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Jointly optimizing ship sailing speed and bunker purchase in liner shipping with distribution-free stochastic bunker prices

Yadong Wang[a], Qiang Meng[a,*], Haibo Kuang[b]

[a] Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576, Singapore
[b] Transportation Management College, Dalian Maritime University, Dalian 116026, China

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ABSTRACT

This paper jointly designs the optimal ship sailing speeds on shipping voyages and the optimal amount of bunker fuel to purchase at each port of a shipping network operated by a container liner shipping company. Bunker prices at these ports are assumed to be correlated random variables. Considering the difficulties in calibrating these prices into specific joint probability distribution in practice, this study merely requires some fundamental descriptive statistics information of these bunker prices, including lower and upper bounds, means and covariances, which can be tangibly estimated from historical data. To solve this problem, a mixed integer programming model is first formulated for deterministic bunker prices to minimize the sum of ship operating cost and bunker consumption cost. This model is subsequently extended to incorporate stochastic bunker prices by developing a series of approximation techniques using the bunker price descriptive statistics information. A numerical example based on real-case price data of a liner shipping network from an international shipping company shows that the proposed model is able to simultaneously control the average bunker purchase cost as well as the risk resulting from the extremely high bunker prices.

1. Introduction

Container liner shipping plays a very important role in the maritime and global logistics system by transporting containerized cargos from origin ports to destination ports based on a series of shipping services according to fixed schedules. Bunker fuel is the main energy source for container ships. To sustain the liner shipping services, container ships have to purchase and refuel bunker at some port of calls on their round-trip voyages. The total bunker purchase cost incurred in the shipping network usually occupies a very large part of the total operating cost of a shipping company. Previous studies have revealed that the percentage of bunker purchase cost in the total operating cost of a container ship varies from 30% to more than 70% depending on bunker price (Notteboom and Vernimmen, 2009; Ronen, 2011). Therefore, it is a vital problem for the shipping companies to determine the bunker purchase amount at each port to control the total purchase cost in its shipping network. This problem is especially urgent nowadays when the liner shipping industry has extreme low profit margin and the majority of 20 largest liner shipping companies suffer losses (OECD, 2015).

The bunker purchase cost is mainly impacted by its sailing speed. It has been well accepted by academic researchers and industrial practitioners that the ship bunker consumption is proportional to the sailing speed with the power no less than two (e.g., Du et al., 2011; Norstad et al., 2011; Psaraftis and Kontovas, 2014; Wang et al., 2015). In this regard, shipping companies choose to adjust ship

* Corresponding author.
E-mail address: ceemq@nus.edu.sg (Q. Meng).

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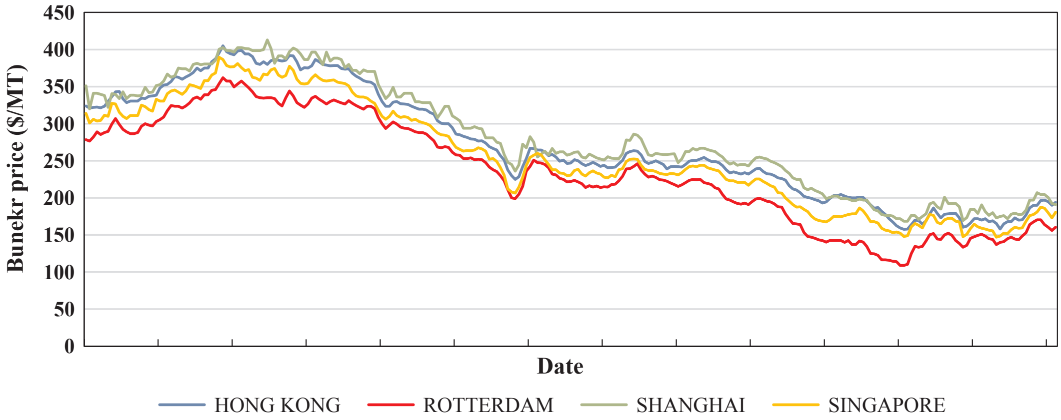

