A New Insight on Conceptualizing a Sustainable Ocean Carrier Network Design Problem

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***Résumé- D*e nombreuses réglementations établies par l'Union européenne pour la période 2015-2020 vont être mises en place afin de réduire l'impact environnemental des activités maritimes. Dans ce cadre, le présent article propose de concevoir un modèle de réseaux maritimes adaptée à la notion de durabilité et notamment des émissions aériennes telles les émissions de CO_2. Les techniques de recherche opérationnelle telle la formulation de modèles mathématiques permettront de modéliser un Problème de Conception de Réseaux Maritimes Durables (PCRMD). Cette étude de conception de réseaux maritimes vise à définir deux modèles mathématiques différents. Le premier est défini comme un Problème de Conception de Réseaux Maritimes (PCRM) traditionnel tandis que le second inclura des indicateurs de durabilité. Notre objectif à travers ces deux modèles est de trouver quels indicateurs de durabilité devront être incorporés dans le premier modèle afin d'optimiser des itinéraires en tenant compte de l'approche de développement durable.**

***Abstract-* The present article purposes an Ocean Carrier Network Design Problem (OCNDP) through adjusting it to include the approach of port sustainability. This study comes after many regulations set by the European Union for the period 2015-2020 to reduce seriously the emission of CO_2 and other air quality indicators in order to have a more positive impact on the surrounding community. This study will investigate the incorporation of port sustainability indicators in an OCNDP by modeling it. This will be done using Operations Research techniques such as formulation of mathematical models. The work will have a focus on how such a network design may adjust to the triple bottom line of port sustainability. The research aims at defining two different mathematical models. The first one is defined as a traditional OCNDP excluding any port sustainability indicators, while the second one will include them. Our aim through these two models is to find which port sustainability indicators should be incorporated in our first model in order to find an optimal and enhanced way to define an optimal route while considering the sustainability approach.**

***Mots clés-* durabilité, problème de conception de réseau maritime durable (PCRMD), modèle mathématique.**
***Keywords-* port sustainability, sustainable ocean carrier network design Problem (SOCNDP), mathematical model.**

1 INTRODUCTION

The European Union (EU) wants a global approach taken to reducing emissions from international shipping. So, it has been decided that owners of large ships using EU ports should report their verified emissions from 2018. It has been fixed that for 2015, the lower sulfur fuels should not exceed 0.001 ULSD (Ultra-low-sulfur diesel). It has been suggested that EU's CO_2 emissions from maritime transport should be

cut by at least 40 per cent of 2005 levels by 2050, and if feasible by 50 per cent. However, international shipping is not covered by the EU's current emissions reduction target. It has been forecasted that the sulphur emissions from shipping will exceed those from all land-based sources in the EU by 2020. Further action is then needed to improve human health and the environment.
Shipping is a large and growing source of the GreenHouse Gas (GHG) emissions that are causing climate change. This article will address the issue of choosing the optimal route for containers while explicitly taking into account port sustainability indicators through a developed mathematical model for the Ocean Carrier Network Design Problem (OCNDP). We seek to provide a new insight of the traditional OCNDP by including the triple bottom line of the sustainability approach (social, economic and environmental) to reach the Sustainable Ocean Network Design Problem (OCNDP). Our objective is to provide research a new insight for conceptualizing the traditional OCNDP while including the sustainability concept.
This article is organized as follows: Section 2 presents the problem description of the research through the formulation of a traditional OCNDP; Section 3 develops the OCNDP with the mathematical model taking into account the port sustainability indicators. Finally, section 4 provides a conclusion with a future insight to the study.

