PLANNING MULTIMODAL FREIGHT TRANSPORT OPERATIONS: A LITERATURE REVIEW

Aysun Mutlu
Faculty of Engineering and Natural Sciences, Sabanci University, Turkey

Yasanur Kayikci
Faculty of Engineering, Turkish-German University, Turkey

Bülent Çatay
Faculty of Engineering and Natural Sciences, Sabanci University, Turkey

ABSTRACT

Purpose:
Multimodal freight transport developed in the transportation sector as an alternative to unimodal transport faced with the challenges brought by the growing global demand for transporting goods. Multimodal transport is the transportation of goods using at least two modes of transport, usually door-to-door. The common transport modes include railways, maritime routes, and the roads. When restructuring and reconfiguring their logistics strategies, freight operators seek optimal operational plans to increase cost efficiency, improve customer service effectiveness, and enhance environmental sustainability throughout their entire supply chain network. In addition, collaborative planning enables multimodal transport providers (MTPs) in the multimodal transport chain to optimize mainly their operational plans.
A vast collection of scientific literature focuses on different objectives taking into account various limitations. For instance, in the context of short-term planning the challenge is to take real-time decisions considering the interests of all stakeholders. With the need for real-time decision making, this problem becomes complex, dynamic, and stochastic. Thus, the purpose of this study is to concentrate on the literature related to dynamic processes at the operational level from customer to consignee and provide a systematic classification of different planning and solution techniques.

Methodology/approach:
Multimodal operational planning is investigated from two perspectives: modelling modal shift policy and planning of multimodal freight transportation. We describe the modal shift policies, discuss the advantages and barriers, and elaborate on the actors involved in this process and the factors affecting efficiency. Furthermore, we explain the importance of these factors for operational freight planning and denote the constraints in the planning problems. Finally, we present an illustrative example of a multimodal freight transportation network from customer to consignee.

Findings:
Modal shift and operational planning lead to reduced lead times and operational costs, and also ensure convenient transportation according to the user's preferences. Studies on these issues can be examined with respect to the selection of non-dominated solutions and applicable routes determined based on the preferences of customers, pricing techniques, and revenue management methodologies.

Value:
This study consolidates the knowledge in operational planning of multimodal freight transport from multimodal transport providers' point of view and addresses carbon dioxide mitigation issues as novelty. Moreover, it considers not only operational planning but also pricing and revenue management methodologies. It is a valuable reference to researchers who wish to comprehend entire operations in multimodal transport from different perspectives.

INTRODUCTION

Multimodal transport is mostly preferred because of its flexibility compared to using a single mode and its environmental benefits towards sustainable transportation. The global environmental issues and carbon dioxide mitigation problems have induced the importance of maritime and rail transport since these transport modes play an important role in reducing carbon footprints (Pruzan-Jorgensen et al., 2010; SteadieSeifi et al., 2004). The efficiency of these modes increases even more with the right decisions and accurate system implementations. In other words, efficiency is directly linked with the construction of right conditions and choices of operational planning (Caris et al., 2008; Guajardo et al., 2015). The need for modal shift was examined and discussed in the literature through various measurement methods and several solution methodologies were proposed for achieving competitive advantages against unimodal transportation.

Multimodal transport network has inherently complex structure with numerous stakeholders. Its planning involves a multi-criteria decision making process where the objectives might consist of the minimization of cost, time, and/or carbon emissions as well as improvement of service levels and utilizations (Chang, 2008). MTPs establish horizontal collaborations across the same or different type of modes where it is necessary to gain benefits during the seamless transition of consecutive modal shift processes (Kayikci et al., 2012; Krajewska et al., 2008). Collaborative planning enables MTPs in the multimodal transport chain to optimize mainly their operational plans. On the other hand, the allocation of the benefits achieved through collaboration among the corresponding stakeholders and beneficiaries arises as a key issue to be resolved.

In this paper, we review the literature related to dynamic processes at the operational level from customer to consignee and provide a systematic classification of different planning and solution techniques. We describe the modal shift policies, discuss the advantages and drivers, and elaborate on the actors involved in this process and the factors affecting efficiency. Furthermore, we explain the importance of these factors for operational freight planning and denote the constraints in the planning problems. Finally, we present an illustrative example of a multimodal freight transportation network from customer to consignee. Our aim is to investigate the answers to the following three research questions: i) What are the key points of multimodal transportation, especially on the operational planning process? ii) What types of modal shift policy have been revealed in various studies? iii) Which solution techniques are proposed/applied in the literature from 2000 to 2017?

