysis, we will focus on import hinterland networks, mainly motivated by the hinterland network of the Port of Rotterdam. Similar (and partially overlapping) hinterland networks exist for other ports in Northwestern Europe, and ideas and concepts could be transferred (albeit adaptation may be necessary) to hinterland networks that are primarily export oriented (such as in China, or other import hinterland networks such as in North America and Africa).

17.2 The Hinterland System and Its Evolution

The increase of container trade as well as the logistic integration and network orientation in the port and maritime industry have redefined the role of sea ports and the approach to the hinterland (Notteboom and Rodrigue 2005). The total cost of global supply chain transportation is to a large extent affected by the efficiency of the hinterland transportation system. According to Notteboom (2004), 40–80 % of the total transportation costs are the cost of hinterland transportation. The improvement in logistics and transportation in this leg has therefore a large impact on the final cost for the customer.

As discussed above, a regionalization phase is currently evolving with the strengthening of the connections between deep sea ports and their hinterland. The role of intermediary transshipment centers as inland terminals or hub-and-spoke terminals is part of the so-called regionalization that brings the perspective of port development beyond the port perimeter (Notteboom and Rodrigue 2005).The targets of the regionalization are many, including the deployment of other concepts such as "dry port". Dry ports facilitate pushing large quantities of cargo, as soon as they land, far into the hinterland, where multiservice hubs would replicate the services of sea ports, such as customs, handling, and storage (Jarzemskis and Vasiliauskas 2010; Roso et al. 2009). Further, sea ports—by connecting with inland hubs—try to reduce congestion and pollution (Roso 2007) and dwelling times of containers.

As hinterland transportation is evolving, also the role of inland terminals is becoming more and more important. Over time, inland terminals have been increasing their role in the deployment of multimodal transport. The locations and the services offered by the inland terminals can be the added value that makes high capacity means of transport, such as barges and trains, more cost-effective and also more convenient than trucks (Notteboom and Rodrigue 2009a).

Konings (1996) predicted early on the current criticalities in hinterland transport due to extensive trucking and claimed that the key of success is in integrated centers for transshipment, anticipating the concept of dry ports: "*The demand in container transport increases and clients want their goods delivered faster, cheaper and just-in-time. Road transport and its network would increasingly become unable to meet the demand and the quality criteria of the clients. The consequence would be that road transport becomes more expensive, less sustainable, more time consuming and less attractive*."

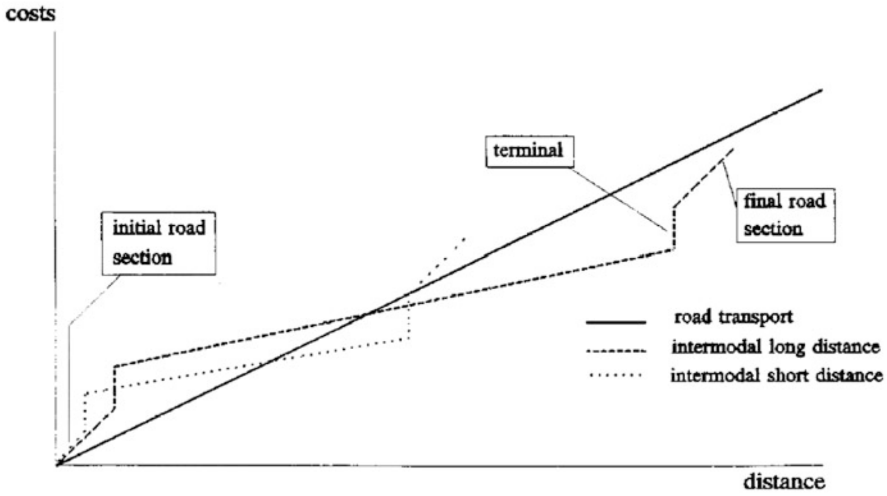

Fig. 17.3 Cost structure of unimodal road haulage versus multimodal transport. (Source: Konings 1996)

The shift to barge and rail transport can be the solution. Nevertheless, their advantages are often limited by the added costs for handling and initial and final road transport legs. These additional costs are relatively high it is difficult to absorb these costs over shorter distances and smaller volumes (see Fig. 17.3).

As road transport prices increase, so will these additional costs and combined transport will be affected proportionally, unless initial and final road transport and its cost can be somehow limited or cancelled out. In fact, it is clear that the growth of intermodal transport can entail an increase of trucking immediately around the sea-terminal, threatening the accessibility and the sustainability of the terminal itself. In a sense, as stated by Konings, multimodal transport can fall victim of its own success without smart logistic structures behind as: collection centers, new terminals, improved internal transportation. Such logistic centers have to be located both where trucking cannot affect in large part the success of the intermodality (hub-and-spoke centers in the sea port (Konings et al. 2013)) and where trucking becomes less competitive than barge and rail (faraway terminals with dry port concept (Roso et al. 2009)). We will now briefly discuss the hub-and-spoke and dry port concepts.

17.2.1 The Hub-and-Spoke System Within the Sea Terminals

A Hub-and-Spoke philosophy entails the bundling of containers in a hot-spot (Fig. 17.4). As claimed by Konings et al. (2013), a hub-and-spoke network would transform the situation in the sea port—currently characterized by separate collection and distribution centers (Caris et al. 2011)—into a system where bundles of containers for a pre-determined set of hinterland destination are gathered in one terminal. This can entail positive aspects, both for rail and barge.

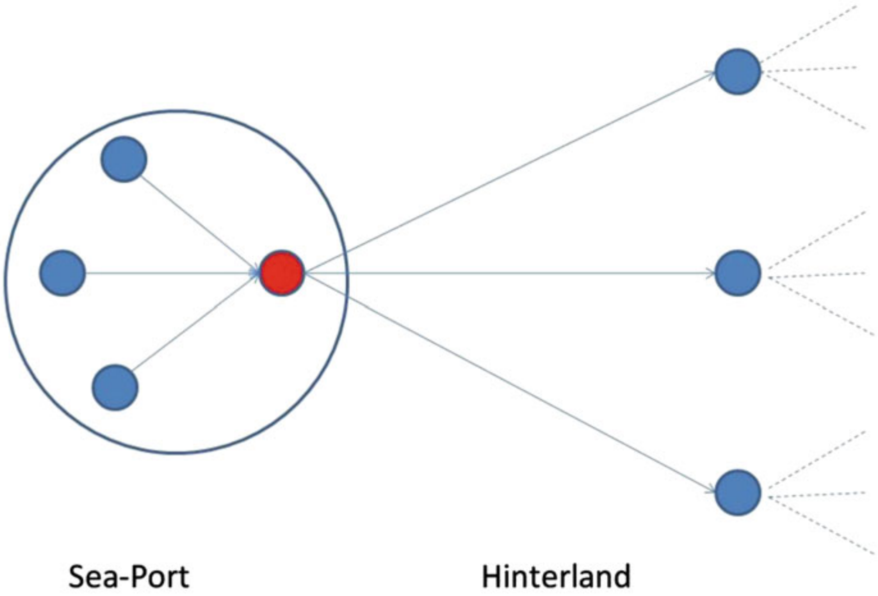

Fig. 17.4 The conceptual hub-and-spoke model, consolidating containers in a hub that is located in the deep sea port area

For hinterland transport by rail, the internal handling and transportation system of the sea port, where usually trucks but in some cases also AGVs are used, would gather containers at a central hub dedicated to rail, not far from the sea terminals.

