Transportation Research Part B 82 (2015) 141–161

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Liner container seasonal shipping revenue management

Yadong Wang [a], Qiang Meng [a,*], Yuquan Du [b]

[a] Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576, Singapore
[b] Centre for Maritime Studies, National University of Singapore, Singapore 118414, Singapore

ARTICLE INFO

Article history:
Received 17 June 2015
Revised 28 September 2015
Accepted 15 October 2015
Available online 11 November 2015

Keywords:
Liner shipping
Bunker consumption
Revenue management
Mixed-integer nonlinear programming model
Global optimization
Branch and bound

ABSTRACT

This paper proposes a liner container seasonal shipping revenue management problem for a container shipping company. For a given weekly multi-type shipment demand pattern in a particular season, the proposed problem aims to maximize the total seasonal shipping profit by determining the number of multi-type containers to be transported and assigned on each container route, the number of containerships deployed on each ship route, and the sailing speed of containerships on each shipping leg subject to both the volume and capacity constraints of each containership. By adopting the realistic bunker consumption rate of a containership as a function of its sailing speed and payload (displacement), we develop a mixed-integer nonlinear programing with a nonconvex objective function for the proposed liner container seasonal shipping revenue management problem. A tailored branch and bound (B&B) method is designed to obtain the global ε-optimal solution of the model. Numerical experiments are finally conducted to assess the efficiency of the solution algorithm and to show the applicability of the developed model.

1. Introduction

Container shipping is the backbone of worldwide maritime freight transportation. UNCTAD (2012, 2014) reported that 52% of the sea cargos are containerized and the volume of total container trade is 160 million twenty-foot equivalent units (TEUs) in 2013. A container liner shipping company gains shipping revenue by transporting laden containers from their origin ports to destination ports over its shipping network with a fleet of containerships. The operating cost of the container liner shipping company in transporting containers with the fleet of containerships is mainly composed of two components: fixed cost and variable cost. Fixed cost refers to the maintenance cost, insurance, salaries of the crews, etc. This can be estimated as a constant per unit time e.g., one week, because a liner containership route has a fixed rotation of ports with a predetermined schedule to maintain its regular service frequency. Variable cost includes the container handling cost at ports and the containership bunker fuel consumption cost during voyage. The container handling cost is charged by port operators when loading, discharging and transshipping containers at a port, and it depends on the number of containers handled. The bunker fuel consumption cost of a containership is mainly determined by its sailing speed and its actual tonnage related to the number of containers on board during voyage.

Containers transported by container shipping company are classified into several categories according to their attributes including origin and destination ports, container usage (e.g., dry, refrigerated, open top, etc.), container size (e.g., 1 TEU, 1 FEU, Forty-feet Equilibrium Unit, etc.) and inside cargo characteristics (e.g., clothes, food, etc.). These attributes determines the freight

* Corresponding author. Tel.: +65 6516 5494; fax: +65 6779 1635.
E-mail address: ceemq@nus.edu.sg, dr.qiangmeng@gmail.com (Q. Meng).

http://dx.doi.org/10.1016/j.trb.2015.10.003
0191-2615/

rate charged by a container liner shipping company. Without loss of generality, containers transported from an origin port to a destination port are categorized into different types in accordance with the three attributes – freight rate, weight and size – which are referred to as the multi-type containers. In other words, containers from an original port to a destination port with the same freight rate, weight and size will be considered as one type.

Liner shipping operators usually plan their shipping service every 3–4 months (approximate seasonally) (Liu et al., 2011) under the assumption that the demand pattern between ports over a shipping network operated by a container liner shipping company does not change within a season. The containership fleet has a shipping capacity in terms of volume and weight because each containership is capacitated by its maximum volume in terms of TEUs and by its maximum weight in terms of metric tons (MTs). Given the multi-type container demand pattern for a particular season, the container liner shipping company has to simultaneously make the following three vital decisions for maximizing its seasonal profit: the container shipping revenue minus the operating cost. This is called the liner container seasonal revenue management problem in this paper.

