Transportation Research Part B 93 (2016) 762–788

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Real-time schedule recovery in liner shipping service with regular uncertainties and disruption events

Chen Li[a], Xiangtong Qi[a,*], Dongping Song[b]

[a] Department of Industrial Engineering and Logistics Management, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
[b] School of Management, University of Liverpool, Chatham Street, Liverpool, L69 7ZH, United Kingdom

ARTICLE INFO

Article history:
Received 11 December 2014
Revised 14 October 2015
Accepted 15 October 2015
Available online 10 November 2015

Keywords:
Liner shipping
Real-time control
Uncertainty
Disruption

ABSTRACT

This paper studies real-time schedule recovery policies for liner shipping under various regular uncertainties and the emerging disruption event that may delay a vessel from its planned schedule. The aim is to recover the affected schedule in the most efficient way. One important contribution of this work is to explicitly distinguish two types of uncertainties in liner shipping, and propose different strategies to handle them. The problem can be formulated as a multi-stage stochastic control problem that minimizes the total expected fuel cost and delay penalty. For regular uncertainties that can be characterized by appropriate probabilistic models, we develop the properties of the optimal control policy; then we show how an emerging disruption may change the control policies. Numerical studies demonstrate the advantages of real-time schedule recovery policies against some typical alternatives.

1. Introduction

Container shipping has experienced a rapid growth in the last two decades and is now moving over 90% of manufactured goods in the world trade. Shipping lines provide container transportation service following a fixed port rotation on a regular basis (mostly weekly). The service schedule is often published several months in advance. In an ideal situation container vessels should arrive at ports on time following the published timetable. However, this is often not possible due to various uncertain factors during transportation.

We may classify the uncertainties in container transportation into two categories. The first refers to recurring and regular uncertainties such as port congestion (before berthing or before handling), variable terminal productivity, and unexpected waiting time in port channel access (Notteboom 2006). This type of uncertainties occurs frequently such that it is possible to use probabilistic models to characterize its realization and the degree of the uncertainty. The second refers to rare or one-off eventful uncertainties such as bad weather and labor strikes, which can be termed as disruption events (see Brouer et al. 2013 in liner shipping, Yu and Qi 2004 in other areas). This type of uncertainties occurs occasionally and irregularly, but it may become partially known some time before its occurrence. Although this type of uncertainties is rare for a specific vessel at a specific location, the occurrence of such disruption events in the world is not unusual due to the large number of container vessels and their global geographical coverage. For example, the following disruption events are extracted from the newsletters in Lloyd's List:

* Corresponding author. Tel.: +852 2358 8231.
E-mail addresses: cliad@connect.ust.hk (C. Li), ieemqi@ust.hk (X. Qi), Dongping.song@liverpool.ac.uk (D. Song).

http://dx.doi.org/10.1016/j.trb.2015.10.004
0191-2615/

- the UK's two largest container hubs, Felixstowe and Southampton, suffered breaks in service due to high winds in January 2012;
- the pilot at Antwerp stopped working from 0800 h to 1700 h on a day by day basis in a row over a change in national pension regulations, which affected MSC's container services over 21 vessels in February 2012;
- container terminal operations at New York-New Jersey were closed for one week due to hurricane in November 2012;
- the worst flooding in more than five decades caused severe disruption in container traffic at Thailand's main port Laem Chabang in November 2012;
- the container traffic at Los Angeles and Long Beach was brought a virtual standstill as 10 of the 14 terminals were shut due to industrial action by clerical workers in November 2012;
- the failure of a quay-crane's gearbox at the DP World Port Botany terminal caused sudden and unforeseen slot cancellations and significant terminal disruption in September 2013;
- Maersk Line spokesperson blamed poor weather for falling box line reliability saying that carriers were affected by high number of port closure hours caused by fog and wind in north China in November 2013.

