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# Fleet deployment in liner shipping with incomplete demand information

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ABSTRACT

This paper examines the liner fleet deployment problem when only conditional shipping demand information is known. For such a case, it is generally not possible to determine the exact optimal solution. A set of complementary upper and lower bounds on the optimal cost are derived by exploiting the problem structure. These bounds are explicitly shown to converge to the optimal cost when a sufficiently refined partition is available. A numerical example illustrates the model.

## 1. Introduction

The liner fleet deployment problem seeks to maximize profits when deciding on the number and types of ships to be deployed on the various trade routes. This problem was first examined in the seminal work by Perakis and Jaramillo (1991) and Jaramillo and Perakis (1991) who formulated (integer) linear programming models for this planning problem, assuming known shipping demand. Although ignoring uncertainty has long been known to impact decision making in transportation (e.g. Waller et al., 2001), only until 2010, did the first liner shipping studies appear in which shipping demand was considered stochastic (Meng and Wang, 2010), with the common motivation being that otherwise sub-optimal decisions can be made (Ng, 2015). Other work in the liner shipping literature examined the (deterministic) fleet deployment problem in conjunction with other decision problems, including the liner network design problem, the maritime fleet size and mix problem and sailing speed optimization, (e.g. see Álvarez, 2012, Brouer et al., 2013; Plum et al., 2013; Mulder and Dekker, 2014; Pantuso et al., 2014; Andersson et al., 2015; Huang et al., 2015). For a review of publications in the liner fleet deployment literature (and other related studies in liner shipping), the reader is referred to Meng et al. (2013).

This research builds on the class of liner fleet deployment models proposed by Meng and Wang (2010), who assumed that complete probability distributions are available to characterize shipping demand. Ng (2014, 2015) later relaxed this assumption and assumed that only a subset of the information was known, such as the support and moments of the distribution. However, with such limited information, the solution might become more conservative than one desires. *The key contribution in this paper is the presentation of an "intermediate solution method" that requires conditional demand information, together with a partition of the sample space and their probabilities.* The algorithm is rigorously shown to converge to the optimal solution when a sufficiently fine partition is available.

The remainder of this paper is organized as follows. In Section 2, a variation of an existing liner fleet deployment model will be presented. The model is then analyzed in detail in Section 3 for the case that only limited distributional information is known, culminating in a set of complementary lower and upper bounds that are explicitly shown to converge to the optimal solution. A

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numerical example illustrates the proposed model in Section 4. Finally, Section 5 concludes the paper.

## 2. Liner fleet deployment model

Consider the following variation of a liner fleet deployment model (Meng et al., 2012; Ng, 2014). The key contribution in this paper will be how this model can be solved, when only limited distributional information is known (cf. Section 3)

*Sets*

$R$ set of routes
$K$ set of ship types

*Parameters*

$c^v_{kr}$ the operating cost for a complete voyage of a ship of type $k \in K$ on route $r \in R$
$c^i_k$ the cost of chartering in a ship of type $k \in K$
$c^o_k$ the revenue of chartering out a ship of type $k \in K$
$D_r$ the maximum shipping demand among the legs on route $r \in R$
$g_r$ the penalty per TEU on route $r \in R$ incurred by the shipping line when it is not able to transport the container within the planning horizon (e.g. due to a loss of profit, or loss of goodwill among shippers)
$h$ the planning horizon (in days)
$l_k$ the number of ships of type $k \in K$ available in the ocean carrier's own fleet
$m_k$ the maximum number of ships of type $k \in K$ that can be chartered from other ship owners
$M_k$ a sufficiently large number, e.g. $l_k + m_k$, $k \in K$
$n_r$ the number of times a port on route $r \in R$ needs to be visited to maintain the desired service frequency
$q_k$ the capacity of a ship of type $k \in K$ (in TEU)
$t_{kr}$ the transit time of a ship of type $k \in K$ traversing route$r \in R$(in days)

*Decision variables*

$u_{kr}$ the total number of ships of type $k \in K$to be deployed on route $r \in R$
$v_k$ the number of ships of type $k \in K$to be chartered from other ship owners
$w_k$ the number of ships of type $k \in K$to be chartered out
$x_{kr}$ the number of times a port on route $r$ is visited by a ship of type $k$ within the planning horizon
$y_{kr}$ equals 1 if vessels of type $k \in K$ are deployed on route $r \in R$, 0 otherwise.

Model (D)

$$\min \sum_k \sum_r c^v_{kr} x_{kr} + \sum_k c^i_k v_k - \sum_k c^o_k w_k + E\left[\sum_{r\in R} g_r \left(D_r - \sum_k x_{kr} q_k\right)^+\right] \tag{1}$$

subject to:

$$\sum_r u_{kr} \le l_k + v_k, \quad \forall\, k \in K \tag{2}$$

$$v_k \le m_k, \quad \forall\, k \in K \tag{3}$$

$$w_k = l_k + v_k - \sum_r u_{kr}, \quad \forall\, k \in K \tag{4}$$

$$x_{kr} \le u_{kr} h / t_{kr}, \quad \forall\, k \in K, \forall\, r \in R \tag{5}$$

$$\sum_k x_{kr} = n_r, \quad \forall\, r \in R \tag{6}$$

$$u_{kr} \le M_k y_{kr}, \forall\, k \in K, \quad \forall\, r \in R \tag{7}$$

$$\sum_k y_{kr} = 1, \quad \forall\, r \in R \tag{8}$$

$$v_k, w_k \ge 0, \forall\, k \in K, \quad \forall\, r \in R \tag{9}$$

$$u_{kr}, x_{kr} \ge 0 \text{ and integer}, \ \forall\, k \in K, \quad \forall\, r \in R \tag{10}$$

$$y_{kr} \in \{0, 1\}, \ \forall\, k \in K, \quad \forall\, r \in R \tag{11}$$

The objective function (1) states the goal is to minimize the total cost, which includes the operating cost, the cost of chartering ships, the revenue from chartering ships out and the expected capacity shortage cost, where we have used $E[\cdot]$ and $(\cdot)^+$ to denote the expected value of a random variable, and the positive part of a real number, respectively. Constraint (2) ensures that the total number

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