For hinterland transport by barge, currently barges waste valuable time by making many calls at the different terminals of the deep sea ports; this is due mainly because containers meant for the same destination can arrive with different ocean vessels docking at different terminals and quays (Caris et al. 2011). Intrinsically, a route of a barge with many calls already entails a bigger effort in terms of itinerary and setup needed for the terminal operators and the cranes. The latter, when operating small size calls, do not work continuously, making the system not efficient. Moreover, long waiting times and congestion in a system with many calls is inevitable. One of the main reasons is that ocean vessels have priority over barges. Deep sea careers have usually contracts with terminal operators while barge operators do not (Fransoo and Lee 2013). That is why barge operators insert large margins in their schedules when planning terminal visits, in order to not compromise the reliability of the service. However, the competitiveness of the service is somehow undermined by such long waiting times and loose schedules. Also here, a hub-and-spoke system can be the solution to reduce the number of calls by barges and the waiting times and as a direct consequence the reliability of the service (Konings 2013; Fransoo et al. 2013).

There is an increasing interest in this topic. Designing and operating a hub-and-spoke system implies decisions on its location (Rutten 1998; Bouchery and Fransoo 2014), bundling strategies (Jourquin et al. 1999; Caris et al. 2011) and vertical integration with inland terminals (Veenstra et al. 2012). With concern to this last point, inland terminals located in the same region can co-operate along a hinterland corridor to bundle their freight. An example is a co-operation recently established in the Brabant region, in the Netherlands. *Brabant Intermodal* includes four terminals that coordinate and bundle their shipments in order to make larger call sizes in the sea port. Then the bundles consolidate in the port area and split on the way to the different inland terminals. We will further discuss the hub-and-spoke networks in Sect. 3 of this Chapter. An extensive description of the cost structure of the hub-and-spoke system in barge transportation has been described and analyzed by Fransoo et al. (2013).

17.2.2 The Dry Port Concept and Its Evolution: The Extended Gate

The dry port concept has been successfully implemented in various geographical contexts. Dry ports relieve congestion at sea terminals and the port city, by bundling large quantities of containers and pushing them to the hinterland toward equipped intermodal terminals. The use of high capacity modes is then further encouraged (Roso et al. 2009). Roso et al. (2009) investigate the pros and cons of dry ports when these are positioned on the short, medium and long distance. Practically, the dry ports have to be considered as a natural extension of the sea ports, whose common activities are replicated: stacking, custom clearance, and handling. Some port authorities, such as the Port of Barcelona, have been very active in developing the hinterland hub-and-spoke network (Van den Berg et al. (2012).

The Extended Gate is an evolution of the dry port concept, as it includes some of the natural consequences, such as integral network design and direct operational control in the transport network between the sea terminal and the dry port (Veenstra et al. 2012). The main idea of an Extended Gate is to extend the delivery point from the perspective of the shipper/receiver from the deep sea terminal along a corridor to an inland multimodal terminal and, possibly, the final destination such as a distribution center of a logistics service provider or shipping (Veenstra et al. 2012). The gate of the sea terminal is basically moved to the inland terminal. Receivers agree to pick up their containers at the inland terminal; the final leg of the journey can be arranged by the terminal or another operator. Therefore, the receiver can deal with a wide variety of inland terminals close to multiple delivery locations rather than with the sea terminal. This delivery at the inland terminal is typically offered as an additional premium service to the customer, such as the Extended Gate service provided by the Rotterdam-based Europe Container Terminals. Inland terminals strategically located in economic centers are the most suitable for this purpose, because they could facilitate the flow of import and export containers and the flow of intercontinental cargo as well.

As stated by Veenstra et al. (2012), one of the crucial factors for the success of such efficient hinterland networks in Europe is the availability of the right information on containers that arrive from overseas. This includes information on the nature of the transported goods, their quality, safety and other handling instructions, destination, shipper, receiver, intended mode of hinterland transport, and required arrival date and time. Currently, such information is not regularly available to container terminal operators or hinterland transport operators, until the very last moment. Information is usually in the hands of freight forwarders, and of the owners of the goods. Limited research has so far been conducted on the value of information in container transport networks. Early work by Zuidwijk and Veenstra demonstrates that information can be valuable under certain conditions (Zuidwijk and Veenstra 2014).

A possible solution for a smooth and real time exchange and update of information can be the introduction of a collection agent that collects and organizes the information and guarantees their availability online. Currently, such systems are being implemented, especially in those ports bringing forth the Extended Gate concept. For instance, ECT, a container terminal operator in the port of Rotterdam, is driving the deployment of the Extended Gate, by developing strong connections with a network of inland terminals. The exchange of information is managed by a new business entity created by ECT. The system is a web-based application and available to the inland terminals involved in the transportation.

17.2.3 The Transportation

Hinterland transport has recently attracted the attention of authorities and stakeholders. In fact, origins and destinations of virtually all intercontinental flows are always situated in the hinterland. However, they merge in the areas close to the ports, contributing to traffic jams, pollution and congestion (Van Schijndel and Dinwoodie 2000). These problems are more and more considered by Port Authorities, especially in the areas where the majority of the cargo is moved by trucks. The option of multimodal transportation has been acknowledged as priority measure to solve EU transport system problems (Jarzemskis and Vasiliauskas 2010) and to reduce CO_2 emissions (Liao et al. 2009; Roso 2007). As an example, in the Port of Rotterdam area new regulations are very strict and they constrain terminal operators as part of the concession to transport a high percentage of the containers by barges and trains. The target for the 2035 so-called "modal split" is to transport at least 45 % of the volumes by barge, at least 20 % by train and at most 35 % by truck (Konings et al. 2013). Interestingly, this target is part of the lease-contract with the terminal operators. Earlier, Fransoo and Lee (2013) noticed that the terminal operators do not hold contractual relationships with the hinterland transport operators. Since most of the inbound transportation in Europe is under a merchant-haulage contract, it will be interesting to see how the terminal operators can influence their modal split.

17.3 Design of Hinterland Networks

Transportation of containerized cargo has become increasingly popular in recent years. Container transportation indeed enables quick and undamaged arrival of the entire shipment to destination. As a result, world container traffic has been growing at almost three times world gross domestic product growth since the early 1990s (Fransoo and Lee 2013). This trend towards containerization is shaping the design of hinterland freight transportation networks. When focusing on hinterland supply chains, containerization provides protection against damage and theft and standardization. But the most important feature related to the transportation of containerized cargo is that the entire load may be handled in one time. Two main trends in hinterland networks may be associated with this ease of handling. First, containerization favors consolidation systems such as hub-and-spoke networks. Second, containerization facilitates intermodal transportation. These two main concepts are reviewed in Sect. 3.1 and 3.2. Then, Sect. 3.3 focuses on future research opportunities.