2 TRADITIONAL OCEAN CARRIER NETWORK DESIGN PROBLEM

2.1 Problem Background

Literature on the OCNDP is quite scarce [Brouer et al., 2014] compared to related maritime shipping transportation problems, but recent years showed increased interest in the OCNDP. The works of Agarwal and Ergun [2008]; Alvarez [2009]; Reinhardt and Pisinger [2012]; Brouer et al. [2014]; Notteboom [2006] reveal that the liner shipping network design problem is a very complex optimization problem, where current mathematical formulations and state-of-the-art exact solution methods cannot scale to realistic sized problem instances at the time of writing. Heuristic approaches have been applied to large-scale instances in Alvarez [2009] and Brouer et al. [2014].
A core concept in liner shipping is the transshipment of containers. More than 50% of cargoes are transported on more than one service from origin to destination. Brouer et al. [2014] give an introduction to the OCNDP focusing on mathematical modeling of the business domain and the introduction of a benchmark suite of OCNDP problems. Christiansen et al. [2004] review the field of operations research within shipping in general and a good introduction to the OCNDP may be found in Christiansen et al. [2007]. Bell et al. [2011] published a classification scheme for routing and scheduling problems within liner shipping, reviewing and classifying 24 references. A more recent review may be found in Meng et al. [2014], as a thorough study was driven to find ways to determine optimal maritime routes. Meng et al. [2004] used a traditional OCNDP to achieve optimality. The OCNDP was initially studied by Rana and Vickson [1991] as a mixed integer program (MIP) for a multiple container ship problem without transshipment and where vessels return to the origin node empty. The benders decomposition principle divides the MIP into an integer network sub problem and a cargo allocation problem. Results are reported for 10–20 ports and three vessels.
In recent literature several variants of the OCNDP have been studied. Fagerholt [2004] developed a model and solution method for a regional carrier along the Norwegian coast. The model assumes the carrier loads at a single port and finds optimal routes of vessels to service the unloading facilities. The problem may be dealt with as a vehicle routing problem, given that a designated depot is known and transshipments are not allowed. The solution method enumerates first all feasible routes and then solves a set covering model using a MIP solver. Karlaftis et al. [2009] solve a similar problem for the region of the Aegean Sea using a genetic algorithm. These problem variants do not deal with the important concept of transshipments at multiple ports and the resulting interaction between different services. Then, a recent study by Liu et al. [2014] on a global intermodal network design model assigns inland demand to seaports via an intermodal inland transportation network, and subsequently solves a network design problem with compulsory and optional shipping routes. The model is concerned with the selection of optional shipping routes and a case study of 88 shipping lines, 289 ships and 19672 commodities is provided. Moreover, Brouer et al. [2014] present a reference model for the OCNDP derived from the model of Alvarez [2009] accounting correctly for transshipments on butterfly routes. The largest instance solved contains 111 ports and 4000 demands. Notteboom [2006] present a service flow model with the novelty of handling non-simple cycles in general, while accounting correctly for transshipment costs. The service flow model ensures weekly frequency of services, and is guided by restrictions on the total number of services and port calls.

However, optimal solutions are not found due to the large number of variables and constraints. Mulder and Dekker [2014] present a genetic algorithm for a fleet-design, ship-scheduling and cargo-routing problem with no limitations on fleet availability. A case study for a 58-port instance is reported. In light of the literature published on the OCNDP, exact solution methods are presently not able to solve large-scale instances to optimality. Heuristic methods are often based on route generation in a branch-and-bound framework with the exception of Alvarez [2009]; Brouer et al. [2014]; Mulder and Dekker [2014], where the overall framework is a local search with route generation as the underlying method for producing a new candidate solution.

The aim of this paper is to propose a concise mathematical model (model one) that will provide a starting point for a more developed one taking into account some of the port sustainability indicators (model two).

2.2 Model Outline

The OCNDP addressed in our work corresponds to the problem of minimizing cost while incorporating port sustainability indicators as it will be presented in our second model. Liner shipping companies design fixed schedules and routes as a weekly service, which are kept in place for a relatively long time, e.g., for a few months or for a year. Deciding the voyage routing schedule depends upon several factors such as seasonal cargo fluctuations, market requirements, company policy, etc.

Therefore, the shipping companies estimate potential cargo demand at each calling port on a weekly basis and try to construct service routes or networks by explicitly taking into consideration incurred costs and corresponding revenues during a specified planning horizon. The decision making process involves finding the optimal cruising speed (in practice however, the speed is sometimes set in advance and is therefore regarded as an important constraint in finding the optimal routes and calling schedules) and the number of ships for an optimized schedule.