METHODOLOGY

This literature review is conducted using a desktop research methodology; i.e. our study reviews articles related to multimodal transportation published in major academic journals and conference papers addressing multimodal transportation. Published papers are collected from 2000 to 2017. Few papers published before 2000 are excluded from this study since they have already been referred to in the recent literature and our primary objective is to shed light on the recently developments on the topic.

Firstly, a keyword search in major digital academic journal databases including ScienceDirect, INFORMS, Emerald Insight, Wiley Online Library, Taylor & Francis Online, and Springer has been performed. The principal keywords utilized are "multimodal transportation", "multimodal collaboration", "multimodal transport provider", and "planning multimodal transportation". Furthermore, the reference lists of selected articles have also been carefully exploited in order to form a large database of articles. Dispersion of these resulted articles in the databases and their types are shown in Table 1. In consequence, a total of 111 articles were gathered and classified under subtitles of Literature Review (LR), Case Study (CS), Mathematical Model, Modal Split, Sustainability (Green House Gases (GHG) Emissions), Collaboration and Revenue Management (RM).

This study may provide reference to researchers interested in several aspects of multimodal transportation.

Database	LR	CS	Model /Plan	Modal Split	Collabo-ration	GHG	RM/ Pricing	Total
ScienceDirect	7	1	16	9	6	4	4	47
Springer	4	-	8	-	2	1	2	17
EmeraldInsight	1	1	2	-	1	1	-	6
INFORMS	1	-	3	-	-	-	3	7
Taylor&Francis	4	-	1	1	1	-	2	9
Wiley	-	-	-	-	1	-	-	1
OpenAccess	2	-	8	1	1	-	-	12
Conference Paper	4	1	5	1	1	-	-	12
Total #	23	3	43	12	13	6	11	111

Table 1: Articles gathered from major digital academic journal databases

LITERATURE REVIEW AND RESULTS

Multimodal operational planning is investigated from two perspectives: modelling modal shift policy and planning of multimodal freight transportation. The section on the modal shift focuses on evaluating modal shift transport policy measures and aims to raise awareness and consideration towards the change of transportation mode as a transport policy option. It also includes various collaboration settings throughout the freight flow from the origin to the final destination. The section on the operational planning discusses practical planning techniques and case studies that deal with the implementation of multimodal transport at the operational level in order to assess the feasibility of a modal shift.

Modal shift policy

The actors of the operational side of international multimodal transport are shippers, multimodal transport providers, and freight forwarders. A shipper is the company that is responsible for initiating a shipment and who may also decide on the total freight cost. This type of member has control on the supply chain and is capable of stabilizing the financial part improving their cost levels, service capabilities, and/or environmental footprint (Cruijssen, 2012). MTPs are the companies that can offer multimodal transport operations within the framework of national and international trade and transport practices in the sector. Freight forwarders play an important role in sea routes, acting as agents of shippers who are less popular to reach customers (Lu, 2013).

The freight transport network consists of three essentially components including pre-haulage, main-haulage, and end-haulage, as illustrated in Figure 1. While pre-haulage and end-haulage are usually provided by road transport for short distances, the main-haulage is carried out by using other types of transport such as rail, sea, and inland water for longer distances. It is known that multimodal transport is competitive during main-haul transportation, if the transported distances are beyond 300 km which is longer than one day of trucking (SteadieSeifi et al., 2013).

In this transport chain, cooperation can be established between carriers, shippers, and all MTPs. Different forms of collaboration, both vertical and horizontal are important for the competitiveness of companies. The system where the operators and shippers work together is considered as the most suitable combination of these collaborations; however, it is also the most difficult system to establish and maintain despite being the most effective. The cost components of this system should be identified and the distribution of income should be arranged carefully since it is necessary to consider revenue and cost allocations, risks and involvement of each operator. Describing and measuring the performance of different stakeholder in the collaboration are one of the key points in allocating revenue. At the core of their partnership lies the fact that each shipping or transport company has to reduce or share their costs while they are satisfying the demands of the shippers (Ergun et al., 2007). These horizontal collaborations reduce costs and increase productivity. A good example is the replacement of empty container shipments with those that are filled in a coordinated manner, and the transfer of loads in rapid coordination instead of waiting for the storage and landfilling. On the other hand, time to share information and mutual self-sacrifice are required to establish and maintain mutual trust and transparency among collaborative stakeholders (Caris et al., 2008).