17.3.1 Strategic Models for Flow Consolidation in Hinterland Networks

Several hinterland transportation network topologies may enable flow consolidation compared to direct shipment from origin to destination (e.g. corridor, connected hubs, and hub and spoke networks). The most commonly used network topology is by far the hub-and-spoke system.

The first papers focusing on hub-and-spoke networks design problems may be traced back to 1986 (O'Kelly 1986a, b). From these first papers, the literature on hub location has expanded very quickly. We refer to Alumur and Kara (2008), Campbell and O'Kelly (2012) and Farahani et al. (2013) for recent reviews. Several classical formulations of the hub location problem may be found in the literature (i.e. hub median, hub center, hub covering, and hub location) but the most commonly used model for hinterland transportation network design is the p-hub median problem.

The p-hub median problem consists in finding the most appropriate way to transport demand flows from origins to destinations. To do so, the problem consists in locating $p \in N*$ hubs and to decide how to allocate these hubs to the set of origin/destination nodes in order to minimize the total transportation costs of the system. The demand from origin to destination may correspond to an amount of freight (freight transportation network), passengers (passenger air transportation network) or data (telecommunication network). In the basic settings of this static deterministic problem, the demand flow has to be routed from origin to destination through at least one hub. Routing demand flow via a hub indeed enables flow consolidation. This consolidation may occur on spokes (the arcs connecting origin/destination nodes to hub nodes) as the flow from one origin to several destinations may be combined if routed via the same hub. However, this consolidation is often much stronger on inter-hub arcs. The underlying benefit of this consolidation is that the cost of transporting one unit of flow per unit distance is discounted on inter-hub arcs. This creates an incentive to route origin/destination flows through more than one hub as this will increase the distance travelled but may lead to cost reduction. The hubs are generally assumed to be fully interconnected; thus, there is no reason for routing any origin/destination flow through more than two hubs.

The most important feature of the p-hub median problem is that the location of the hubs and the allocation of these hubs to origin/destination are two inter-related questions. As the allocation part of the problem (where the locations of hubs are fixed) is known to be NP-hard, the p-hub median problem is also NP-hard. However, a lot of research has been conducted to find efficient ways of solving the problem (either optimally or by using heuristic approaches) and large scale problems are nowadays solved very efficiently. The p-hub median problem may be considered as an extension of the p-median problem proposed for facility location (Hakimi 1964, 1965) that takes interdependency between facilities into account. As for the facility location research, a tremendous number of extensions from the basic models have been investigated. Reviewing the entire literature on hub location is outside of the scope of this chapter. Note that some extensions are reviewed in Sect. 3.3 as these ones are of great interest for future research on hinterland network design problems.

Even if the advantages of consolidation are undeniable in terms of cost per unit of flow per unit of distance, using a hub-and-spoke network implies increasing the traveled distance. The comparison of direct versus terminal (equivalent to hub) freight routing has been extensively studied (see e.g. Blumenfeld et al. (1985); Campbell (1990); Daganzo (1987); Hall 1987a, b). These papers focus on continuous approximation models in order to obtain analytical formulations. Moreover, only the allocation decisions are made. Even though approximating the demand for transportation as continuous over a region (by using density) may be viewed as unrealistic, these models are mainly used to provide insights and guidelines. Moreover, these models are proven to be quite robust when used to approximate the optimal transportation cost for discrete demand hub location problems (Campbell 1993). Numerical optimization and continuous approximation methods could thus be viewed as complementary and should be used together (Smilowitz and Daganzo 2007). We refer to Langevin et al. (1996) for a review of models applying the continuous approximation.

17.3.2 Design of Intermodal Hinterland Networks

Intermodal freight transportation implies transporting the load from origin to destination in the same transportation unit without handling of the goods themselves when changing modes (Crainic and Kim 2007). The main characteristic of intermodal transportation is the use of more than one mode of transportation. This feature also corresponds to other terminologies proposed in the literature such as multimodal or co-modal transportation. Even if the definitions are slightly different from one terminology to another, these terms are often used interchangeably

(SteadieSeifi et al. 2014). Intermodalism is clearly related to containerization as the containers are the most common transportation unit used for intermodal transportation. When focusing on hinterland networks, intermodal transportation and hub-and-spoke networks are two interrelated concepts as they share the issue of flow consolidation. We refer to Bontekoning et al. (2004) for review on the early development of the research on intermodal transportation for hinterland supply chains. The remaining of this section focuses on reviewing the most recent literature related to this issue.

Arnold et al. (2004) model an intermodal rail-road system as a hub-and-spoke network. Intermodal terminals are considered as hubs that have to be located. They apply their model to the rail-road transportation system in the Iberian Peninsula. As the size of the real world application is a concern, they propose a heuristic procedure to find an approximate solution. Racunica and Wynter (2005) extend the p-hub median problem to take into account classical features of intermodal rail-road transportation. Among others, the model accounts for non-linear concave cost functions in order to represent flow dependent economies of scale (see Sect. 3.3 for a detailed discussion on this topic). The authors propose a linearization procedure as well as two heuristics that enable solving large instances of the problem. A case study based on data from the Alpine region is also presented. Groothedde et al. (2005) focus on a road-barge transportation network in the Netherlands and explain how collaborative intermodal hub networks may be developed. Similar to Racunica and Wynter (2005), Jeong et al. (2007) extend the p-hub median problem to take some specificities of an intermodal rail-road network into account. In the same context, Limbourg and Jourquin (2009) specifically focus on the effect of considering flow dependent economies of scale in transshipment cost. Their study mainly focuses on a case study based on the European rail-road network. Ishfaq and Sox (2010) use a tabu search based meta-heuristic to solve another extension of the p-hub median problem in the context of intermodal transportation. They conduct an empirical study based on US freight data. Meng and Wang (2011) specifically include multi-type containers as well as user equilibrium constraints on a hub-and-spoke model for intermodal transportation. These user equilibrium constraints are intended to model the behavior of the users of the network who are willing to optimize their individual cost in making their route choice. This feature is discussed in more detail in Sect. 3.3. Alumur et al. (2012a) focus on including customer de-pendent service time on the intermodal p-hub median problem and consider travel times in addition to travel costs. The authors study the structural properties of the problem and propose a set of valid inequalities and a heuristic that enable to efficiently solve large in-stance of the problem. Finally, Alumur et al. (2012b) propose to apply an extension of the hub median problem called the hierarchical hub median problem Yaman (2009) to represent intermodal logistic networks. This literature mainly aims at bridging the gap between the theoretical p-hub median problem (and its extensions) with the current practices in real life intermodal transportation networks. By following this line of research, several future research directions based on current developments of hinterland networks are highlighted in the next section.