Most container shipping companies assign a number of ships on a particular trade route, which is characterized by two end ports (*i.e.*, head-end harbor or origin and tail-end harbor or destination) and many intermediate calling ports. In order to minimize cost, the companies must decide: ports to be called and the order of calling sequence for the chosen ports.

As the problem must determine the above decision factor, it is the so-called location routing problem or OCNDP. In most existing voyage routes, all ports to be called on the way from the head-end port to the tail-end port (referred to as outbound direction) are not always called on the way back to the head-end port (referred to as inbound direction), as shown in Figure 1, where ports 1 and 5 are the head- and tail-end ports. In the outbound direction, all intermediate ports except for port 2 are called, whilst only ports 4 and 5 are called in the inbound direction. Note that both outbound and inbound directions have the same calling sequence of ports 4 and 5 in this example.

The model minimizes cost by forming a single route, which does not necessarily call at all the ports in the trade area. The model assumes a weekly cargo demand for all origin/destination pairs.

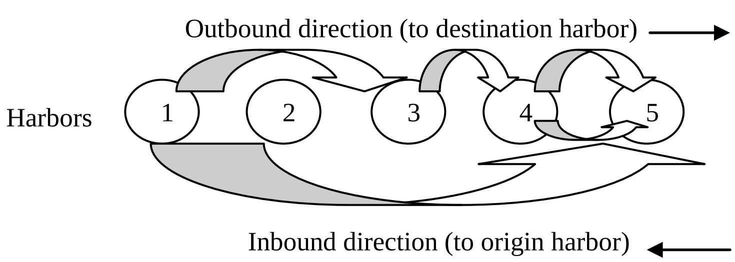

Figure 1. Example of ship's itinerary

Our aim is to find an optimal route by selecting an optimal set of calling ports and associated calling sequence of ports. This selection will be formulated through an OCNDP. The OCNDP has been commonly used in ship scheduling problems as well as in other general scheduling problems.

The problem will be presented in two distinct models. The first model will be defined as a traditional OCNDP without any port sustainability indicators, and the second will be a new, enhanced model that will take the first one as an initiative to integrate some of the port sustainability indicators as identified in our

conceptual framework. Our first mathematical model presents the optimal set of calling ports that associate to the calling sequence.
A solution to the network design problem is a set of services S. A service is a cyclic route visiting a set of harbors H0#H. The service may be non-simple, that is, harbors can be visited more than once. The rotation time is the time needed to complete the cyclic route including a day for handling cargo at each harbor call. Depending on the vessel class Vc, a minimum (Min) and maximum (Max) rotation time in weeks may be defined. It is common in liner shipping to offer a regular service with a weekly frequency. The weekly frequency of harbor calls is obtained by deploying multiple vessels to a service sailing one week apart. Let NVs be the number of vessels of class deployed on service S to maintain a weekly frequency.
A service S carries a set of demands Ks#K either by serving both Ok and Dk or by serving either Ok or Dk and a designated transshipment port Hk valid for transshipping demand K.
The objective function minimizes all travel dependent costs spent from transporting cargoes from ports *o* to their destination port *d*.

Table 1 gives an overview of the sets and constants which will be used to formulate the traditional mathematical model (Table 2).

Table 1. Overview of sets, constants, and variables used in the traditional OCNDP

Sets

-H: Set of calling harbors in s.
-S: Non-empty subset of H.
-K: Set of demands, where each demand has an origin (o) Ok, a destination (d) Dk, and a quantity (q), qk.
-V: Set of vessel classes with Vc each vessel's capacity with minimum and maximum speed limits, bunker consumption per nautical mile as a function of the speed and bunker consumption, when the vessel is idle at harbors.

