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Speed optimization and bunkering in liner shipping in the presence of uncertain service times and time windows at ports

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ABSTRACT

Recent studies in maritime shipping have concentrated on environmental and economic impacts of ships. In this regard, fuel is considered as one of the important factors for such impacts. In particular, the sailing speed of the vessels affects the fuel consumption directly. In this study, we consider a speed optimization problem in liner shipping, which is characterized by stochastic port times and time windows. The objective is to minimize the total fuel consumption while maintaining the schedule reliability. We develop a dynamic programing model by discretizing the port arrival times to provide approximate solutions. A deterministic model is presented to provide a lower bound on the optimal expected cost of the dynamic model. We also work on the effect of bunker prices on the liner service schedule. We propose a dynamic programing model for bunkering problem. Our numerical study using real data from a European liner shipping company indicates that the speed policy obtained by proposed dynamic model performs significantly better than the ones obtained by benchmark methods. Moreover, our results show that making speed decisions considering the uncertainty of port times will noticeably decrease fuel consumption cost.

1. Introduction

Sailing speed is an important decision variable affecting fuel consumption and consequently, greenhouse gas emission. Many operational strategies in container shipping have focused on reducing fuel costs (Christiansen, Fagerholt, Nygreen, & Ronen, 2013). For instance, Maersk, one of the major liner shipping company, introduced slow steaming strategy in 2008 to cope with the increasing bunker price. Although sailing with the slowest speed is favorable with respect to the fuel cost and greenhouse gas emissions, it may not be always feasible due to the uncertainties in sea transport legs and the ports that may affect service level agreement with customers. Sailing speed decision at sea transport legs mainly depends on the port time windows and the transit time between ports. Therefore, it is natural to expect that the speed decision should be made by considering both the time windows and the uncertain port service times.

Stochastic port service time and travel time play important roles on the total cruise time of vessels. Port and travel times can be highly variable due to congestion, handling and weather conditions (Notteboom, 2006). Congestion or disruption in a port may result in deviation from the planned schedule and hence, it may cause delays at the following ports along the route. Vernimmen, Dullaert, and Engelen (2007) state that only about 52% of the vessels dispatched for liner services arrived at the planned schedule. Drewry (2016) presents a detailed reliability report by trade and reports that the average percentage of on-time delivery ranges from 55% to 89%. Notteboom (2006) reports that 93.6% of the delays are caused by disruptions in port and terminal operations. citeLee15 state that container handling capacity at ports becomes insufficient for the growth in the container transport demand and the variability in port times is a vital problem for liner operators. To prevent the delays and maintain schedule reliability, vessels may increase their speeds, which in turn increases the total fuel consumption and greenhouse gas emission. In some cases like unforeseen delay in a port, vessels may not reach the next port on time even if they sail at maximum speed. To avoid poor service level and meet the planned schedule on time, uncertain port times should be considered in speed decision. Despite this expectation, numerous studies in the literature do not consider the uncertainties in liner shipping. Psaraftis and Kontovas (2013) provide a detailed review of speed models in maritime transportation and reveal that only few studies consider the uncertainties in liner

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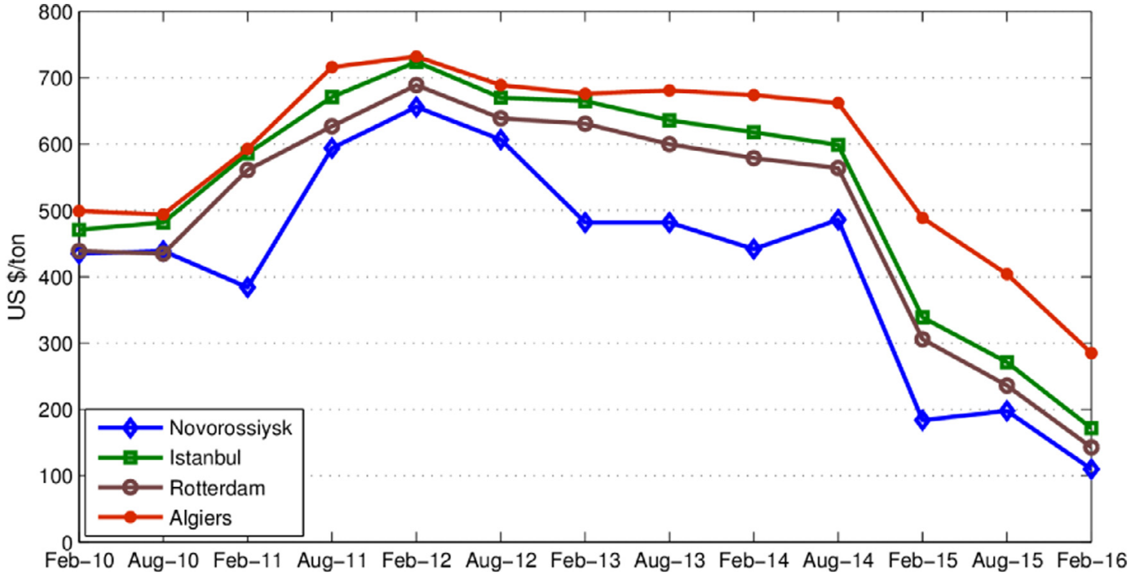