17.3.3 Future Research Opportunities

Several research directions may be emphasized based on the existing literature as well as the key trends in current hinterland transportation networks. Among them, the most straightforward feature of intermodal transportation is that economies of scale are necessary to make rail and barge transportation viable. Economies of scale is the "raison d'ê tre" of hub-and-spoke networks. However, the basic p-hub median model (as well as much of its extensions) assumes that economies of scale are somehow exogenous to the decisions taken on hub location and on origin/destination allocation. A fixed discount factor is generally used to account for economies of scale on inter-hub arcs. This hypothesis of considering economies of scale as independent of the decisions taken in the p-hub median problem is rather questionable as the volume of cargo transported on each arc strongly depends on the decisions taken. This limitation has been firstly addressed by O'Kelly and Bryan (1998) who account for flow dependent economies of scale on inter-hub arcs by considering strictly increasing concave transportation cost functions. They prove that the optimal hub locations may greatly differ from the results obtained without taking flow dependent economies of scale into account. Moreover, they propose a linearization technique to approximate the general concave strictly in-creasing function as piecewise linear. Note that several other papers have built on this idea. However, only few papers consider flow dependent economies of scale when focusing on intermodal hub location models. Racunica and Wynter (2005) take flow dependent economies of scale on each arcs (both inter-hub arcs and spokes) into account. Limbourg and Jourquin (2009) also account for flow dependent economies of scale but they take this feature into account only for transloading operations. Finally, Meng and Wang (2011) account for flow dependent economies and diseconomies of scale on inter-hub arcs in order to additionally take congestion into account. We are not aware of any paper considering flow dependent economies (and diseconomies) of scale for both transportation and terminal activities in the context of intermodal hub location problem. More research is required on this topic.

The second key feature in current hinterland networks is that several actors are generally involved. Indeed, various organizations generally control a part of the hinterland transportation chain, with no single-actor fulfilling the role of chain leader (Bontekoning et al. 2004). This idea is clearly in contradiction with the classical settings of the hub location literature as the objective of most of the models is to minimize the total transportation costs incurred in the system. Several other objectives may be chosen depending on the position of the actor in the supply chain. For instance, a terminal operator may follow the objective of maximizing the hubs utilization. A barge or rail service provider may tend to favor solutions with a high utilization of the intermodal service while a policy maker would certainly favor solutions that maximize the modal shift (Arnold et al. 2004). However, there are no theoretical reasons that allow considering that these objectives would lead to the same solution in a general setting. Taking several objectives into account is not classical in the hub location literature. To our knowledge, da Graça Costa et al. (2008) is one of the only papers proposing a multiobjective formulation of a hub location problem (the model account for both cost and time and both objective are taken into account separately). Another way taking multiple actors into account would consist in adopting a game theoretic perspective. To our knowledge, game theory has mainly been employed to account for competition among several independent hub-and-spoke networks (Lin and Lee 2010; Lüer-Villagra and Marianov 2013). We can conclude that the multiple actors setting of typical hinterland networks is not appropriately taken into account in the existing literature and that multiobjective optimization may be seen as a promising path for future research.

While combining flow dependent economies of scale with a multiple actors setting, interesting new allocation sub-problems may arise. As already pointed out by O'Kelly and Bryan (1998), "some origin-destination pairs may be routed via a path that is not their least-cost path because doing so will minimize total network travel cost". Two comments may be derived. First, the question of how to allocate costs if the objective is to minimize the total costs incurred in the network is of interest. We refer to Skorin-Kapov and Skorin-Kapov (2005) and to Skorin-Kapov (1998) for relating issues, even if the way of taking flow dependent economies of scale is somehow different in these papers. Second, O'Kelly and Bryan's statement may not hold if several actors act independently. The situation is similar to a classical problem in the traffic assignment literature. Due to congestion, the solution which minimizes the total traveling time in the system is not equivalent to the solution minimizing the travel times of each individual users. This leads to two extreme behaviors described by Wardrop (1952) as user equilibrium (where each user minimizes its own travel time) versus system optimum (where the total travel time of the system is minimized). Most of the existing literature on hub location assumes that the system optimum principle holds. Only one recent paper applies user equilibrium principle by constraining each origin-destination pair to be allocated to its lowest cost path (Meng and Wang, 2011). From our discussions with managers in industry, we would argue that classical intermodal networks do not follow any of these two principles. Indeed, several logistics service providers often use the same intermodal hub-and-spoke network they aim at optimizing their own transportation costs. Thus, real systems are generally sub-system optimal, meaning that each sub-system is independently optimized. More research is needed to account for this special feature of intermodal transportation networks.

As pointed out in the introduction of this section, containerization has some major advantages for hinterland transportation as this favors hub-and-spoke networks and intermodalism. However, we need to keep in mind that containerization has drastically modified the management of hinterlands transportation networks by raising new issues. Indeed, container transportation requires sending the container back to the shipper when the cargo has been delivered. This could be efficiently done by finding an export match. However, this is a challenging task for two main reasons. First, the import and export flows are often unbalanced, implying that some containers need to be sent back empty. Second, the containers belong to a particular shipping line who aims at reusing the container as quickly as possible (the shipping lines are charging detention fees if the containers are not sent back after a definite time limit).

Empty container management is thus a crucial issue that has deserved a lot of research (see e.g. Crainic et al. (1993)). Moreover, due to the preeminent role of ocean transportation in global supply chains (Fransoo and Lee 2013), the most widely used containers are specifically designed for ocean shipping. Thus, they are not optimized for hinterland transportation. For instance in Europe, conventional 40ft containers may contain up to 26 euro pallets instead of 33 euro pallets for conventional trailers. Even if these drawbacks seem to be counterbalanced by the advantages resulting from containerization, further improvements in hinterland container transportation efficiency may be obtained by implementing innovative solutions. Among these solutions, several projects in the Netherlands focus on assessing if cross-docking in the port area (Mangan et al. 2008) or at an inland terminal (Notteboom and Rodrigue 2005) may be valuable for optimizing hinterland networks. In general, the cross-docking activity takes place at the retailer's distribution center further down-stream in the supply chain. The idea of cross-docking upstream in the hinterland supply chain is to empty the maritime containers and to use special types of containers designed for hinterland transportation for delivering the cargo to the final customer. By doing so, multiple items may be loaded within the same container and this could improve the efficiency of hinterland transportation systems. Such innovative ideas may deserve future research as they are promising from an industrial perspective as well as challenging from an academic perspective.

Finally, it is very striking to note that eventhough intermodal transportation is generally claimed to be environmentally friendly in the introduction of the papers, no further investigations are conducted on assessing the environmental impacts of intermodal transportation. To our knowledge, Craig et al. (2013) is the only published paper focusing on this issue. Further research is definitely needed.

As a conclusion of this section, we would like to emphasize that several methodologies would be required to appropriately address the highlighted new issues. Indeed, even if mixed-integer programming techniques would continue to be very useful to solve real life problems, single hub formulations as well as continuous approximation models should supplement mathematical programming techniques and may help gaining better insights on these challenging issues.

17.4 The Trade-Offs in Multimodal Transport Operations

In North-West Europe, excellent waterway networks favor the use of barges. For instance, in the Ports of Rotterdam and Antwerp, in 2010, respectively 33 and 34 % of the total volume were handled by barge. These volumes compared to the share of container barging in other ports (Hamburg 1 %, Le Havre 7 %) are remarkable. In the Netherlands, high-quality waterways guarantee the success of the deployment of this modality by offering access to major industrialareas in Germany (Konings et al. 2013).