Constants

-D(s): Current distance (in nautical miles) of the route associated with s.
-Bp: Berth time at harbor H in hours.
-H(i): Harbor associated with a harbor call i.
-K(s): Estimated speed of the service s (in nautical miles per hour).
-Cv(s): Weekly cost of a vessel (time charter rate) assigned to s.
-Dv(s): Number of deployed vessels to s.
-Uv(s): Number of undeployed vessels in the current solution.

This kind of problem can be modeled as an OCNDP as described by Norstad et al. [2011] and presented in details in the following mathematical model (Table 2):

Table 2. Mathematical model of traditional OCNDP

Decision Variables	*xodvk*=1, if a ship of type *v* is traversing an arc from harbor *o* (origin) to *d* (destination) with a certain demand k; 0, otherwise. *aodvk:* Duration of the route from traversing harbor *o* and arriving at harbor *d* of a ship of type *v* with a certain demand k.
Objective Function	Minimize (cost) Z= C(*xodv*k; *aodvk*), (1) Shipping cost function of selected arcs (o, d).
Constraints	*Subject to* $\Sigma xodvk = \Sigma xdovk$, $\forall o \epsilon H$ $\forall d \epsilon H$ (2) H set of calling harbors $\Sigma aodvk \geq 1$ $\forall S \subset H$, (3) S non-empty subset of H $\Sigma aodvk = \Sigma adovk$ $\forall S \subset H$, (4) $o \epsilon S$ $d \epsilon S$
Non-negativity Constraints	$xodvk \in \{0,1\}$ $\forall o, d \in H$, (5) $aodvk \geq 0$ $\forall o, d \in H$, (6)

3 OCEAN CARRIER NETWORK DESIGN PROBLEM AND SUSTAINABILITY

We will provide a mathematical model that will to the economic aspect of the above figure (Figure 2) the environmental and social aspects.

3.1 Literature Review

Extensive literature reviews on ship routing and scheduling are given in Bell et al. [2011], Christiansen et al. [2004, 2014] and Ronen [1983, 1993]. In contrast to truck vehicle routing problems, little work has been done on ship routing and scheduling. Increasing fuel costs and consumer expectations to reduce carbon dioxide and sulphur emission during the transport of products are forcing ship owners and shipping companies not only to minimize costs but also to minimize ship's emissions. In addition, governments are planning to enact the use of even more expensive diesel instead of heavy fuel oil for ocean going ships on their territorial waters. To comply with this framework, vessels are already operated in slow steaming mode for the purpose of cost and emission reduction purposes. A reduction in speed has significant impact, since vessel fuel consumption has a cubic function in regard to speed. We will introduce a new perspective for the traditional OCNDP by incorporating port sustainability indicators in order to obtain a Sustainable Ocean Carrier Network Problem (SOCNDP), which will be presented in the coming section.

Whereas CO_2 can be directly related to fuel consumption, other information is needed to calculate air pollutant emissions (engine types, fuel quality, abatement measures). This is reflected in the figures for air pollutants; where CO_2 emissions estimated for the same domain are relatively close, the air pollutant emissions from the same studies show larger variations. For example, while the CO_2 emissions from Gelareh and Meng [2010] and Gelareh et al. [2010] from national and international shipping (dark blue bars) are rather close, the emissions from NO_x, SO_x and PM are different. Another example is found when comparing the Wagner, Bosch and Gelareh studies for year 2000; the difference between the studies depends on the type of pollutant, with a relatively large difference for PM. In the case of NO_2, the average implied emissions factors range mainly between 23 and 24 Micrograms/NO_2 per Gg CO_2. Only the studies by Imai et al. [2009] and Imai et al. [2013] estimate a somewhat higher emissions factor. In the case of SO_2, it is known that the applied sulphur content of marine fuels strongly determines the SO_2 emissions. The implied emissions factor ranges from 14 to 17, highlighting that the sulphur content in marine fuels is rather similar between studies. Emissions from PM are more difficult to estimate because the emissions depend on fuel type, sulphur and ash content. Normally, higher quality marine fuels (and thus more expensive) have lower PM emissions. The range in implied emissions factors is relatively large with values of 1.5–2.1 Mg PM per Gg (gigagram) of CO_2 emitted. For PM the differences are relatively large but this can be caused by the fact that some studies included emissions from fuel evaporation and other studies did not. The number of different studies presenting CO_2 emissions is too small to discuss differences in implied emissions factors.

