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ScienceDirect

Transportation Research Procedia 25 (2017) 251–260

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

Multi-objective optimization for a liner shipping service from different perspectives

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Abstract

This paper considers the optimization problem for the ship deployment, the planned sailing speed, and the service scheduling in a liner shipping route with both sea and port uncertainties taking multiple objectives from different perspectives. The main purposes are three-folds: first, defining key performance indicators (KPI) in liner shipping service design problem from different stakeholders' perspectives; second, investigating the relationships between the identified KPIs and their impact on the optimal solutions; third, evaluating the impact of different speed strategies on the KPIs and the optimal solutions.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Liner shipping; service reliability; uncertainty; multi-objective genetic algorithms.

1. Introduction

Liner shipping provides container transportation service following a fixed port rotation on a regular basis (mostly weekly frequency). A service schedule is often published several months in advance. Due to various uncertainties in the shipping operations at sea and ports, it has been an on-going issue that vessels often arrive at a port out of the scheduled time window. It was reported that vessel arrival reliability against published schedules can be as low as 50% for many service routes (Notteboom 2006; Vernimmen et al. 2007). Recent report revealed that only 49% and 55% of ships in the three key East-West trades arrived within 24 hours of the advertised estimated arrival times in January and February 2015 respectively (Drewry 2015). Associated with the service scheduling decision, ocean carriers have to determine the number of ships to be deployed in the given service route and the planned sailing

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2352-1465
Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.
10.1016/j.trpro.2017.05.392

speed for the vessels in the route. The above three types of tactical decisions are closely related and required to be coordinated in order to operate the service route efficiently and effectively.

Three types of criteria have been used in the literature to optimize shipping service route design. The first is the operational cost (cf. Meng et al. 2014 and the references therein); the second is the service reliability (Lee et al. 2015); and the third is the carbon emissions (c.f. Psaraftis and Kontovas 2013 and the references therein). The importance of the above three criteria is obvious in service route design. It is noted that the majority of the extant studies focused on a single criterion. Only recently, Mansouri et al. (2015) examined the potential of multi-objective optimization as a decision support tool to achieve the trade-off between environmental objectives and economic objectives in maritime shipping; and Song et al. (2015) analyzed the conflicting and/or compatible relationships between three objectives: cost, reliability, and emission. A multi-objective method is used to optimize three objectives simultaneously in the situations with uncertain port time. They demonstrated that the best solutions under the emission criterion are often included either in the best cost solutions or in the best reliability solutions. For that reason, we will focus on the cost and the reliability criteria.

Note that container shipping is a supply chain process, which is highly associated with a number of stakeholders in the chain, e.g. ocean carrier, shipper, freight forward, and port/terminal operator. Therefore, a given criterion can be measured quite differently by taking different stakeholders' perspectives. For example, the cost from ocean carrier's perspective is significantly different from shipper's perspective. The former usually does not include the in-transit inventory cost, whereas the latter has to consider the inventory cost as it is a major component in its total logistics cost. The schedule reliability may be measured by the probability of on-time arrivals, or by the average amount of delays, or by the standard deviation of the vessel arrival variation (here the variation is defined as the difference between the actual arrival and the planned arrival). The probability of on-time arrival is the most frequently used measure by ocean carriers, consultancy companies and public databases (e.g. Drewry, SeaIntel, Alphaliner). The amount of delays and the standard deviation of arrival variation are probably of more interest to shippers and terminal operators, because they are closely related to the shippers' safety stock level and the terminals' berth allocation plan. For example, some container ports such as Dalian Port in China have an 8 hours buffer time in the berth allocation plan, which means if the amount of vessel delay is less than 8 hours, it won't affect the terminal's berth allocation plan for the next vessel. However, little literature has considered the shipping performance criteria from different stakeholders' perspectives, particularly in the aspect of service reliability. Therefore, there is a need to examine how different key performance indicators (KPI) would influence the optimal solutions to the service schedule design problem.

In addition, ocean carrier's operational speed strategy may impact on the tactical decisions of the service design. For example, some ocean carriers adopt a flexible speed strategy, under which the carrier is willing to increase the vessel sailing speed to a certain level in order to catch up the delays, whereas others may adopt a constant speed strategy, under which the carrier is able to manage and predict the fuel consumption easily. A few studies have considered the flexible sailing speed in the tactical planning context (e.g. Wang and Meng 2012a, 2012b; Qi and Song 2012). However, no studies have explicitly examined the impact of different speed strategies on the tactical service design.

This paper attempts to fill the above research gaps. We aim to tackle the optimization problem for the ship deployment, the planned sailing speed, and the service scheduling in a liner shipping route with both sea and port uncertainties taking multiple objectives from different perspectives. The main purposes are: (i) to define key performance indicators (KPI) in liner shipping service design from different perspectives; (ii) to investigate the relationships between different KPIs and their impact on the optimal solutions, (iii) to evaluate the impact of different speed strategies on the KPIs and the optimal solutions.

2. System description

Consider a specific service route with weekly service frequency. Assume the same type of vessels (e.g. the same size) is deployed in the service route. The decision variables include: the number of deployed vessels, the planned sailing speed, and the planned arrival times at each port-of-call. If a constant speed strategy is adopted, the planned speed will be used as the actual sailing speed. If a flexible sailing speed strategy is adopted, then the planned sailing speed is used as the operational maximum speed that the ship operator is willing to sail at, where the actual sailing