Although other regions are less favored by the geographical conditions, container barging can still be considered as a valid option. Fremont et al. (2010), describe the particular condition of the Port of Le Havre in France and its connection to the Paris region. The Port of Le Havre does not handle volumes that are as high as those in Antwerp and Rotterdam, and therefore high-frequency multimodal services may encounter difficulties to obtain cost effectiveness. However, Fremont et al. (2010) state that even under these unfavorable conditions, multimodality can compete with trucks, especially when these deliver an empty container in one transportation leg. However, the sole cost structure cannot guarantee the success of multimodality as the distances are short. They emphasize the fact that additional changes are of importance to make rail and barge transport more attractive. A first required additional change is to offer more flexibility with regard to dwelling times. In fact, the use of high capacity modalities can trigger overstays at the sea terminal premises. For instance, shipping lines could extend the periods of free demurrage and detention when the container is delivered by barge or train. A second additional change is to provide customs facilities to shippers. In France, for import flows, French customs and some multimodal operators made deals to ease the customs procedures for such flows. Fremont et al. (2010 claim that shippers can almost wait until their products are sold at the outlet before paying the customs. Therefore, such additional services, which are not provided by road transport, can make the difference. Strangely enough, the time factor can be on the side of multimodal transport.

17.4.1 Operational Decision Processes

For transport providers, the operational decision of choosing certain modes of transport is not only a matter of costs. When the positions of hubs, inland terminals and dry-ports are defined, the trade-off of choosing high capacity modes rather than trucks can be difficult to resolve.

In general a transport planner has to consider several features concerning both the fleet and the containers; the decision is made according to the available information. As mentioned earlier in this Chapter, information is generally not shared or becomes only available gradually over time. As the system is highly dynamic and the exchange of information between sea terminals and inland terminal planning systems is usually not in real time, the planner has to face also critical decisions in a rolling horizon manner. Planners can make their decision at any point in time; they can wait until more data becomes available in the system. For instance, new containers can become available at the deep sea terminal and therefore be ready to be picked up. As a consequence, the schedules may change until a certain moment, when a planner has to confirm a final schedule. The final decision is usually required when scheduled containers cannot wait any more time to be processed. After the decision is made, there is a time range where it is still possible to slightly modify the decision. As an example, assume that a barge leaves the inland terminal at time 0 and that it takes 12 h to reach the sea terminal. The planner can make a call (appointment) to pick up containers at the sea terminal with some margin. In the port of Rotterdam, a call can be made at most 2–3 h before the barge arrives to pick up containers. Then, it is clear

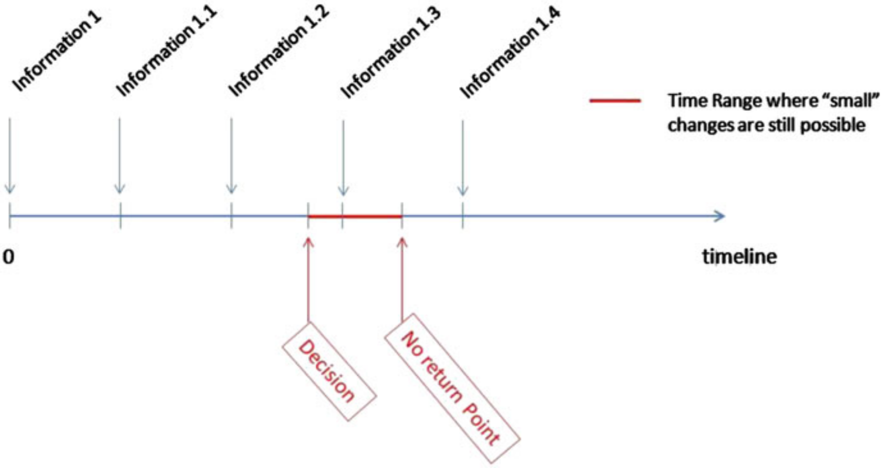

Fig. 17.5 Dynamic updating: after a schedule is made, small changes are still possible

that planners can have a margin of 9–10 h, where they can adapt the schedules to the newly available information and in that case pick up more containers. See Fig. 17.5 for a graphical explanation.

A similar problematic was tackled by Fazi (2014). In their paper, they add time features to the classical variable-size bin packing problem. Bins of larger size (barges) are able to process items slower than small bins (trucks), but they can generate economies of scale. The authors generated instances with data affected by variability. Numerical experiments showed that in case of uncertainty in the availability of the items (containers), planners are pushed to use more small bins (trucks) to face variability. In parallel, in the real system, planners have to deal with uncertain information and trucks are the only way to face the variability in the system.

With regard to information about containers, planners usually consider several features to come up with a final schedule. These are:

- Size
- Availability
- Initial location and destination
- Deadline
- Demurrage and detention deadlines
- Closing dates
- Status of the container: empty/full
- Particular requests of the customer

The status of the container can affect the decision of the planner. If the container is empty, the trade-off needs to be made whether to send back the container, incurring transportation costs but avoiding detention costs, or whether to keep the container until an export load becomes available, avoiding the transportation costs of (possibly twice) sending an empty container but incurring detention costs.

The fleet is usually limited in terms of capacity and availability. Planners have to consider in their schedules the following features of the fleet:

- Current and future availability
- Cost
- Capacity
- Transportation time
- Utilization
- Contract with the carrier

Utilization of the means of transport is highly related to whether the vehicle is owned or is under a specific contract. When the vehicle is owned, ideally the planner follows the strategy of the company: high frequency service vs. efficient use of the vehicle. When the vehicle is not owned, then the specific contracts play a role in the usage. When a vehicle is paid per ride, the planner tries to fill the capacity. When a vehicle is paid at a flat rate, then the planner may want to increase the frequency of the service by letting vehicle to be not fully utilized.

A case study that can explain the trade-off between barges and trucks in this planning process is presented in the next section.

17.4.2 A Case Study

In the Netherlands many inland terminals have become transport providers and offer barge and truck service for import and export container flows. In the Brabant region, canals have still relatively small size and allow the sailing of barges of 28 TEU capacity. Despite this small size and the short 120 km distance from the Port of Rotterdam, container barging can provide economies of scale, on condition that barges are fully utilized for both legs. Considering solely the rough transportation costs, for each leg an amount of six 2 TEU containers on a barge can compete with the cost of six trucks sent either from or to the port, based on our calculations for the Veghel Inland Terminal.

The system includes import and export containers. For import containers, the inland terminal typically has information on their arrival time at the sea terminal, the quay they are located, the time windows when is possible to pick them up and the deadline at the customer site. Analogously, export containers are available at the inland terminal and need to be delivered to the sea terminal. When these are packed with goods, usually the delivery has to take place before a closing date, which is the departure time of the ocean vessel. Otherwise, they just need to be repositioned to a depot for empties before the end of the detention period. According to these available information, the operational decision making process occurs.

Planners decide the allocation of containers to the fleet, the schedules and the routes of the barges. The terminal is dealing mainly with the Port of Rotterdam area and two main sea terminals areas: the Maasvlakte and the Rotterdam city terminal, see Fig. 17.6.