(i) (*Multi-type container selection*) What is the number of containers of each type to be transported over the shipping network? Not all available multi-type containers can be transported due to the capacity of containerships when the container shipment demand exceeds the shipping capacity. As a profit maximizer, the container liner shipping company will only choose the most profitable multi-type containers to transport. "Profitable" here means that its marginal freight revenue is larger than the marginal cost incurred.
(ii) (*Multi-type container routing and assignment*) How do these multi-type containers flow over the different container routes in the whole shipping network, especially when transshipment is taken into account? The multi-type container routing and assignment affect not only the container handling cost at ports but also the containership bunker consumption cost during the voyages because the bunker consumption of a containership is a function of its sailing speed and the weight of containers carried.
(iii) (*Container ship speed optimization*) What is the sailing speed of a containership on each leg of its voyage? The sailing speed influences not only its bunker consumption cost but also the number of containerships required to maintain the regular shipping service frequency.

This study aims to develop an optimization model and design an effective solution algorithm for solving the tactical seasonal liner container revenue management problem. The three interrelated questions, i.e., multi-type container selection, container routing and assignment as well as container ship speed optimization, are jointly addressed in this paper, because they are intrinsically coupled together in practice. This paper thus serves as a useful guide to determine the tactical revenue management measures for liner shipping companies facing fierce competition in the liner shipping industry.

1.1. Literature review

Revenue management, since first raised more than 50 years ago, has been studied in many areas such as airlines (McGill and van Ryzin, 1999), media and broadcasting (Kimms and Müller-Bungart, 2006), healthcare services (Lieberman, 2004) and lodging and hospitality (Feng and Gallego, 1995; Bitran and Gilbert, 1996; Mauri, 2013). Among all of these studies, the study of airline revenue management draws a considerable amount of the attention. For example, many studies focus on "overbooking" strategy, which means selling more tickets in excess of the actual supply in order to avoid empty seats due to no-shows. Moreover, some studies investigate the seat inventory control and ticket pricing for airline seats with different classes. For a comprehensive review, the readers can refer to the work by McGill and van Ryzin (1999).

For the revenue management of container liner shipping, the earliest studies can be traced back to the works of Brooks and Button (1994) and Maragos (1994). Brooks and Button (1994) studied the possible application of revenue management on the freight pricing in liner shipping service and Maragos (1994) explored the dynamic ship capacity allocation and pricing in liner shipping. Currently, many studies on revenue management in liner shipping focus on the container slot allocation, i.e., assigning the available container slots of the containership fleet to the incoming container shipping demand, which is similar to seat inventory control in airlines. Ting and Tzeng (2004) proposed a conceptual model for liner shipping revenue management and a mathematical programming model for slot allocation to determine the optimal number of containers to transport for each origin-destination port pair. Lu et al. (2010) studied the slot allocation planning problem to satisfy the estimated seasonal demand in order to maximize the potential profit per round trip voyage for a liner shipping company. Zurheide and Fischer (2014) developed a bid-price strategy to handle container booking acceptance and slot allocation. In addition to container slot allocation, other topics regarding revenue management in liner shipping include freight rate pricing, container assignment and shipping network design. For example, by viewing freight transportation as newsvendor type products, Yin and Kim (2012) investigated the optimal freight rates with the consideration of quantity-based discount pricing to maximize the expected profit of a shipping company. Wang et al. (2015) jointly optimized the freight rate and the container assignment to maximize the total profit in a liner shipping network. Brouer et al. (2014) studied the liner shipping network design problem using a meta-heuristic method to maximize the revenue of cargo transport and minimize the operating cost over the network. However, currently many studies assume that all containers are exactly the same to simplify problem setting. They cannot analyze the effect of different container attributes (e.g., freight rate, weight, volume) on profitability of shipping companies. In reality, the shipping company transports some number of containers with a specific type but ignores others. Therefore, the multi-type container transportation strategy is worthwhile for investigation and will be covered in this study.