Fig. 1. Bunker price from 18/03/2015 to 19/03/2016..
Source: Ship and Bunker (2016)

sailing speed to reduce bunker consumption. For example, "slow steaming" is a strategy adopted by the liner shipping industry. However, sailing speed cannot be unlimitedly reduced. First, some container shipping demands are sensitive to shipping time, such as food and fashion clothes. Longer shipping time means higher inventory cost (Psaraftis and Kontovas, 2014), a lower level of service and less demand level from these kinds of goods. The second reason is that liner shipping companies usually maintain weekly service frequency for each port of call. Lower sailing speed indicates more ships deployed on this service, which increases the ship operating cost (Wang et al, 2013). Therefore, liner shipping companies should choose optimal sailing speed so as to balance its benefits and losses.

Another factor affecting the bunker purchase cost is bunker price. Historical data have revealed that the bunker price fluctuates significantly due to many factors such as the crude oil prices, the world GNP and the NYSE index, and can be considerably different on different bunkering ports (Stefanakos and Schinas, 2014). For example, Fig. 1 shows the variations of bunker prices at Hong Kong, Rotterdam, Shanghai and Singapore from March 18, 2015, to March 19, 2016, from the website Ship and Bunker (2016). On March 19, 2016, the bunker prices at ports Shanghai, Hong Kong, Singapore, and Rotterdam are $191, $194, $180.5, and $160.5 respectively. If a container ship sails through the route: Shanghai → Hong Kong → Singapore → Rotterdam → …, refilling more bunker at Rotterdam leads to lower total bunker purchase cost. At the same time, it can be seen that the bunker price at a specific port varies significantly between 100 $/MT and 400 $/MT during the one-year time. But it also seems that the bunker prices at different ports are interrelated as they have more or less the same tendency during the same time interval. Therefore, the bunker prices at these ports can be viewed as the correlated random variables. From the above analysis, in order to reduce the total bunker purchase cost, how to plan the refueling strategies under different but correlated uncertain bunker prices is a research issue worthwhile to be solved.

This study aims to solve a tactical level sailing speed and bunker purchase optimization (SSBPO) problem on how to jointly determine the optimal ship sailing speeds on the shipping voyages and the optimal amount of bunker to purchase at each port of a shipping network so as to minimize the bunker purchase cost. The fluctuating bunker prices at these ports are viewed as the correlated random variables, whose joint stochastic distribution is generally hard to obtain from historical data in a large number of ports in the network. Hence, a tangible method is developed to solve this problem which only requires some fundamental descriptive statistics information on these prices, including upper and lower bounds, means and covariances, which can be easily estimated from historical data. This method thus gives the "distribution-free" optimal solutions as it does not rely on any specific distribution of the random variables. This method is more general for application than simply optimizing a pre-assumed distribution.

It should be noted that the proposed SSBPO problem benefits the liner shipping operations in the following aspects. First, for the operational level, the SSBPO gives a good reference for the ship operators to determine the ship sailing speed in shipping legs and the amount of bunker to refuel at each port considering the fluctuating and port-specific bunker prices. By choosing a proper value of the input parameter ε for our model (whose definition is given in Section 3), it is able to give a good balance between the expected bunker purchase cost and the adverse effect (e.g. the purchase risk) of the bunker price fluctuations on bunker purchase cost stability. Second, for the tactical level, the SSBPO problem can be used to plan the medium-term and long-term bunker purchase at each port.

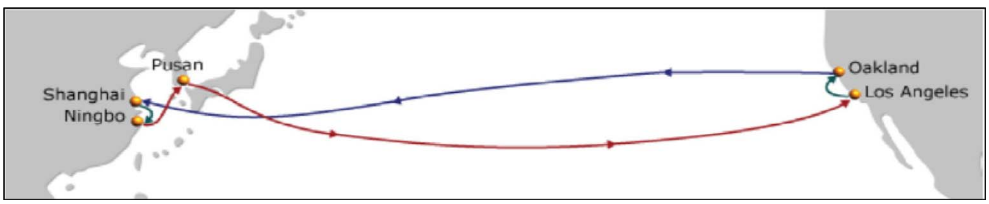

Fig. 2. CKYH Alliance CALCO-M service (Song and Dong, 2013).