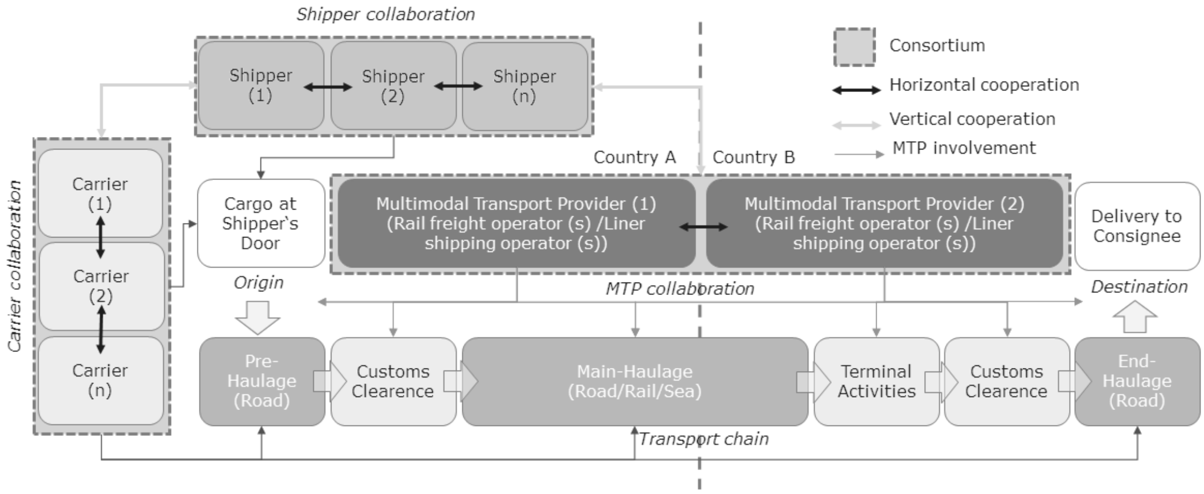

Figure 1: Freight Transport Network, MTP Collaborations

Globalization and improvement in the communication facilities have encouraged the multimodalism and the latter is recognized worldwide as an efficient way to reduce logistics cost exploiting different operational methods. To illustrate, collaboration between the carriers and also between the MTPs is an important example of cost saving approaches. Through collaboration, MTPs decide together on which shippers' reservations can be executed, postponed, or cancelled by analyzing different slot allocation scenarios. If they accept the reservation of a shipper, they arrange all the necessary slots from both vessels and trains simultaneously on the main-haul.

In order to be competitive in the transport sector, service providers should be more flexible favoring multimodal choices such as combination of road, sea, rail, and air. At this point, the transport service provided should be preferable by shippers and also multimodal transport providers (MTP) should arrange their services environmentally friendly. Flodén et al. (2017) gathered key factors contributing to the decision making process such as cost, quality, reliability, transport time, and sustainability of the system and environment. In general, reduction of carbon dioxide (CO2) emissions through the terminal network design and operations are the objectives of the governments and CO2 pricing can be regulated accordingly as a part of the cost structure (Zhang et al., 2015).

In multimodal freight transportation, uncertainties and randomness always take place throughout the freight flow process. This complexity increases the importance of reliability, smart disruption management, and sustainability of the operation while determining the decision criteria (Huang et al., 2011). Ferrari (2015) concluded that dynamic parameters of modal split of a multimodal freight transport system between origin and destination are gathered under three subtitles. These are the increase rate of overall freight flow, the delay, and the dynamic cost functions of different modes. Since the multimodal network is complex and dynamic, determining dynamic characteristics and modeling modal split are useful to forecast overall freight flow and to decide accordingly on the unknowns of future time periods.

Planning multimodal freight transportation

The operational planning basically consists of deciding on which freight to accept or reject for routing and planning the overall route to transport selected vessel, train, and trucks. Freight mode choice is one of the most problematic issues while preferring the multimodal transportation. The main drivers of the decision making process are cost, transit time, reliability, and frequency of the service. Frequency is usually preferred by manufactured good sectors while temporal reliability and security of the service are mostly preferred by automobile manufacturers and exporters (Shinghal et al., 2002; Cho et al., 2012). In addition to these, constraints related to the capacity of modes and nodes, pickup and delivery times should also be incorporated into the model and the associated data should be collected and gathered for taking the necessary actions. The selection of the non-dominated and applicable routes to construct multiple Pareto solutions pool is achieved via various mathematical models. The subsequent phase is determining the best route according to user's preferences among the optimal alternatives.
Each mode of transportation has its own characteristics, limitations, similarities and differences, advantages and disadvantages. Planning each of them separately requires different techniques, but planning them together within a systemic framework coherently needs more complex techniques and models. Various operations research techniques are widely utilized in order to improve the design and operations of multimodal networks (Gorman et al., 2014). Furthermore, transport solutions have to be realizable, flexible, easy to apply, reliable, transparent, and efficient to cope with the preferences of different decision makers operating in the multimodal transport network (Caramia, 2009). The solution techniques for operational planning are mainly classified under the following five categories: direct solution methods using linear programming; stochastic solution methods using dynamic programming; heuristics; decision analysis models for mode choice, and other methods such as survey and simulations.

