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Segment-based alteration for container liner shipping network design

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ABSTRACT

Container liner shipping companies only partially alter their shipping networks to cope with the changing demand, rather than entirely redesign and change the network. In view of the practice, this paper proposes an optimal container liner shipping network alteration problem based on an interesting idea of *segment*, which is a sequence of legs from a head port to a tail port that are visited by the same type of ship more than once in the existing shipping network. In segment-based network alteration, the segments are intact and each port is visited by the same type of ship and from the same previous ports. As a result, the designed network needs minimum modification before implementation. A mixed-integer linear programming model with a polynomial number of variables is developed for the proposed segmented-based liner shipping network alternation problem. The developed model is applied to an Asia–Europe–Oceania liner shipping network with a total of 46 ports and 11 ship routes. Results demonstrate that the problem could be solved efficiently and the optimized network reduces the total cost of the initial network considerably.
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1. Introduction

International containerized cargos are transported by container shipping lines over their shipping networks. A container liner shipping network operated by a particular shipping line comprises a set of ship routes, and a ship route can be expressed by a sequence of ports (port rotation) called at by ships in a way that ships visit the first port again after visiting the last one. Generally, a fleet of homogenous ships in terms of capacity and average sailing speed is deployed on each ship route to provide a regular (usually weekly) service frequency. Once the shipping network is designed, including port rotation design and ship deployment, the ship chartering cost, bunker cost, port charges (excluding container handling cost) and canal dues are almost determined. Moreover, the liner shipping network also determines how many containers can be transported and how these containers are routed. Consequently, it is of significant importance for a shipping line to design an efficient shipping network.

1.1. Literature review

Most studies on container liner shipping planning require a given liner shipping network as an input of the models (Bell et al., 2011, 2013; Qi and Song, 2012; Song and Dong, 2012). For a review on operations planning for container liner shipping,

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we refer to the latest works of Christiansen et al. (2013) and Meng et al. (2014). One category of relevant literature is liner shipping network design, which aims to design a liner ship route or a liner shipping network from scratch. The second category of literature is liner shipping network alteration, which aims to improve an existing network where the newly designed network should not deviate too much from the existing one.

In liner shipping network design, Fagerholt (1999) proposed a set-partitioning model by enumerating all possible routes. Fagerholt (2004) later extended the set-partitioning model to address a heterogeneous ship fleet with a given cost structure, capacity and sailing speed for each type of ship. He reported results for 40 ports and 20 ships. Shintani et al. (2007) considered empty container repositioning to design a single ship route, assuming that the ship capacity was infinity. A genetic algorithm was employed to solve the problem. Reinhardt and Pisinger (2012) presented an integer programming model and a branch-and-cut method for designing butterfly ship routes to optimality. A butterfly ship route is a ship route with a port visited twice in a round trip and containers can be transshipped at the port. For example ship route 1 in Fig. 1 is a butterfly ship route, where port 3 is visited twice in a round trip. The model of Reinhardt and Pisinger (2012) selected a route for each individual ship in a fleet. They commented that the configuration is suitable for smaller liner shipping companies as global liner shipping companies tend to group a set of ships with similar characteristics to a single service to reduce the complexity of the network design and to provide a regular schedule for customers. Song and Dong (2013) investigated a liner long-haul ship route design problem. They assumed that the set of ports to be serviced is determined at the strategic level and proposed a three-stage optimization method. The first stage was the topological structure. For example, ship route 1 in Fig. 1 has two cycles, ship route 2, 3, 4, and 5 each has one cycle. In view of the observation that most long-haul routes in practice have no greater than three directed cycles, the network design decisions were significantly simplified compared to enumerating all possible port rotations. The second stage was laden and empty flow optimization, and the third stage was ship deployment. Plum et al. (2014a) proposed a branch-and-cut-and-price approach to design a single liner shipping service. The numerical experiments demonstrated that the algorithm could solve instances with up to 25 ports to optimality. Wang and Meng (2014) designed multiple ship routes with a weekly frequency and no transshipment. The ports were assumed to follow a geographical order, which is typical for the Asia–Europe trade. The demand for each origin–destination (OD) pair has a maximum allowable transit time. Moreover, the port time is a linear function of the number of containers handled. A column generation based heuristic method was developed to address the problem.

The above studies have mainly focused on designing a small feeder network, a single ship route, or several ship routes without allowing container transshipment. There are a few works on more general liner shipping network design problems, in which multiple ship routes are designed, forming a network in which containers can be transshipped at any ports that are visited more than once a week. Agarwal and Ergun (2008) proposed a multi-commodity-based space–time network model for liner shipping network design with cargo routing. Transshipment costs were not considered in the network design stage. A greedy heuristic, a column generation-based approach, and a two-phase Benders' decomposition-based algorithm were developed, and their computational efficiency was tested on networks with up to 20 ports and 100 ships. Alvarez (2009) extended the problem addressed by Agarwal and Ergun (2008) in two aspects. First, the transshipment costs were explicitly incorporated. Second, he discretized the speed range and considered each combination of ship type and speed interval as a separate ship type. A combined Tabu search and column generation-based heuristic was applied to design a network with 120 ports and 5 types of ship. Meng and Wang (2011) presented a network design model that captured a combination of a hub-and-spoke network and a multi-port-call network with empty container repositioning. A set of candidate port rotations were given a priori and the objective was to choose the optimal port rotations and assign containerships to them. Laden containers were allowed to be transshipped only at hub ports, while empty containers could be transshipped at any port. The problem was tested on a case study with 46 ports. Meng et al. (2012) dealt with an intermodal liner shipping network design problem that consisted of a hub-and-spoke based maritime network and an inland intermodal transportation network including truck, rail, and barge services. Wang et al. (2013) designed a liner shipping network taking into account many practical features in real-world operations, such as multi-type containers, container transshipment operations, empty container repositioning, OD transit time constraints, consistent services with the current network, and joint services with other liner shipping companies. A large scale numerical test was performed based on the global shipping network of a liner that consisted of 166 ports. Brouer et al. (2014) contributed a seminal benchmark suite for global container transport network design.

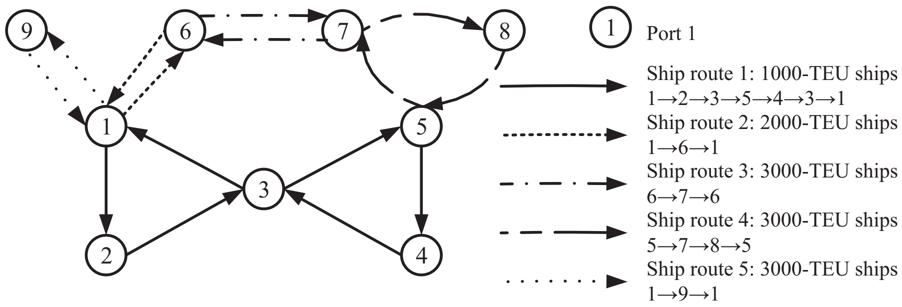

Fig. 1. An illustrative liner shipping network (TEU: twenty-foot equivalent unit).

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