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Measuring the perceived container leasing prices in liner shipping network design with empty container repositioning

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ABSTRACT

This paper aims to measure the perceived container leasing prices at different ports by presenting a two-stage optimization method. In stage I, we propose a practical liner shipping network design problem with empty container repositioning. The proposed problem further considers the use of foldable containers and allows the mutual substitution between empty containers to decrease the number of empty containers to be repositioned. In stage II, the inverse optimization technique is used to determine the perceived container leasing prices at different ports, based on the solution obtained in stage I. Based on a set of candidate liner shipping service routes, a mixed-integer nonlinear programming model is built for the proposed problem in stage I. The nonlinear terms are linearized by introducing the auxiliary variables. Numerical experiments based on a realistic Asia-Europe-Oceania liner shipping network are carried out to account for the effectiveness of our two-stage optimization method.

1. Introduction

In liner shipping industry, different types of containers (i.e., multi-type containers) are shipped by the liner shipping companies on the regularly scheduled shipping service routes (i.e., liner shipping network). When the liner shipping network is designed, it will be operated over a seasonal planning horizon. For every seasonal planning horizon, the liner shipping company will alter its current liner shipping network, according to the container shipment demand forecasted for the next seasonal planning horizon. Based on the liner shipping network, the liner shipping company transports both laden containers and empty containers. When the liner shipping company cannot maintain a balance between supplies and demands of empty containers for certain ports, container leasing offers an alternative way for container management (Shen and Khoong, 1995; Moon et al., 2010; Dong and Song, 2012; Liu et al., 2013; Wu and Lin, 2015; Jiao et al., 2016).

Evidently, different container leasing contracts lead to different leasing terms and prices (Dong and Song, 2012; Liu et al., 2013; Jiao et al., 2016). In this paper, we do not consider realistic container leasing when satisfying supplies and/or demands of empty containers at different ports. Alternatively, we aim to measure the perceived container leasing prices at different ports. Different from realistic container leasing prices in practice, the perceived container leasing prices are calculated based on the costs on repositioning empty containers via our liner shipping network. According to our perceived container leasing prices, it is helpful for the liner shipping company to make decisions on container leasing strategies at different ports.

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Actually, if the perceived container leasing price at any particular port is larger than the realistic container leasing price in the container leasing market, it is costly to reposition their own empty containers for this port; otherwise it is economic for the liner shipping company to reposition their own empty containers, as compared with that adopts container leasing for this port. In order to determine the perceived container leasing prices, this paper presents a two-stage optimization method. In stage I, we propose a practical liner shipping network design (LSND) problem with empty container repositioning. Based on the solution obtained in stage I, the perceived container leasing prices are determined in stage II.

Generally, the formulation of the LSND problem can be classified into two categories, according to whether the set of liner shipping service routes is given or not. For the first category, the LSND problem is often formulated as a multi-commodity flow assignment model or a container flow assignment model (Agarwal and Ergun, 2008; Meng and Wang, 2011; Wang and Meng, 2013; Brouer et al., 2014a, 2014b; Zheng et al., 2015b; Huang et al., 2015; Wang et al., 2015). The set of liner shipping service routes in the first category can be given in advance or generated by using some algorithms such as the column generation method as shown in Agarwal and Ergun (2008). For the latter one, the LSND is generally formulated as a vehicle routing problem (Fagerholt, 1999, 2004; Sambracos et al., 2004; Karlaftis et al., 2009; Zheng et al., 2014) or a hub location problem (Gelareh et al., 2010; Gelareh and Pisinger, 2011). This paper considers the first one. In practice, the liner shipping company will not completely redesign its liner shipping network from scratch after every seasonal planning horizon. In other words, the current liner shipping network operated by the liner shipping company can be regarded as an efficient portion of the set of candidate shipping service routes.

Due to the imbalance of imports and exports, liner shipping companies have to transport laden containers and reposition empty containers. Meng and Wang (2011) demonstrated the potential cost-savings by incorporating the empty container repositioning issue in the LSND problem. In order to reduce the cost for repositioning empty containers, this paper mainly considers two strategies, i.e., the mutual substitution between empty container containers and the use of foldable containers. Both of these two strategies have been considered by the liner shipping company to reduce the repositioning cost (Chang et al., 2008; Moon et al., 2013). Note that high production cost of foldable containers have made liner shipping companies hesitant to adopt these units (Moon and Hong, 2016). By considering the mutual substitution between empty containers, the number of empty containers to be repositioned can be decreased (Chang et al., 2008). Generally, empty containers with different sizes can be easily substituted each other. However, it is basically not allowed to substitute between the general empty containers and reefer empty containers. Based on the use of foldable containers, the ship capacity occupied by empty containers can be decreased (Moon et al., 2013). Hence, the ship storage space can be saved efficiently. However, it incurs the extra handling cost for folding and unfolding empty containers. In practice, several foldable container designs have been developed, leading to different folding principles, such as 4:1, 5:1 and 6:1. For any folding principle, e.g., 4:1, four folded empty containers can be regarded as one standard empty container from the occupied capacity point of view. Furthermore, it brings us a new problem on where to fold and/or unfold empty containers and how many empty containers to be folded or unfolded at different ports.

1.1. Literature review

In the aspect of empty container repositioning, there have been many recent studies in the literature, e.g., Cheung and Chen (1998), Imai and Rivera (2001), Li et al. (2007), Lam et al. (2007), Feng and Chang (2008), Dong and Song (2009), Francesco et al. (2009), Moon et al. (2010), Song and Dong (2011, 2012), Moon and Hong (2016). The majority of literature assumed that empty containers should be transported only when the laden container load of a ship is not full. Shintani et al. (2010), Moon et al. (2013) and Moon and Hong (2016) studied how the use of foldable containers could reduce the repositioning costs. Recently, Chen et al. (2016) investigated pricing and competition in a shipping market with carriers providing services between two locations, as well as considering the repositioning of empty containers.

There have been some studies on container leasing. Shen and Khoong (1995), Moon et al. (2010) studied empty container repositioning, as well as considering the leasing of empty containers. Dong and Song (2012) focused on leasing term optimization in container shipping systems. Wu and Lin (2015) investigated the selection between owned and leased containers. Moon and Hong (2016) studied the reposition of empty containers using both standard and foldable containers, as well as considering container leasing. Recently, Liu et al. (2013) and Jiao et al. (2016) focused on investigating container leasing contracts.

Network design, ship fleet deployment, ship scheduling and container routing for the liner shipping industry have attracted much attention, following the five review papers: Ronen (1983, 1993), Christiansen et al. (2004, 2013) and Meng et al. (2014). As mentioned before, the existing studies on the LSND problem can be classified into two categories – with and without the set of shipping service routes.

Based on the set of shipping service routes, Agarwal and Ergun (2008) proposed a multi-commodity based time-space network model for the LSND problem with cargo routing, which is formulated as a mixed-integer linear programing model. In order to generate the shipping service routes, three different methods (i.e., a greedy heuristic, a column generation method and a benders decomposition method) were proposed. Agarwal and Ergun (2010) and Zheng et al. (2015a) studied the LSND problem considering liner alliances, as well as determining capacity exchange cost for sharing ship capacity among liners in an alliance. Meng and Wang (2011) introduced the concept of segment in order to formulate a LSND problem with empty container repositioning as a mixed-integer linear programing model. They assumed that the candidate ship fleet deployment plans (ship size and number of ships) and the candidate shipping service routes were given in advance.