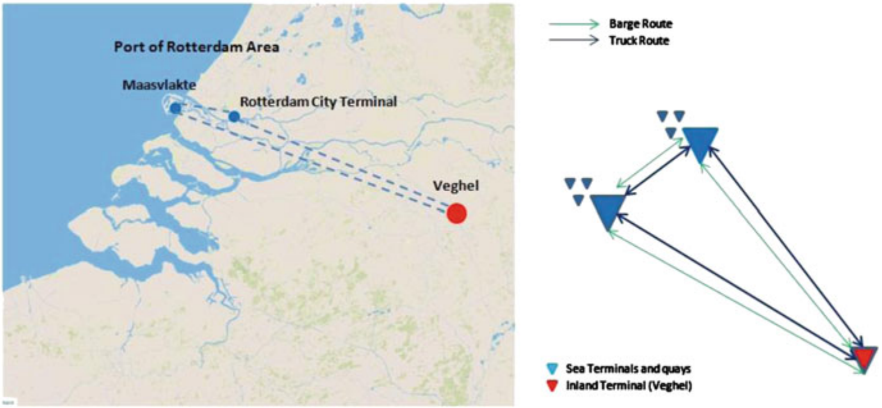

Fig. 17.6 Geographical location of the players and main flows

Both deep sea terminal areas have several quays to pick up the available containers. So the planner has to consider also a routing problem. In the work of Fazi (2014), the same problem was tackled under a pure operational point of view. Basically, the problem was modeled as a Vehicle Routing Problem with Pick-up and Deliveries (VRPPD) and heterogeneous fleet, see (Berbeglia et al. 2007) and (Toth and Vigo 2001) for a review. The particular time windows of the system, where the deadlines are defined at the destination of the single containers, have also been added to the formulation. The aim is to replicate exactly the decision making process that the planners face every day. The authors proposed some data set from a case study and solved them heuristically.

With regard to barge transport, barges have to visit the quays, meeting the capacity constraints. At each quay, the containers are first dropped and then picked up. Figure 17.7 shows a typical barge route. In the literature the transportation of containers between a depot and one or multiple destination has seen an exponential growth in the last two decades. The general terminology that includes these problems is ship routing problems. In his review paper, Ronen (1993) defined the ship routing problem as the assignment of shipments to ships and which sequence of ports to do. In his previous work, a heterogeneous fleet of vessels is scheduled on a set of predefined routes, from a single origin and multiple destination. Many papers have network design perspectives. Routes are generated a priori and then selected at later stage using Linear Programming formulations. Further, many problems are solved by set partitioning. When the total number of schedules are too large to enumerate, the most promising schedules are generated heuristically; see Christiansen et al. (2004) for a review of these papers. To the best of our knowledge, few papers address the problem of finding a route for a fleet of ships in a direct manner. Karlaftis et al. (2009) investigate route scheduling for a homogeneous fleet of containerships, performing pick-ups and deliveries between some ports and considering deadline constraints. They develop a VRPPD formulation. Every port has quantities to be picked up and

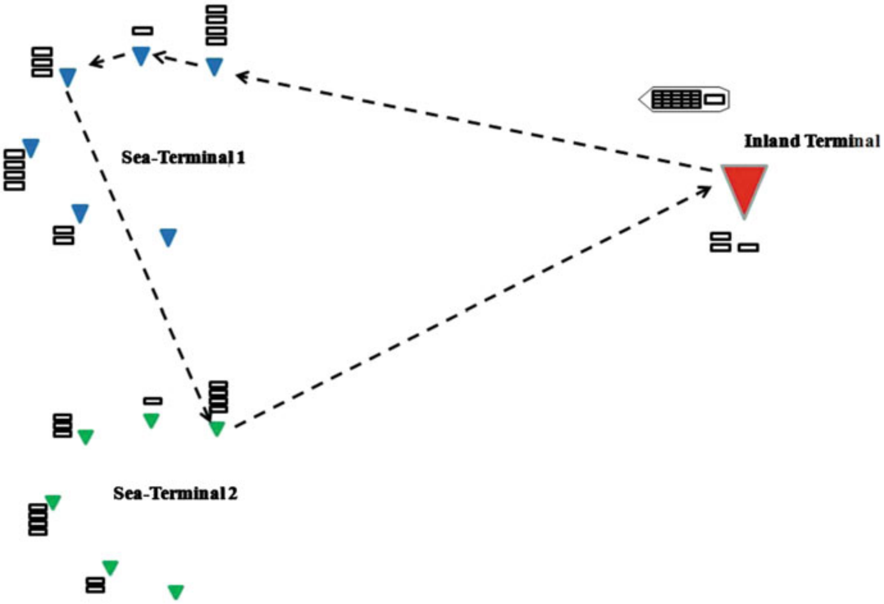

Fig. 17.7 A typical barge route. From the inland terminal through the sea terminals

delivered and it has to be processed before a certain deadline. They solve the problem by means of a genetic algorithm and they process real-world instances from the Aegean islands. Karlaftis et al. (2009) directly generate best containership routes and schedules, different from the existing literature.

With regard to truck transport, Imai et al. (2007) consider one depot and pick-up and delivery locations. In its round trip, a truck can go empty in one leg and full in the other (individual trips), or it can go full in both legs (merged trip), see Fig. 17.8. A VRPPD has been applied. They propose a Lagrangian relaxation-based heuristic to solve the problem. The problem is a special case of the models known in literature as VRP with backhauling or truck backhauling. In these models pickup customers can only be served after all delivery operations have taken place.

Fazi (2014) is the first of its kind, where different modalities, with such a strong trade-off, are considered together. In the literature, VRP with heterogeneous fleet has been tackled in many papers (Baldacci et al. 2008), but the considered test instances are basically for means of transport with same speed and with costs not reflecting an economy of scale.

Nowadays, many planners are not supported by computer tools for their decisions. Such tools, jointly with the new frontiers and restructuring of the sea-land system are essential to make the system smoother and limit the drawbacks of transportation in the hinterland. As underlined in the previous section, the role of information is also important. A better information system can be crucial in the quality of the schedules. The dry port with its evolution, the extended gate, entails that information is shared and real time. We suggest that this is the direction that sea-land systems have to follow to limit drawbacks in hinterland transportation.

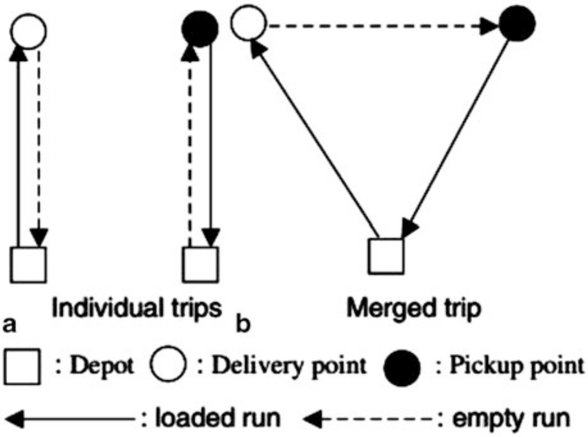

Fig. 17.8 Truck routes. (Source: Imai 2007)

17.5 Conclusion

The trend toward containerization and the huge increase in traded volumes worldwide put a lot of pressure on the hinterland transportation network. Volumes to be transportation are large and in many countries the road network cannot handle this sufficiently, leading to congestion problems. Congestion problems occur both in the port and port-city area, but also in the more extended hinterland, such as on main transportation axes between the Ports of Rotterdam and Antwerp and the German hinterland. On the other hand, the pressure on the road transportation system provides an extraordinary opportunity for the development of efficient hinterland transportation systems based on intermodal transportation and hub-and-spoke networks. In this chapter, we have analyzed the most important features of such container transportation systems for the hinterland supply chain.