3.2 Model Outline

In the SOCNDP**,** we will change the decision variables that reflect the fuel and engine types. Both the sets and constants will be changed to account for the different factors that affect the marine air quality. Our objective is to formulate a model that will be able to analyze the influence of the emissions of the different air quality indicators on the decision variables, and how the formers will be modified to reflect these changes. We will add also the social indicators in order to account for all three components of the triple bottom line approach: economic (model one), environmental and social (model two).

In Table 3, we give an overview of the sets, constants, and variables used in the SOCNDP.

Table 3. Overview of sets, and constants used in the SOCNDP

Sets
-H: Set of calling harbors in s.
-F: Set of vessel using a certain marine fuel type f.
-E: Set of vessel operating with a certain engine type e.
-CO: Set of CO_2 emissions (in ppm) for arc (o;d).
-NO: Set of NO_2 emissions (in kilotonnes) for arc (o;d).
-SO: Set of SO_2 emissions (in kilotonnes) for arc (o;d).
-PM: Set of PM emissions (in kilotonnes) for arc (o;d).
-PS: Set of prompt servicing in harbor.
-RS: Set of reliable servicing in harbor.
-SS: Set of society satisfaction in harbor.

Constants
-D(s): Current distance (in nautical miles) of the route associated with s.
-K(s): Estimated speed of the service s (in nautical miles per hour).
-Cv(s): Weekly cost of a vessel (time charter rate) assigned to s.
-V(s): Volume of CO2 in the container assigned to s.
-T(s): Temperature in the container assigned to s.
-P(s): Pressure in the container assigned to s.

We present in Table 4 the SOCNDP an extended mathematical model of the traditional OCNDP by incorporating the air quality and social indicators to account for port sustainability approach.

Table 4. Sustainable Ocean Carrier Network Problem (SOCNDP)

Decision Variables	*xodf*=1, if a ship using fuel type *f* is traversing an arc from harbor *o* (origin) to *d* (destination); 0, otherwise. *xode*=1, if a ship using engine type *e* is traversing an arc from harbor *o* (origin) to *d* (destination) with a certain demand k; 0, otherwise. *ycods*: CO_2 emission associated with s for the route arc from harbor o (origin) to d (destination) in ppm. *ynods*: NO_2 emission associated with s for the route arc from harbor o (origin) to d (destination) in kilotonnes. *ysods*: SO_2 emission associated with s for the route arc from harbor o (origin) to d (destination) in kilotonnes. *ypmods*: PM emission associated with s for the route arc from harbor o (origin) to d (destination) in kilotonnes.
Objective Function	Minimize (cost) Z= C(*xodf*;*xode*;*ycods;ynods;ysods;ypmods*), (14) Shipping cost function of selected arcs (o, d).
Constraints	*Subject to* Σ*xodf* = Σ*xode* , ∀o∈H;*f;e* ∀d∈H;*f;e* (15) Σ*ycods* =Σ*ynods*=Σ*ysods*=Σ*ypmods* , ∀o∈H;*PS;RS;SS* ∀d∈H;*PS;RS;SS* ∀*ycods* ∈*V;T;P* (16) Σ *ycods* ≥ *xodf* , ∀o∈H;*f* ;*PS;RS;SS* ∀d∈H;*f;PS;RS;SS* ∀*ycods* ∈*V;T;P* (17) Σ *ynods* ≥ *xodf* , ∀o∈H;*f*; ;*PS;RS;SS* ∀d∈H;*f;* ;*PS;RS;SS* *(18)* Σ *ysods* ≥ *xodf* , ∀o∈H;*f* ;*PS;RS;SS* ∀d∈H;*f* ;*PS;RS;SS* *(19)* Σ *ypmods* ≥ *xodf* , ∀o∈H;*f* ;*PS;RS;SS* ∀d∈H;*f* ;*PS;RS;SS* *(20)* Σ *ycods* ≥ *xode* , ∀o∈H;*e* ;*PS;RS;SS* ∀d∈H;*e* ;*PS;RS;SS* ∀*ycods* ∈*V;T;P* *(21)* Σ *ynods* ≥ *xode* , ∀o∈H;*e* ;*PS;RS;SS* ∀d∈H;*e* ;*PS;RS;SS* *(22)* Σ *ysods* ≥ *xode* , ∀o∈H;*e*;*PS;RS;SS* ∀d∈H;*e* ;*PS;RS;SS* *(23)* Σ *ypmods* ≥ *xode* , ∀o∈H;*e*;*PS;RS;SS* ∀d∈H;*e*;*PS;RS;SS* *(24)*
Non-negativity Constraints	*xodf* ∈ {0,1} ∀o;d∈H;f (25) *xode* ∈ {0,1} ∀o;d∈H;e (26) *ycods* ≥0 ∀o;d∈H;*PS;RS;SS* (27) *ynods* ≥0 ∀o;d∈H;*PS;RS;SS* (28) *ysods* ≥0 ∀o;d∈H;*PS;RS;SS* (29) *ypmods* ≥0 ∀o, d ∈H; *PS;RS;SS* (30)

