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A stochastic programming formulation for strategic fleet renewal in shipping

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ABSTRACT

Shipping companies repeatedly face the problem of adjusting their vessel fleet to meet uncertain future transportation demands and compensating for aging vessels. In this paper, a new multi-stage stochastic programming formulation for strategic fleet renewal in shipping is proposed. The new formulation explicitly handles uncertainty in parameters such as future demand, freight rates and vessel prices. Extensive computational tests are performed, comparing different discretizations of the uncertain variables and different lengths of the planning horizon. It is shown that significantly better results are obtained when considering the uncertainty of future parameters, compared to using expected values.

1. Introduction

Building a new ship can cost more than 200 million USD and capital expenses may account for 80% of the cost of running a shipping company with a fleet of modern vessels (Stopford, 2009, p. 269). For running a ten-year old ship the capital cost may still account for more than 40% of the total running costs (Stopford, 2009, p. 225), see Table 1. Having an unnecessarily large vessel fleet can thus be very expensive. On the other hand, too low capacity may imply that the shipping company cannot meet its obligations or that it has to use expensive charter options. It is therefore an important task for shipping companies to continually adjust their fleet composition to meet future transportation requirements.

Shipping companies also regularly make adjustments to their fleet due to aging vessels. When vessels reach a certain age they will become unprofitable to operate, due to increased risk of break-downs and increased maintenance and operation costs. Furthermore, vessels with new technology that improves fuel and cost efficiency may become available. Decisions about which fleet adjustments to make are usually considered regularly, typically once a year, following a thorough decision process. The decisions are often made with respect to forecasts that estimate future values of the main uncertain parameters, such as demands and prices. However, the shipping industry is among the most volatile businesses, with fluctuations in parameters that are difficult to predict. Even over just a few years, uncertainty in demands, costs and revenues related to the fleet operation is high. As an example, the capital valuation of a vessel may vary by a factor of three over only 2 years (Stopford, 2009).

In general, problems that deal with determining the size and composition of a fleet are often referred to as *fleet size and mix problems* (FSMP). In cases with only one vessel type, the problem becomes a *fleet size problem*. For land-based

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transportation problems there exists a significant amount of published work, see the review by Hoff et al. (2010). For several reasons, FSMPs for the land-based context are not directly transferable to the *maritime FSMP* (MFSMP). First, investments and thus capital costs are higher for maritime problems than for land-based problems. Second, the lifetime of a ship (typically 20–30 years) is much longer than for trucks, and thus uncertainty over the lifetime of ships are greater than for trucks. Third, ships are often more industry specific, implying that investments are sometimes irreversible and that the market for second-hand vessels is not as liquid as the one for trucks. Fourth, the valuation of ships is more complicated than that of trucks. The value of a truck is often assumed to be strictly decreasing with age, while for ships there are additional factors that affect the value. Adland and Koekebakker (2007) use age and the state of the freight market to determine the value of a ship. Fifth, there are different operational challenges between maritime and land-based FSMPs, see for example the discussion by Christiansen et al. (2013).

The literature on the MFSMP is scarce. However, since the first known work within the topic (Dantzig and Fulkerson, 1954), there have been some specific studies from which to draw information, especially during recent years. Even so, more research is still required. First of all, there exists only a limited number of publications on FSMP for any transportation mode that considers uncertainty (Verderame et al., 2010). Furthermore, even within deterministic approaches to the MFSMP there are knowledge gaps. A recent literature study by Pantuso et al. (2014) surveys the literature regarding the MFSMP. One of the conclusions is that, in addition to the lack of studies treating uncertainty, most research studies consider the design of a brand new fleet to transport a given demand, see for example Jaikumar and Solomon (1987) and Zeng and Yang (2007). This is in contrast to the more common case in the industry where an initial fleet must be adjusted over time, which calls for a time-staged modeling approach. Such an approach must take into account possible changes in demand over time and the timing of the fleet alterations, in addition to the uncertainty factors.

A recent contribution to the literature on MFSMP is by Meng and Wang (2011), which proposed a time-staged model with an initial fleet for the MFSMP in liner shipping. A limited number of possible fleet configurations is considered for each time period, and the problem is solved by using dynamic programming. The possible fleet configurations that meet the expected transportation demand should be provided by the shipping company's experts. However, the proposed model does not take into account uncertainty in the demand forecast. Meng et al. (2014) also base their solution method for the fleet planning problem of liner container shipping on a limited number of fleet configurations made by company experts, but include uncertainty in demand as part of the deployment considerations. The demand is assumed to be dependent on that of the previous period. Which ship is deployed at which route is, together with the number of voyages and amount of lay-up, determined before the actual demand is revealed. Then the amount of cargo carried is determined after demand is revealed. Within airline fleet composition, Listes and Dekker (2005) show the importance of accounting for uncertainty when determining a robust airline fleet composition. The airline mode is the mode most like the international shipping mode in terms of investment costs, but meets different operational challenges. Another contribution on the MFSMP is by Alvarez et al. (2011), who proposed a mixed integer programming (MIP) model of the multi-period fleet sizing and deployment problem in bulk shipping. They extend the MIP model into a robust optimization model to account for uncertainty in purchase prices, sale prices, sunset values, and charter rates. Uncertainty in demand is not considered within the model.

A decision support methodology for strategic planning in tramp and industrial shipping was presented by Fagerholt et al. (2010). This proposed methodology combines simulation and optimization by building a Monte Carlo simulation framework around an optimization-based decision support system for short-term routing and scheduling. The simulation proceeds by considering a series of short-term routing and scheduling problems using a rolling horizon principle where information is revealed as time goes by. The uncertainty of the parameters is then treated within the simulation. The approach can easily be configured to provide decision support for a wide range of strategic planning problems, such as fleet size and mix problems, analysis of long-term contracts, and contract terms. However, as with Meng and Wang (2011), the approach is not efficient in cases where there is a large number of alternative fleet configurations to evaluate. It can therefore only be used as an evaluation tool for a limited number of fleet composition scenarios.

For a comprehensive literature review on FSMP in general, we refer to Hoff et al. (2010), while we refer to Pantuso et al. (2014) for a survey on specific maritime cases. For a recent literature review on planning and scheduling under uncertainty across multiple sectors readers are referred to Verderame et al. (2010).

In contrast to the majority of literature on MFSMP, in most practical situations there already exists an initial fleet. The problem then becomes how and when to make long-term alterations to the vessel fleet, rather than determining the optimal fleet given no starting position. To emphasize the difference in these problem structures, we name the problems that require an initial fleet the *strategic fleet renewal problem in shipping* (SFRPS). The objective of the SFRPS is to minimize the expected long-run cost of serving the company's demand, by doing the best adjustments of the vessel fleet.

Table 1
Rough guide to the cost structure of a 10-year-old Capesize bulk carrier (Stopford, 2009).

Operating costs	14%
Periodic maintenance	4%
Voyage costs	40%
Capital costs	42%