Fig. 1. Bunker fuel prices (IFO380) at various ports (source: bunkerindex.com).

shipping. In this paper, we focus on speed optimization problem with stochastic port times. We develop new models to optimize sailing speed for liner shipping.

Another important factor that affects ship liners' operating cost is bunker price. Since fuel cost constitutes a major portion of operational cost of a container ship, shipping companies focus on efficient ways to reduce bunker cost (Ronen, 2011). Through private conversation with a major liner company in the Mediterranean, it was realized that liner operators can make long term or short term contracts with the fuel suppliers. Long term contract is generally set for a year and during this period, fuel price has been fixed for the contracted amount. Liner operators who want to avoid the risks of fluctuating bunker price, prefer long term contracts. On the other hand, short term contracts are made approximately ten days before the liner service starts. The contract specifies the bunkering ports, price and quantity. Short term contracts are preferred in short-haul routes like those in the Mediterranean. Fig. 1 shows the monthly average fuel price at several bunkering ports in the Mediterranean and the Black Sea area from 2010 to 2016. As it is seen in this figure, bunker prices at different ports have significant differences. For instance, in February 2015, the average monthly prices in Novorossiysk and Algiers were 184 dollars and 489 dollars per metric ton. Bunkering ports significantly affect the total fuel cost of a liner service. Therefore, bunkering port selection is an important decision. In this paper, we also consider bunkering port selection strategy. In particular, we focus on short term bunkering contracts and study the decisions regarding where to bunker and how much to bunker? Bunkering decision is directly related to fuel consumption and affects the sailing speed. For instance, to avoid high fuel costs liner companies prefer slow steaming strategy (Maloni, Paul, & Gligor, 2013). Therefore, sailing speed and bunkering decisions are interrelated. In this paper, we study the joint speed and bunkering problem.

We make the following research contributions in this paper. First, we present a new dynamic programing formulation for the fuel consumption problem in liner shipping that can handle random port times. Our model takes into account future possible port service times in assessing the current speed decision. The objective is to optimize sailing speed along the route to minimize fuel consumption cost and the cost of delays by considering port time windows. We use the term "time window" to describe the reserved time period that a port allocates to serve the vessel. In our study, we assume that ports report the available time windows and then, the vessel determines the arrival times according to these given windows (Meng, Wang, Andersson, & Thun, 2014). The literature addressing the uncertainties at ports is limited. The proposed studies generally utilize heuristical approaches due to the difficulty in solving the stochastic problem and these approaches do not guarantee the global optimality unless the objective function has a special structure. Second, we examine the properties of the proposed dynamic model and provide some theoretical results regarding the optimal speed decision and port arrival time. Third, we work on the deterministic model formulation and we show that this model provides a lower bound on the optimal expected cost. Consequently, by using the discretized dynamic model and deterministic model, we can provide an upper bound on the optimality gap. Fourth, we develop a new model for bunkering problem. In particular, we work on where to bunker and how much to bunker decisions in short-term contracts. Different than the proposed bunkering studies in the literature, we allow liner vessel to bunker at the ports which are not on the planned route schedule. Finally, we perform a computational study by using real shipping data from a liner company. Our experiments are motivated by the fact that the liner shipping industry is interested in what-if scenarios, and this observation leads us to evaluate the impacts of problem parameters on speed and bunkering decision, fuel consumption and service level.

The rest of the paper is organized as follows. In Section 2, we provide an overview of the related literature. In Section 3, we develop a dynamic programing formulation of the speed optimization problem for liner shipping. Section 4 presents a deterministic approximation to the dynamic model that provides a lower bound on the optimal total expected cost. In Section 5, we extend the dynamic programing formulation by considering bunkering problem. In Section 6, we present our computational study. We conclude and discuss some future research directions in Section 7.

2. Review of related literature

There is an extensive literature on ship routing and scheduling problems in maritime transportation. For a comprehensive review of this area, we refer to Psaraftis and Kontovas (2013), Christiansen et al. (2013) and Meng et al. (2014). These review studies demonstrate that recent trend in maritime transportation have focused on sailing speeds and environmental impact of ships.