Therefore, from the above mathematical model, we have reached a new perspective by including the traditional OCNDP (just economic impact) the two other aspects of the triple bottom line of the port sustainability approach (environmental and social impacts). This model will be a cornerstone for further studies in the maritime field and especially in solving the network design problem.

4 CONCLUSION

This paper has focused on the traditional ocean carrier network design problem. Yet, the problem is inherently not taking into account the environmental and social aspects of the ort sustainability. This paper therefore proposed a holistic mathematical model that accounts for these issues. The SOCNDP implies that the sustainability aspect should not be neglected in liner shipping network design.

Through the extended traditional OCNDP, we have reached a new model incorporating port sustainability indicators which is called the Sustainable Ocean Carrier Network Problem.

This new problem was conceptualized using a mathematical model that integrates in the traditional problem complementary constraints accounting for air quality indicators, such as CO_2, NO_2, SO_2, and PM; as well as social indicators. We seek to show that it is possible to minimize the shipping costs by taking into consideration the CO_2, NO_2, SO_2, and PM emissions. These emissions can be reduced by using more environmental friendly fuel types, engine types, and managing overall the maritime activities at both berth and sea. It is wise for ports to begin to operate with the environmental strategy in mind and change the fuel and engine types used in both the berth and sea activities.

Figure 2 provides a summary for our present work which clarifies the relationship between the first and the second model.

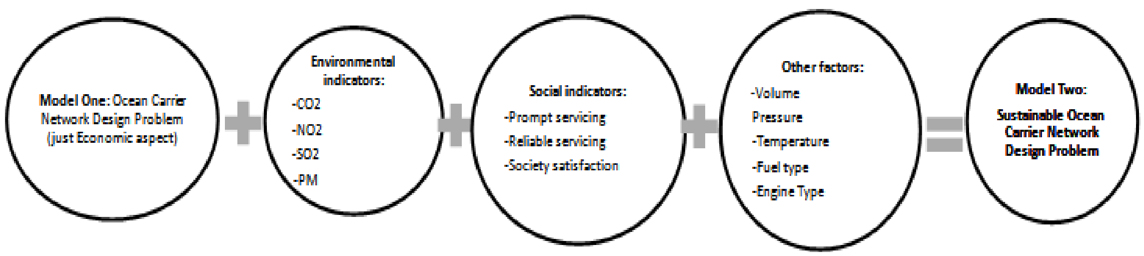

Figure 2. Link between the traditional OCNDP and the SOCNDP

More effort is needed to extend the work presented in this paper by testing the model in the port of Alexandria which will be taken as the port of reference and associating various routes with other ports in order to reach a more "environmentally and socially" responsible route. How to measure these environmental and social aspects is a worthwhile future research topic.

