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Liner services network design and fleet deployment with empty container repositioning

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A R T I C L E I N F O

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A B S T R A C T

Transportation demand of shipping container fluctuates due to the seasonality of international trade, thus, every 3–6 months, the liner company has to alter its current liner shipping service network, redeploy ships and design cargo routes with the objective of minimizing the total cost. To solve the problem, the paper presents a mixed integer linear program model. The proposed model incorporates several relevant constraints, such as weekly frequency, the transshipment of cargo between two or more service routes, and transport time. Extensive numerical experiments based on realistic date of Asia–Europe–Oceania shipping operations show that the proposed model can solve real-case problems efficiently by CPLEX. The results demonstrate that the model can reduce ship's capacity consumption and raise ships' capacity utilization.

1. Introduction

Maritime transportation offers cheaper rates, higher safety levels and less environmental impact than most comparable transportation modes. In the last decades, maritime transportation has played an important role in the international trade, due to the strong and rapid growth in the world economy resulting in a larger volume of production. A forecast ending in 2020 indicated that container trade is expected to reach 287 million TEUs in 2016 and to exceed 371 million TEUs in 2020. For more details one can refer to ISL (2013). In addition to transporting laden containers from shippers, liner container shipping companies have to reposition their empty containers caused by the imbalance of import and export trade. According to PIERS (Port Import Export Reporting Service) data, U.S. imports from China reached nearly 4.1 million TEUs in the first half of 2011, while exports during the same period represented only 1.2 million TEUs.

Every 3–6 months, the liner company has to alter its current liner shipping service network and redeploy ships according to the port-to-port container shipment demand forecasted for the next 3–6 months. This alteration aims to determine which shipping lines among the candidate shipping lines should be chosen to operate, what type of ship and how many ships should be deployed on each chosen shipping line, how to route laden containers and reposition empty containers subject to the existing shipping lines and shipment demand with the objective of minimizing the total operating cost. The purpose of this study is to develop a proper mathematical model for this problem and confirm its validity.

2. Literature review

In the liner network problem, Kunnathur, Nandkeolyar, and Li (2005) addresses the problem of partitioning and transporting a shipment of known size through an n-node public transportation network with known scheduled departure and arrival times and expected available capacities for each departure to minimize the makespan of shipping. Agarwal and Ergun (2008) proposed a multi-commodity based space–time network model for the liner shipping service network design problem with cargo routing. This model covers heterogeneous ship fleet, weekly service frequency, multiple shipping lines and cargo transshipment operations. Gelareh and Pisinger (2011) develop a mixed integer linear programming model for the simultaneous design of network and fleet deployment of a deep-sea liner service provider. Reinhardt and Pisinger (2012) design the liner network in a strongly competitive market. Chuang, Lin, Kung, and Lin (2010) plan the container route with uncertain market demand.

In the area of empty container repositioning, Shintani, Imai, Nishimura, and Papadimitriou (2007) design container liner shipping service networks with empty container repositioning. Deploying ships and containers are considered simultaneously as a two-stage problem. A genetic algorithm-based heuristic is

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developed for the problem. Dang, Yun, and Kopfer (2012) deals with the problem of positioning empty containers the operation level, in a port area with multiple depots, Customer demands and returning are assumed to be dependent random variables. A genetic-based optimization procedure is developed to obtain optimal policies corresponding to different methods of inland positioning in order to minimize the expected total costs. Chang, Jula, Chassiakos, and Ioannou (2008) studies substitution between empty containers of different types in an attempt to reduce the cost of empty container interchange. Lei and Church (2011) presents three strategic-level models for locating away-from-port storage yards for empty shipping containers. The main objective is to reduce the mileage involved in repositioning empty containers. Imai, Shintani, and Papadimitriou (2009) examine two typical service networks with different ship sizes: multi-port calling by conventional ship size and hub-and-spoke by mega-ship, analyses advantages and disadvantages of the two methods.

As for the fleet deployment problem, Fagerholt, Johnsen, and Lindstad (2009) developed a fleet deployment model that required ships to fulfill a given number of voyages. Liu, Ye, and Yuan (2011) developed a fleet deployment model with container routing where the revenue is a concave increasing function of the volume of containers shipped to account for discounts for customers. Wang and Meng (2012) developed a MILP model for the fleet deployment problem in which containers may be transshipped at any port. Meng and Wang (2012) examined a fleet deployment problem with week dependent container shipment demand and transit time constraint. Gelareh and Meng (2010) develop a mixed integer nonlinear programming for a short-term fleet deployment problem of liner shipping operations. Meng, Wang, and Wang (2012) proposes a short-term liner ship fleet planning problem with uncertain container shipment demand.

