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Risk management in liner ship fleet deployment: A joint chance constrained programming model

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ABSTRACT

This paper provides a tangible methodology to deal with the liner ship fleet deployment problem aiming at minimizing the total cost while maintaining a service level under uncertain container demand. The problem is first formulated as a joint chance constrained programming model, and the sample average approximation method and mixed-integer programming are used to deal with it. Finally, a numerical example of a liner shipping network is carried out to verify the applicability of the proposed model and solution algorithm. It is found that the service level has significant effect on the total cost.

1. Introduction

Liner shipping involves picking up and delivering containers on regularly scheduled shipping routes. Due to its regular and reliable service, liner shipping occupies a dominant proportion of the global shipping market share with 60% of cargoes by value (Stopford, 2009) and 70% of containers by volume in terms of TEUs (Twenty-foot Equivalent Units) (UNCTAD, 2011). Consequently, liner shipping is of considerable significance for shipping industry and attracts the attention of researchers in the recent years (see Meng et al., in press). As the liner shipping market is intensely competitive, a liner container shipping company has to provide efficient shipping service for shippers with the aim of survival and development. Therefore, the liner ship fleet deployment (LSFD) problem that addresses assignment of types and numbers of ships to each shipping route at lowest operating cost in order to effectively utilize and manage these assets (i.e. ships) is highly concerned about by the liner container shipping companies, which is also the issue of this paper intends to study.

Container shipment demand between any two ports of call is an essential input of the LSFD problems. Before the actual container demand is realized, decisions of types and numbers of ships assigned to shipping routes have to be made using the forecasted or estimated container demand. However, some uncontrollable and unpredicted factors such as the cancellation of a shipping contract or the delay in arrival of containers at the port, do exist in practice. As a result, it is almost impossible that the estimated container demand matches the realistic demand precisely. Whatever overestimate or underestimate of the demand, it will lead to a loss for a liner container shipping company. The potential of uncontrollable and unpredicted factors that would result in uncertainty of container shipment demand is referred to as a risk faced by the liner container shipping companies in this paper. It should be pointed out that the issue of risk of uncertain container shipment demand

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in the LSFP problems has not been fully examined in the literature (Ronen, 1983, 1993; Christiansen et al., 2004, 2007). Consequently, there is a need to take the risk of uncertain container demand into account in the LSFD problem.

In practice, the container shipment demand often varies from season to season, and hence the liner container shipping companies have to alter their service routes and redeploy ships season by season. Therefore, the planning horizon for the LSFD problem studied in this paper is specified over a short-term planning horizon (3–6 months). We summarize that this paper aims to study a LSFD problem by taking into account container shipment demand uncertainty over a short-term planning horizon.

1.1. Literature review

Perakis and Jaramillo (1991) made the first step to develop a linear programming model for a LSFD problem although they unrealistically assumed that the decision variables of number of ships allocated to a shipping route are continuous rather than integers. Later, the same two authors thus built an integer linear programming model (Jaramillo and Perakis, 1991). By introducing generalized incidence matrices, Cho and Perakis (1996) simplified the expression of mathematical optimization models for LSFD problems in a matrix form. Powell and Perakis (1997) extended the model of Jaramillo and Perakis (1991) by adding the ship lay-up costs to the objective function. Building on their work, Gelareh and Meng (2010) involved ship speed optimization and proposed a nonlinear programming model to determine the optimal ship sailing speed. While this nonlinear programming model can be approximated as a mixed-integer linear programming model, the formulation was further improved by Wang et al. (2011). Meng and Wang (2011) examined a multi-period liner ship fleet planning and deployment problem with known container demand in each period. Wang and Meng (2012a) investigated the ship fleet deployment problem with weekly demand and transshipment at any port, and this problem was extended by adding transit time constraints (Meng and Wang, 2012).

It is noted that none of the research reviewed above captures the uncertainty of container demand in LSFD problems. Bell et al. (2011), Wang and Meng (2012b) and Qi and Song (2012) have incorporated the uncertainty in the liner service schedules but not investigated the demand uncertainty. To handle demand uncertainty, Meng and Wang (2010) proposed a chance constrained programming approach by which a deterministic LSFD problem was extended to account for the uncertainties. However, the model proposed in this study is based on the assumption that demand of all port pairs are independent and follow normal distribution without verification and assumed that all ships have to be emptied at the start of each sailing voyage, which is not consistent with practice. Some other studies focus on risk analysis of currency fluctuation to liner shipping industry (Menachof, 1996), fuel price fluctuation to shipper (Menachof and Dicer, 2001), default risk in charter market (Adland and Jia, 2008) and environmental regulation and options for marine operators (Schinas and Stefanakos, 2012). Therefore, through the research reviewed above, we can find that the proposed LSFD problem with uncertain container demand is deserved to be made effort to.

1.2. Objective and contribution

The above literature review clearly indicates that the LSFD problem involving container demand uncertainty remains a new research issue with practical significance. The research of this paper focuses on this issue and proposes a joint chance constrained programming (JCCP) model to cope with it. As chance constraints with probability functions in the JCCP model have no closed form, the JCCP model is quite difficult to evaluate. The sample average approximation (SAA) approach is thus used to approximate the JCCP model in this study.

The contribution of this paper is fourfold: First, it contributes to the literature by proposing a realistic LSFD problem with uncertain container demand, which is highly concerned about by the liner container shipping companies, especially given the prevailing volatilities in the business environment with constantly shifting. Second, the proposed LSFD problem is an extension to the study of Meng and Wang (2010) and formulated as a JCCP model. It has to be pointed out that the methodology developed by Meng and Wang (2010) is restricted by a special assumption without verification that the container shipment demand of all port pairs are independent normally distributed and by the definition of the level of service for each liner service route, this study is without such a restriction and examines the container demand uncertainty by enforcing a level of service at the network level. This modeling approach not only nests the model of Meng and Wang (2010) as a special case, but also is more practical and relevant as it provides a liner shipping company service information regarding the whole network. Third, an appropriate solution algorithm is proposed to solve the JCCP model. The solution algorithm to solve the model proposed by Meng and Wang (2010) is only feasible under such strong assumptions that the uncertain demands follow normal distributions and the level of service is define for each liner route, as for the LSFP problem proposed in this study, it cannot be applied. We successfully apply a sample average approximation approach to deal with this problem. Fourth, the methodology of model development and solution algorithm design could be also applied to other similar problems under uncertain environment, such as air transportation planning problem with uncertain demand.

The remainder of this paper is organized as follows: Section 2 elaborates the LSFD problem with uncertain container demand. Section 3 develops a JCCP model for the proposed LSFD problem. Section 4 addresses the difficulties in solving the JCCP model and proposes the SAA approach to handle these difficulties. Section 5 uses a numerical example to evaluate the model and solution algorithm proposed in this study. Finally, Section 6 concludes the study and provides recommendations for future work.