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Container Ocean-transportation System Design with the factors of demand fluctuation and choice inertia of shippers

Chen Kang, Chen Dongxu, Sun Xueshan, Yang Zhongzhen *

Dalian Maritime University, Dalian, Liaoning 116026, China

A R T I C L E I N F O

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This paper introduces an optimization model (COSDM) for a Container Ocean-transportation System with the objective of maximizing the revenue of a liner company while taking into account the seasonal fluctuation in transportation demand and the choice inertia of shippers. The COSDM optimizes shipping network design and fleet deployment simultaneously, and it optimizes plans for changing the shipping network and for distributing slots in ships based on the fluctuation in demand and the characteristics of the shippers' choice inertia. To solve COSDM, a heuristic algorithm is created that combines Genetic Algorithm and Simplex Method. The results show that the COSDM gives an optimized design scheme of the system that takes into account the stability of transportation services and improves the user experience of shippers while increasing the revenue of the liner company. Moreover, the results also reveal new explanations for the increasing size of container ships.

1. Introduction

The Container Ocean-transportation System (COS), also known as the liner shipping system on the main line, is an abstract transportation system formed by several large container ships operating periodically among pre-determined ports according to a fixed port calling sequence (Yang et al., 2012). A good COS can reduce the operational risk of liner companies (the system operator), increase the revenue of the shipping line and act as a cost-saving venture for shippers. A bad COS can lead to a decline in competitive capacity and losses as well as increase the operation cost of COS. Thus, the Container Ocean-transportation System Design Problem (COSDP) is important to maritime industry players and academic circles (Chen et al., 2014).

Two factors cannot be neglected when solving the COSDP. The first is the seasonal fluctuation in container transportation demand. An example is the transportation demand between Asia and Europe. From May to August of each year (the off season of the freight market), transportation demand is inadequate, and the freight rate is low. From September to December (the peak season of the freight market), transportation demand is high, and the freight rate is high. From January to April (the transition period of the freight market), both transportation demand and the freight rate are average. Thus, the liner companies typically adjust the COS every 3–6 months (Meng et al., 2012). The other factor is the choice inertia of shippers. In the context of social and behavioral sciences, choice inertia (see Gärling and Axhausen (2003) for an overview) is often understood as the endurance of stable relationships or the reluctance to adjust the status quo (Zhang and Yang, 2015) "Absent other forces, inertia describes the tendency to remain with the status quo and the resistance to strategic renewal outside

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* Corresponding author.
E-mail address: yangzz@dlmu.edu.cn (Z. Yang).

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the frame of current strategy" (Huff et al., 1992). In transportation networks, there is also the phenomenon of inertia, whereby users of the network tend to stay with a previously chosen alternative unless another alternative provides sufficiently higher utility to warrant a switch (Xie and Liu, 2014). According to the current data and survey results, choice inertia also exists in the international container transportation industry. Because changing carriers might undermine the stability of supply chains and cause unpredictable negative effects, shippers are usually unwilling to change their carrier. In this paper, we define choice inertia as follows: shippers tend to stay with the Ocean liner company that they have previously chosen unless the liner company cannot provide sufficient transportation service.

In a relatively stable environment, choice inertia will guide the shipper and liner company toward a long-term cooperative relationship (Yang et al., 2012). The impact of choice inertia on the COS is manifested in two respects: (1) When the liner company provides stable services, shippers show loyalty to the liner company and will rarely change their selection, even if a better liner company appears. (2) However, when service quality declines, a portion of the customers (shippers) of the company will gradually be lost, and lost customers rarely return to the original liner company in the long term (usually 6–12 months). Choice inertia is precisely why many liner companies prefer losses in the off season to maintain the stability of the COS. Obviously, while designing a COS, liner companies should not only consider problems such as ports of call and the sequence of ports of call but also the following problems. First, the liner company must know how to change the shipping network according to the seasonal fluctuation in transportation demand. Second, the liner must know if it is necessary to provide sustained and stable service to all shippers regardless of cost; if not, the problem of choice arises.