In general, minimizing cost and transport time are the two main objectives that service providers and researchers have looked after. In addition to these, awareness towards environment, willingness to pay, and service quality are the additional objectives and constraints to satisfy. Multi-objectivity requires using a combination of several methods. The crucial point is to choose appropriate model type(s) after the examination of the acquired information about the system. Deterministic models give fairly enough discrete values in order to use in planning but they do not cover the reality completely; so, some dynamic properties and randomness in the data requires stochastic models. Besides these, probabilistic models are utilized to come up with estimations directly such as the mode choice and shipment size (De Jong et al., 2016). Studies implementing different solution methodologies are summarized in Table 2.

As a transportation network, multimodal transportation carries external negativities associated with environmental and societal issues. For instance, Demir et al. (2015) classified these negativities in five groups including air pollution, greenhouse gasses, noise and water pollution, congestion, accidents, and land use. They point out the importance of being aware of these negativities of each transport mode and inventing the model to measure the tradeoff between disadvantages and users' preferences.

The capacity management during routing and scheduling is crucial success factor for the sustainability of the multimodal transport, especially in sea-rail legs. The capacity of freight vessels and trains should be utilized at least at a rate of over 70% per trip in order to maintain profitability (Kayikci, 2014). At this point, revenue management and pricing strategies may help decision makers, principally MTPs; increase their profit by augmenting the capacity utilization rate. The main goal of revenue management is to find the maximum freight travelling along each possible leg in order to maximize the revenue by minimization of costs, allocation of slots, and dynamic pricing. Kayikci demonstrated that the application of different fare and shipper classes may help achieving up to 2%

increase in revenue per combined trip while the minimum capacity requirements are fulfilled. This application is required due to different arrival/booking times of shippers. Contacted shippers are subject to an annual fixed price, shippers who book their slots during the booking time may be subject to another fixed price, and finally the needs of urgent customers may be supplied with more complex pricing strategies. Price discrimination may be applied to the different contents of containers or semi-trailers since hazardous and perishable products require additional equipment and care.

Solution Techniques	References
Direct Solution (MILP, LP)	Cea et al, 2003; Aifadopoulou et al, 2007; Chang, 2008; Kim et al, 2009; Lu et al, 2010; Puettmann et al, 2010; Flórez et al, 2011; Ayar et al, 2012; Bierwirth et al, 2012; Sergio et al, 2012; Bhattacharya et al, 2014; Sun et al, 2015; Verdonck et al, 2016; Baykasoğlu et al, 2016; Corman et al, 2017
Dynamic, Stochastic, Two-Stage	Cho et al, 2007; Agarwal et al, 2008; Bock, 2010; Cho et al, 2012; Kalinina et al, 2013; Ferrari, 2015; Hao et al, 2016
Heuristics, Meta-Heuristics	Yamada et al, 2009; Caramia et al, 2009; Vanovermeire et al, 2014; Kengpol et al, 2014; Gkiotsalitis et al, 2015; Zhang et al, 2015
Mode Choice, Predictive Analysis	Gelders et al, 2003; Frejinger et al, 2009; Macharis et al, 2011; Huang et al, 2011; Lu, 2013; Masiero et al, 2013; Arencibia et al, 2015; Bovy et al, 2015; Kucukaltan et al, 2016; Combes et al, 2016
Survey, Simulation, Others	Shinghal et al, 2002; Luo et al, 2003; Kim et al, 2011 Hanssen et al, 2012; Kelle et al, 2016

Table 2: Classification of solution techniques of operational planning models

ILLUSTRATIVE APPLICATION

According to commercial and governmental agreements between Turkey and European countries, international multimodal freight transport is currently carried out. As the rail transport system in Turkey is not developed and as efficient, the freight is brought to the ports by road during pre-haulage and then transferred to the appropriate ports in Europe on RoRo vessels by sea. The freight coming to the multimodal hub or terminal is loaded to the RoLa or other type of trains and is transported to the destined points in various European countries. If the destined point does not have RoLa or RoRo terminal, post-haulage is conducted by road.