At the network design level, we review the current state of the art and we identify avenues for future research. Among others, we highlight that the coordination of container shipments across the container supply chain is a particularly relevant issue as hinterland networks involve several actors. At the operational level, we characterize the most important factors influencing the trade-off between intermodal transportation and truck-only deliveries. In addition, we provide a case study. We highlight that the exchange of information is the key enabler for efficient hinterland intermodal transportation and we show that a better information system can be of crucial importance.

The management of the hinterland container supply chain has attracted substantial attention from the maritime economics community. The results obtained document very well the current trends and enable identifying and understanding the most important challenges faced by the hinterland supply chain. However, studies in the field of maritime economics either address strategic questions conceptually or focus on descriptive empirical research. We show in this chapter that model-based research addressing the issues raised by the management of the container supply chain is still scarce. Consequently, we incite the operations management community to explore the challenging context provided by the hinterland container supply chain. The expected results would be supplementary to the results obtained by the maritime economics community and they may help achieving substantial improvements.

Acknowledgements The research was partly financed by Dinalog, the Dutch Institute for Advanced Logistics.

References

Alumur, S., & Kara, B. Y. (2008). Network hub location problems: The state of the art. *European Journal of Operational Research, 190,* 1–21.

Alumur, S. A., Kara, B. Y., & Karasan, O. E. (2012a). Multimodal hub location and hub network design. *Omega, 40,* 927–939.

Alumur, S. A., Yaman, H., & Kara, B. Y. (2012b). Hierarchical multimodal hub location problem with time-definite deliveries. *Transportation Research Part E: Logistics and Transportation Review, 48,* 1107–1120.

Arnold, P., Peeters, D., & Thomas, I. (2004). Modelling a rail/road intermodal transportation system. *Transportation Research Part E: Logistics and Transportation Review, 40,* 255–270.

Baldacci, R., Battarra, M., & Vigo, D. (2008). Routing a heterogeneous feet of vehicles. In B. Golden, S. Raghavan, & E. Wasil (Eds.)*, The vehicle routing problem: Latest advances and new challenges* (Chap. 1, pp. 3–27). Springer, New York.

Berbeglia, G., Cordeau, J.-F., Gribkovskaia, I., & Laporte, G. (2007). Static pickup and delivery problems: A classification scheme and survey. *Top, 15,* 1–31.

Bierwirth, C., & Meisel, F. (2010). A survey of berth allocation and quay crane scheduling problems in container terminals. *European Journal of Operational Research, 202*(3), 615–627.

Blumenfeld, D. E., Burns, L. D., Diltz, J. D., & Daganzo, C. F. (1985). Analyzing trade-offs between transportation, inventory and production costs on freight networks. *Transportation Research Part B: Methodological, 19,* 361–380.

Bontekoning, Y., Macharis, C., & Trip, J. (2004). Is a new applied transportation research field emerging?—-A review of intermodal rail–truck freight transport literature. *Transportation Research Part A: Policy and Practice, 38,* 1–34.

Bouchery, Y., & Fransoo, J. C. (2014). Intermodal hinterland network design with multiple actors. BETA Working paper 449, Technische Universiteit Eindhoven.

Campbell, J. F. (1990). Freight consolidation and routing with transportation economies of scale. *Transportation Research Part B: Methodological, 24,* 345–361.

Campbell, J. F. (1993). Continuous and discrete demand hub location problems. *Transportation Research Part B: Methodological, 27,* 473–482.

Campbell, J. F., & O'Kelly, M. E. (2012). Twenty-five years of hub location research. *Transportation Science, 46,* 153–169.

Caris, A., Macharis, C., & Janssens, G. K. (2011). Network analysis of container barge transport in the port of Antwerp by means of simulation. *Journal of Transport Geography, 19,* 125–133.

Christiansen, M., Fagerholt, K., & Ronen, D. (2004). Ship routing and scheduling: Status and perspectives. *Transportation Science, 38,* 1–18.

Craig, A. J., Blanco, E. E., & Sheffi, Y. (2013). Estimating the CO2 intensity of intermodal freight transportation. *Transportation Research Part D: Transport and Environment, 22,* 49–53.

Crainic, T. G., & Kim, K. H. (2007). Intermodal transportation. In: C. Barnhart and G. Laporte, *Transportation. Volume 14 of handbooks in operations research and management science* (pp. 467–537), Amsterdam: North Holland.

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

Da Graça Costa, M., Captivo, M. E., & Clímaco, J. (2008). Capacitated single allocation hub location problem—A bi-criteria approach. *Computers & Operations Research, 35,* 3671–3695.

Daganzo, C. F. (1987). The break-bulk role of terminals in many-to-many logistic networks. *Operations Research, 35,* 543–555.

Farahani, R. Z., Hekmatfar, M., Arabani, A. B., & Nikbakhsh, E. (2013). Hub location problems: A review of models, classification, solution techniques, and applications. *Computers & Industrial Engineering, 64,* 1096–1109.

Fazi, S. (2014). Mode selection, routing and scheduling for inland container transport, PhD Thesis, *Eindhoven University of Technology*, Netherlands.

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

Fransoo, J. C., De Langen, P. W., & Van Rooy, B. (2013). Business models and network design in hinterland transport. In J. H. Bookbinder (Ed.), *Handbook of global logistics, international series in operations research & Management Science*, (Vol. 181, Part 5, Chap. 15, pp. 367–389), Springer, New York.

Fremont, A., & Franc, P. (2010). Hinterland transportation in Europe: Combined transport versus road transport. *Journal of Transport Geography, 18,* 548–556.

Groothedde, B., Ruijgrok, C., & Tavasszy, L. (2005). Towards collaborative, intermodal hub networks: A case study in the fast moving consumer goods market. *Transportation Research Part E: Logistics and Transportation Review, 41,* 567–583.

Hakimi, S. L. (1964). Optimum locations of switching centers and the absolute centers and medians of a graph. *Operations Research, 12,* 450–459.

Hakimi, S. L. (1965). Optimum distribution of switching centers in a communication network and some related graph theoretic problems. *Operations Research, 13,* 462–475.

Hall, R. W. (1987a). Direct versus terminal freight routing on a network with concave costs. *Transportation Research Part B: Methodological, 21,* 287–298.

Hall, R. W. (1987b). Comparison of strategies for routing shipments through transportation terminals. *Transportation Research Part A: General, 21,* 421–429.