Liner network, empty container repositioning and fleet deployment are always considered simultaneously partly. Meng and Wang (2011) propose a liner shipping service network design problem with combined hub-and-spoke and multi-port-calling operations and empty container repositioning, then develops a mixed-integer linear programming model for the proposed problem. Dong and Song (2009) considers the container fleet sizing and empty container repositioning problem in multi-vessel, multi-port and multi-voyage shipping systems with dynamic, uncertain and imbalanced customer demands. Song and Dong (2012) considers the problem of joint cargo routing and empty container repositioning with multiple service routes, multiple deployed vessels and multiple regular voyages.

The existing research has made great contribution, develop a lot of useful modals and algorithms. However, there are little research that jointly consider the laden container routes, network design, fleet deployment and empty container reposition, to which the paper attempt to contribute. Furthermore, applying the proposed model to real liner company is also taken into consideration.

The outline of the paper is as follows. In Section 3, the ship deployment, network design and cargo route optimal problem is more formally described. Section 4 develops a mixed integer linear programming model for the proposed problem. Section 5 carries out numerical experiments based on reality problems, followed by concluding remarks in Section 6.

3. Notations, assumption and formulation

3.1. Liner network

The shipping network is composed of ports and shipping lines which links between ports. There are two types of ports, and let P denotes the set of ports, and P^H denote the set of hub ports, P^F denote the Set of feeder ports, namely $P = P^H \cup P^F$, $P^H \cap P^F = \emptyset$. Each feeder port is served only one hub port and denoted by

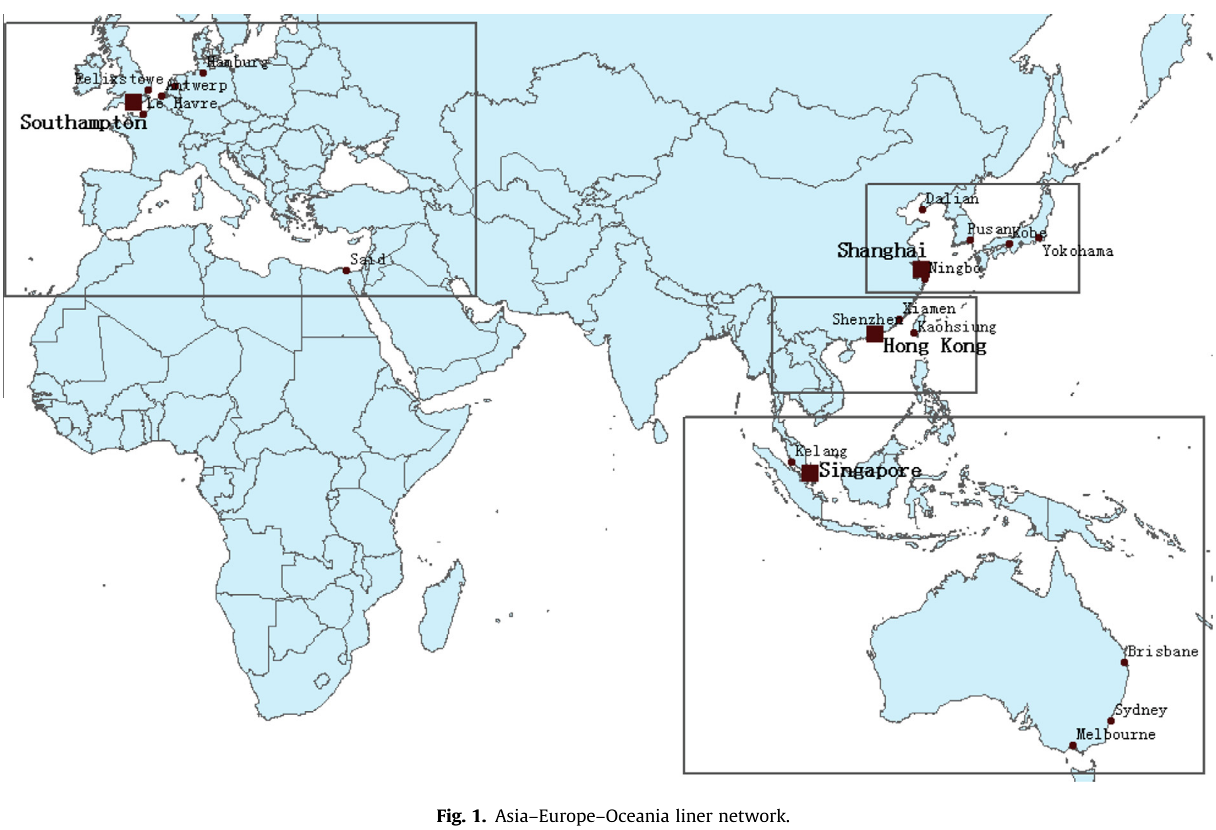

Fig. 1. Asia–Europe–Oceania liner network.