The example in Figure 2 illustrates the alternative routes from Istanbul to Kiel. The analysis is carried out using the information from the website www.intermodallinks.com. From Istanbul, two MTPs are available to conduct this multimodal transportation, Ekol Logistics and U.N. Ro-Ro. Both of them have vessels travelling from Istanbul to Trieste port approximately in 60 hours and their frequency is 4 times per week. Ekol has its own RoLa 64 times per week from Trieste to Kiel (28 hours) directly. Alternatively, it offers its own services to Cologne (24 hours) 640 times per week and which can be combined with dedicated rental trains to Kiel. U.N. Ro-Ro also rents dedicated trains from Trieste to Kiel. The trip takes less time (approximately 4 days) but the frequency is very low, only once every week. If the shipper prefers more frequent sea-rail legs, U.N. Ro-Ro can transport the freight form Trieste to Wien or Salzburg, and then continue to Hamburg which is located just one hour post-haulage road transport from Kiel. In this option, the frequency increases to 3 times per week but the total transport time increases as well, to 6 days.

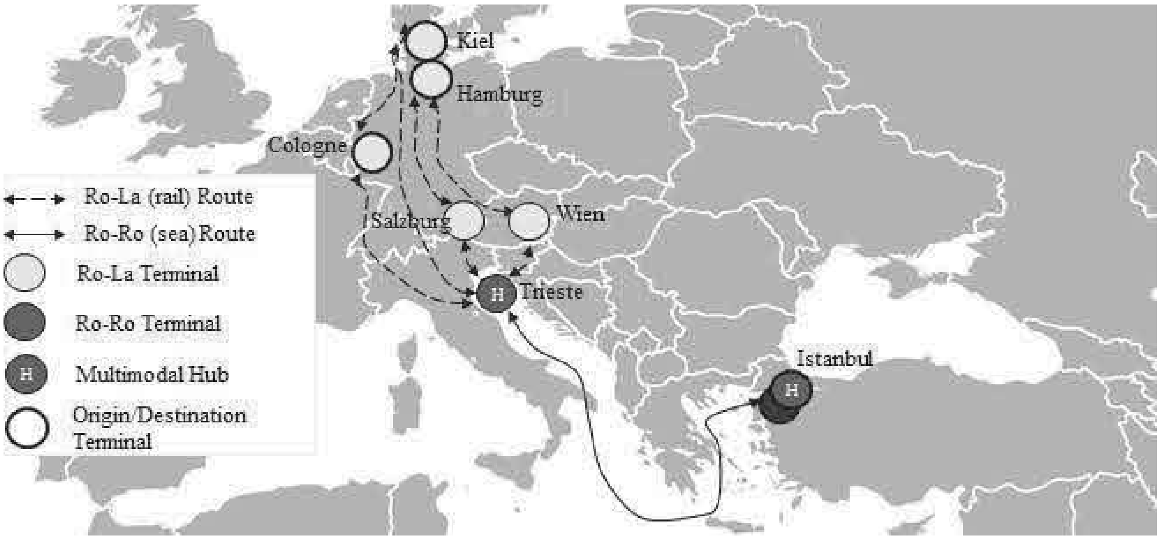

Figure 2: An Illustrative example of multimodal transport from Istanbul to Kiel

The increase in total transport time is caused by the increase in the number of modal changes since the terminal operations require extra time for loading and unloading, and may also raise the cost. The route planning and selecting the optimal alternatives are conducted by exploiting different mathematical models and the decisions are made by customers, mainly shippers upon their decision criteria such as time, cost, frequency, number of modal shifts, CO2 emissions, and reliability of modes.

CONCLUSION

Although the multimodal transport sector is a transportation business driven by diverse equipment and vehicles that require large investments and whose continuity of revenue is largely uncertain due to the changes in the market demand, the advantages of multi-modalism are still increasing day by day. Along with the studies carried out and efficient planning of operations, multimodal transport has become more preferred option in logistics. Moreover, it is rewarding as it reduces the emission of harmful gases, eases the traffic congestion, and prevents unnecessary waste of money and time.