5 REFERENCES

Agarwal, R., Ergun, O., (2008) Ship Scheduling and Network Design for Cargo Routing in Liner Shipping. *Transportation Science*, 42(1) , pp. 175-196.

Alvarez, J.F., (2009) Joint Routing and Deployment of a Fleet of Container Vessels. *Maritime Economics and Logistics*, 11(2), pp. 186–208.

Bell, M.G.H., Liu, X., Angeloudis, P., Fonzone, A., Hosseinloo, S.H., (2011) A Frequency-Based Maritime Container Assignment Model. *Transportation Research Part B*, 45(8), pp. 1152–1161.

Brouer, B.D., Alvarez, J.F., Plum, C., Pisinger, D., Sigurd, M., (2013) A Base Integer Programming Model and Benchmark Suite for Linear Shipping Network Design. *Transportation Science, in press*. http://dx.doi.org/10.1287/trsc.2013.0471.

Christiansen, M., Fagerholt, K., Nygreen, B., Ronen, D. (2007) Maritime Transportation. In C. Barnhart, G. Laporte (Eds.), Transportation, Volume 14, Handbooks in Operations Research and Management Science C, chapter 4. pp. 189-284. North-Holland, Amsterdam.

Christiansen, M., Fagerholt, K., Ronen, D., (2014) Ship Routing and Scheduling: Status and Perspectives. *Transportation Science*, 38(1), pp. 1–18.

Fagerholt, K., (2004) Optimal Fleet Design in a Ship Routing Problem. *International Transactions in Operational Research*, 6(5), pp. 453–464.

Gelareh, S., Meng, Q., (2010) A Novel Modeling Approach for the Fleet Deployment Problem within a Short-Term Planning Horizon. *Transportation Research Part E,* 46(1), pp. 76–89.

Gelareh, S., Nickel, S., Pisinger, D., (2010) Liner Shipping Hub Network Design in a Competitive Environment. *Transportation Research Part E,* 46(6), pp. 991–1004.

Imai, A., Shintani, K., Papadimitriou, S., (2009) Multi-Port vs. Hub-and-Spoke Port Calls by Containerships. *Transportation Research Part E,* 45(5), pp. 740–757.

Imai, A., Nishimura, E., Papadimitriou, S., (2013) Marine Container Terminal Configurations for Efficient Handling of Mega-Containerships. *Transportation Research Part E*, 49(1), pp. 141–158.

Karlaftis, M.G., Kepaptsoglou, K., Sambracos, E., (2009) Containership Routing with Time Deadlines and Simultaneous Deliveries and Pick-Ups. *Transportation Research Part E,* 45(1), pp. 210–221.

Liu, Z., Meng, Q., (2014) Distributed Computing aApproaches for Large-Scale Probit-Based Stochastic User Equilibrium Problem. *Journal of Advanced Transportation*, 47(2), pp. 553–571.

Meng, Q., Wang, S., Andersson, H., Thun, K., (2014) Containership Routing and Scheduling in Liner Shipping: Overview and Future Research Directions. *Transportation Science*. http://dx.doi.org/10.1287/trsc.2013.0461.

Notteboom, T.E., (2006) The Time Factor in Liner Shipping Services. *Maritime Economics and Logistics*, 8(1), pp. 19–39.

Rana, K., Vickson, R.G., (1991) A Model and Solution Algorithm for Optimal Routing of a Time-Chartered Containership. *Transportation Science*, 22(2), pp. 83–95.

Reinhardt, L.B., Pisinger, D., (2012) A Branch and Cut Algorithm for the cContainer Shipping nNetwork Design Problem. *Flexible Services and Manufacturing Journal*, 24(3), pp. 349–374.

Ronen, D., (1983) Cargo Ships Routing and Scheduling: Survey of Models and Problems. *European Journal of Operations Research*, 12(1), pp. 119–126.

Ronen, D., (1993) Ship Scheduling: The Last Decade. *European Journal of Operations Research*, 71(2), pp. 325–333.