Imai, A., Nishimura, E., & Current, J. (2007). A Lagrangian relaxation-based heuristic for the vehicle routing with full container load. *European Journal of Operational Research, 176*(1), 87–105.

Ishfaq, R., & Sox, C. R. (2010). Intermodal logistics: The interplay of financial, operational and service issues. *Transportation Research* Part E: *Logistics and Transportation Review, 46,* 926–949.

Jarzemskis, A., & Vasiliauskas, A. V. (2010). Research on dry port concept as intermodal node. *Transport, 22,* 207–213.

Jeong, S.-J., Lee, C.-G., & Bookbinder, J. H. (2007). The European freight railway system as a hub-and-spoke network. *Transportation Research Part A: Policy and Practice, 41,* 523–536.

Jourquin, B., Beuthe, M., & Demilie, L. D. (1999). Freight bundling network models: Methodology and application. *Transportation Planning and Technology, 23,* 157–177.

Karlaftis, M. G., Kepaptsoglou, K., & Sambracos, E. (2009). Containership routing with time deadlines and simultaneous deliveries and pick-ups. *Transportation Research Part E: Logistics and Transportation Review, 45*(1), 210–221.

Khor, Y. S., Dohlie, K. A., Konovessis, D., & Xiao, Q. (2013). Optimum speed analysis for large containerships. *Journal of Ship Production and Design, 29*(3), 93–104.

Kim, K. H. (2005). Models and methods for operations in port container terminals. In A. Langevin & D. Riopel (Eds.), *Logistics systems: Design and optimization* (pp. 213–243). Berlin: Springer.

Konings, J. W. (1996). Integrated centres for the transshipment, storage, collection and distribution of goods. A survey of the possibilities for a high-quality intermodal transport concept. *Transport Policy, 3,* 3–11.

Konings, R., Kreutzberger, E., & Maras, V. (2013). Major considerations in developing a hub-and-spoke network to improve the cost performance of container barge transport in the hinterland: The case of the port of Rotterdam. *Journal of Transport Geography, 29,* 63–73.

Langevin, A., Mbaraga, P., & Campbell, J. F. (1996). Continuous approximation models in freight distribution: An overview. *Transportation Research Part B: Methodological, 30,* 163–188.

Liao, C.-H., Tseng, P.-H., & Lu, C.-S. (2009). Comparing carbon dioxide emissions of trucking and intermodal container transport in Taiwan. *Transportation Research Part D, 14,* 493–496.

Limbourg, S., & Jourquin, B. (2009). Optimal rail-road container terminal locations on the European network. *Transportation Research Part E: Logistics and Transportation Review, 45,* 551–563.

Lin, C.-C., & Lee, S.-C. (2010). The competition game on hub network design. *Transportation Research Part B: Methodological, 44,* 618–629.

Lüer-Villagra, A., & Marianov, V. (2013). A competitive hub location and pricing problem. *European Journal of Operational Research, 231,* 734–744.

Mangan, J., Lalwani, C., & Fynes, B. (2008). Port-centric logistics. *International Journal of Logistics Management, 19,* 29–41.

Meng, Q., & Wang, X. (2011). Intermodal hub-and-spoke network design: Incorporating multiple stakeholders and multi-type containers. *Transportation Research Part B: Methodological, 45,* 724–742.

Notteboom, T. (2004). Container shipping and ports: An overview. *Review of Network Economics, 3,* 86–106.

Notteboom, T. (2007). Inland waterway transport of containerized cargo: From infancy to a fully-fledged transport mode. *Journal of Maritime Research, 4,* 63–80.

Notteboom, T., & Rodrigue, J.-P. (2005). Port regionalization: Towards a new phase in port development. *Maritime Policy & Management, 32,* 297–313.

Notteboom, T., & Rodrigue, J.-P. (2009a). The future of containerization: Perspectives from maritime and inland freight distribution. *Geo Journal, 74,* 7–22.

O'Kelly, M. E. (1986a). The location of interacting hub facilities. *Transportation Science, 20,* 92–106.

O'Kelly, M. E. (1986b). Activity levels at hub facilities in interacting networks. *Geographical Analysis, 18,* 343–356.

O'Kelly, M., & Bryan, D. (1998). Hub location with flow economies of scale. *Transportation Research Part B: Methodological, 32,* 605–616.

Parola, F., & Sciomachen, A. (2005). Intermodal container flows in a port system network: Analysis of possible growths via simulation models. *International Journal of Production Economics, 97,* 75–88.

Racunica, I., & Wynter, L. (2005). Optimal location of intermodal freight hubs. *Transportation Research Part B: Methodological, 39,* 453–477.

Ronen, D. (1993). Ship scheduling: The last decade. *European Journal of Operational Research, 71,* 325–333.

Roso, V. (2007). Evaluation of the dry port concept from an environmental perspective: A note. *Transportation Research Part D, 17,* 523–527.

Roso, V., Woxenius, J., & Lumsden, K. (2009). The dry port concept: Connnecting container seaports with the hinterland. *Journal of Transport Geography, 17,* 338–345.

Rutten, B. C. M. (1998). The design of a terminal network for intermodal transport. *Transport Logistics, 1,* 279–298.

Skorin-Kapov, D. (1998). Hub network games. *Networks, 31,* 293–302.

Skorin-Kapov, D., & Skorin-Kapov, J. (2005). Threshold based discounting networks: The cost allocation provided by the nucleolus. *European Journal of Operational Research, 166,* 154–159.

Smilowitz, K. R., & Daganzo, C. F. (2007). Continuum approximation techniques for the design of integrated package distribution systems. *Networks, 50,* 183–196.

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

SteadieSeifi, M., Dellaert, N. P., Nuijten, W., Van Woensel, T., Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. *European Journal of Operational Research, 233*(1), 1–15.

Toth, P., & Vigo, D. (2001). The Vehicle Routing Problem. Philadelphia: Siam.

Van den Berg, R., De Langen, P. W., & Rúa Costa, C. (2012). The role of port authorities in new intermodal service development; The case of Barcelona Port Authority. *Research in Transportation Business & Management, 5,* 78–84.

Van Schijndel, W.-J., & Dinwoodie, J. (2000). Congestion and multimodal transport: A survey of cargo transport operators in the Netherlands. *Transport Policy, 7,* 231–241.

Veenstra, A., Zuidwijk, R., & van Asperen, E. (2012). The extended gate concept for container terminals: Expanding the notion of dry ports. *Maritime Economics & Logistics, 14,* 14–32.

Vis, I. F. A., & De Koster, R. (2003). Transhipment of containers at a container terminal: An overview. *European Journal of Operational Research, 147,* 1–16.

Wardrop, J. G. (1952). Road paper: Some theoretical aspects of road traffic research. *ICE Proceedings: Engineering Divisions, 1,* 325–362.

Yaman, H. (2009). The hierarchical hub median problem with single assignment. *Transportation Research Part B: Methodological, 43,* 643–658.

Zuidwijk, R. A., & Veenstra, A. W. (2014). The value of information in container transport. *Transportation Science* (in press).