In this paper, we discussed the key points of multimodal transportation and important actors in the freight transport chain. We also highlighted the requirements of modal shift and the objectives of operational planning. Solution techniques are classified and exemplified for further practices. With the light of the information provided, the next step may address the development of the necessary solution methods according to the available data. The crucial points for the future studies are to consider the system as a whole and come up with a compromising mathematical model(s) which may involve multiple objectives. The model should be compatible with the real-life applications by acting rapidly upon changes. To achieve optimal results, appropriate solution methods that are available in the literature can be applied as well as intuitive, meta-heuristic algorithms suitable to the obtained data can be designed and implemented.

ACKNOWLEDGMENTS

This research is sponsored by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under the project number 116C048.

REFERENCES

Caramia M and Guerriero F (2009) “A heuristic approach to long-haul freight transportation with multiple objective functions”, Omega, 37(3), 600-614.

Caris A, Machasris C and Janssens GK (2008) “Planning problems in intermodal freight transport: accomplishments and prospects”, Transportation Planning and Technology, 31(3), 277-302.

Chang TS (2008) “Best routes selection in international intermodal networks”, Computers & Operations Research, 35(9), 2877-2891.

Cho JH, Kim HS, and Choi HR (2012) “An intermodal transport network planning algorithm using dynamic programming—a case study: from Busan to Rotterdam in intermodal freight routing”, Applied Intelligence, 36(3), 529-541.

De Jong G, Tavasszy L, Bates J, Grønland SE, Huber S, Kleven O, … and Schmorak N (2016) “The issues in modelling freight transport at the national level”, Case Studies on Transport Policy, 4(1), 13-21.

Demir E, Huang Y, Scholts S and Van Woensel T (2015) “A selected review on the negative externalities of the freight transportation: Modeling and pricing”, Transportation Research Part E: Logistics and Transportation Review, 77, 95-114.

Ergun Ö, Kuyzu G and Savelsbergh M (2007) “Shipper collaboration”, Computers & Operations Research, 34(6), 1551-1560.

Ferrari, P. (2015) “Dynamic cost functions and freight transport modal split evolution”, Transportation Research Part E: Logistics and Transportation Review, 77, 115-134.

Flodén J, Bärthel F and Sorkina E (2017) “Transport buyers choice of transport service–A literature review of empirical results”, Research in Transportation Business & Management, 23, 35-45.

Huang M, Hu X and Zhang L (2011) “A Decision Method for Disruption Management Problems in Intermodal Freight Transport”, Intelligent Decision Technologies, 13-21.

Gorman MF, Clarke JP, Gharehgozli AH, Hewitt M, De Koster R and Roy D (2014) “State of the Practice: A Review of the Application of OR/MS in Freight Transportation”, Interfaces, 44(6), 535-554.

Guajardo M and Rönnqvist M (2015) “Operations research models for coalition structure in collaborative logistics”, European Journal of Operational Research, 240, 147-159.

Kayikci Y (2014) “A Collaborative Slot Allocation Model for the Sea-Rail Multimodal Transport Service Providers Based on Revenue Management”, Proceedings of EurOMA 2014, Palermo, Italy.

Kayikci Y and Zsifkovits H (2012) “Transport collaboration strategies” in Blecker T, Kersten W and Ringle CM (Eds.), Pioneering Supply Chain Design: A Comprehensive Insight into Emerging Trends, Technologies & Applications, Josef E Verlag, Cologne, 3-18.

Krajewska MA, Kopfer H, Laporte G, Ropke S and Zaccour G (2008) “Horizontal Cooperation among Freight Carriers: Request Allocation and Profit Sharing”, Journal of the Operational Research Society, 59, 1483 –1491.

Lu JL (2013) “Investigating Critical Factors That Influence Shippers”, Journal of Marine Science and Technology, 21(2), 182-190.

Pruzan-Jorgensen PM and Farrag A (2010) “Sustainability trends in the container shipping industry”, New York: BSR.

Shinghal N and Fowkes T (2002) “Freight mode choice and adaptive stated preferences”, Transportation Research Part E: Logistics and Transportation Review, 38(5), 367-378.

SteadieSeifi M, Dellaert NP, Nuijten W, Van Woensel T, and Raoufi R (2014) “Multimodal freight transportation planning: A literature review”, European Journal of Operational Research, 233(1), 1-15.

Zhang M, Janic M and Tavasszy LA (2015) “A freight transport optimization model for integrated network, service, and policy design”, Transportation Research Part E: Logistics and Transportation Review, 77, 61-76.

A complete list of references which are denoted in tables will be provided upon request.