1.1. Literature review

The key to solving the two problems above is to create an optimization model (COSDM) of the Container Ocean-transportation System that considers the seasonal fluctuation in transportation demand and the choice inertia of shippers. There have been five studies related to CSODP since the 1980s that are important (Ronen, 1983, 1993; Christiansen et al., 2004, 2013; Meng et al., 2014). Based on these studies, the COSDP consists of three sub-problems: the Shipping Network Design Problem (SNDP), the Fleet Design and Usage Problem (FDUP), and the Slots Distribution Problem (SDP).

The SNDP mainly studies the selection and order of ports of call. Before 2000, there were only a few studies on SNDP, including Rana and Vickson (1988, 1991), Perakis and Jaramillo (1991), Jaramillo and Perakis (1991), Cho and Perakis (1996) and Fagerholt (1999). Between 2000 and 2010, a few studies related to SNDP began to emerge in the field of transportation research (see Meng et al., 2014). Sambracos et al. (2004) introduced a 'two-dimension method' to deal with the shipping network design problem in the Aegean Sea in Greece. In their method, a linear programming model is employed to create a reasonable route with known transport demand between ports. Then, based on this reasonable shipping route, a VRP model is used to optimize the transport paths of laden containers. Takano and Arai (2009) optimized the shipping route in the context of a hub-and-spoke network based on the flows of laden containers between several port pairs. They used a ship-routing model with a fixed slot allocation plan that meets all transport demand in the ports. Meng and Wang (2011) provided a new method of solving SNDP based on the User Equilibrium Assignment Model. This method is able not only to optimize a shipping network reasonably but also to optimize the transportation paths of each OD pair. Brouer et al. (2013) designed a benchmark suite for SNDP.

The FDUP mainly discusses the selection of the type of ships, the setting of the number of ships and the optimization of the operation states of ships (such as when to lay up and to reactivate). Many researchers have studied the FDUP from different perspectives, such as Notteboom and Vernimmen (2009), Gelareh and Meng (2010), and Alvarez et al. (2011). Fagerholt (2004) introduced a special 'set-partitioning' model. This model is able to optimize the size of a ship fleet, given a shipping network, transportation demand and the upper bound of ships' average cruising speed. Meng et al. (2012) considered the factor of cargo transshipment while dealing with FDUP. Wang and Meng (2012a) jointly studied the issues of FDUP and ships' average cruising speed control. They provided a mix-integer nonlinear programming model and developed an outer approximation algorithm to solve this model.

The SDP, which is referred to as the multi-commodity flow problem in some papers, mainly determines how to distribute the limited slots in the ship to each port of call and how to design paths of container flows. There are several representative studies that address this issue, such as Cheung and Chen (1998), Li et al. (2007), and Dong and Song (2009). Generally, most studies place emphasis on the issue of empty container repositioning.

The SNDP, FDUP and SDP are the three fundamental sub-problems in the field of container shipping. They are related to one another, and they affect one another. Just as Shintani et al. (2007) and Meng and Wang (2011) have noted, these fundamental sub-problems should be solved under one model frame due to their correlation and interaction. In recent years, many scholars have made various attempts to optimize the above two or three sub-problems simultaneously, and a number of important conclusions and practical approaches have been put forward (Reinhardt et al., 2010; Wang and Meng, 2012b; Wang et al., 2013). Shintani et al. (2007) tried to deal with the issues of the SDNP and the SDP simultaneously using a bi-level model. The object of their model is to minimize the operation cost of the shipping network. Agarwal and Ergun (2008) introduced a mixed-integer programming model to address the issues of SDNP, FDUP and SDP together and tested three different algorithms, including Greedy Heuristic, Column Generation and Benders Decomposition. Meng and Wang (2012) also developed a mixed-integer linear programming model to simultaneously optimize SNDP and SDP. Their model can be efficiently solved by CPLEX for real-case problems. Recently, Angeloudis et al. (2016) introduced another new optimization method for the SNDP and SDP based on game theory. Given transportation demand, their model can help a liner company design a ship-