It can be seen that disruption events may cause unexpected closure of port/terminal, which could severely influence container vessel's operations. The main difference between the above two types of uncertainties is that the former could be buffered against in the tactical planning level due to its regularity, whereas the latter is difficult to be planned against at the tactical level due to its one-off nature. In practice, it is the combination of these two types of uncertainties that cause the deviation of the actual vessel sailing away from the published schedule. This phenomenon is termed as service or schedule unreliability. Recent statistics show that in January and February 2015, only 49% and 55% of ships, respectively, in the three key East-West trades arrived within one day (+/– 24 h) from the advertised estimated arrival times (ETA) respectively. The average deviation from the ETA to actual arrival was 1.9 days in January and 2.1 days in February 2015 (Drewry 2015). Schedule unreliability can have serious financial consequences to the members in the container transport chain, e.g. it can significantly increase the operational costs of shipping lines and container terminals, and the inventory costs and production costs of shippers and manufacturers (Vernimmen et al. 2007). In addition, earlier arrival or later arrival may have significant environmental impact, e.g. emissions from vessel waiting at ports, emissions from vessel speeding-up or changing route at sea, extra emissions from handling equipment at ports or in inland. Therefore, how to mitigate the impact of uncertainties in shipping operations is an important issue economically and environmentally.

There have been a few studies addressing the uncertainties at ports and/or at sea in liner shipping. Wang and Meng (2012a, 2012b) and Qi and Song (2012) took the tactical planning perspective and focused on designing optimal service schedules by allocating appropriate buffer times into the schedule to absorb the uncertainties. The proposed models can be applied to counteract regular uncertainties but are generally not applicable to handle disruption event uncertainties. Brouer et al. (2013) and Li et al. (2015) took the operational scheduling perspective and focused on optimizing the disruption recovery actions including increasing vessel sailing speed, skipping a port of call, and reshuffling the order of ports of call. However, they treated the disruption event and the schedule recovery problem in a deterministic framework. Uncertainties in shipping will directly affect service quality and vessel sailing speed, and therefore influence on the customer satisfaction and the fuel consumption. With the high fuel price in recent years and the increasing concerns on service reliability, it is vital for vessel operators to perform real-time schedule recovery taking into account various uncertainties so that the expected total cost associated with vessel delays and recovery actions could be minimized. To the best of our knowledge no research has been reported on the real-time schedule recovery in container shipping operations considering regular uncertainties and disruption events simultaneously. This paper aims to fill this research gap.

The rest of the paper is organized as follows. In Section 2, we provide a brief literature review. We formally define the problem and propose the optimal control policy for the problem in Section 3. Section 4 focuses on the case under terminal operations without the earliest handling time constraint, and Section 5 investigates the case under terminal operations with the earliest handling time constraint. In Section 6, we extend to the case with the option of skipping the disruption port. We then present numerical studies in Section 7 and conclude the paper in Section 8.

2. Literature review

Container vessel management covers a wide range of decisions at different time scale, e.g. long-term decisions such as shipping network and service route design (e.g. Wang and Meng 2013; Song and Dong 2013; Brouer et al. 2014); medium-term decisions such as vessel deployment and schedule design (e.g. Agarwal and Ergun 2008; Alvarez 2009; Christiansen, et al. 2013; Meng et al. 2014); short-term decisions such as vessel sailing speed scheduling and terminal operations (e.g. Ronen 2011; Fagerholt et al. 2010; Psaraftis and Kontovas 2010; 2013). This paper belongs to the third group. Therefore, we mainly focus on the relevant literature associated with short-term operational decisions, but also include the closely related literature on medium-term tactical decisions.

Vessel sailing speed has a significant impact on the operating cost and the amount of emissions from shipping. It is well recognized that fuel consumption of a vessel is approximately a cubic function of the sailing speed (Ronen 1982; Fagerholt et al. 2010). Due to the high and fluctuating fuel price in recent years, the fuel cost has accounted for the major part of the total operating cost in a liner shipping company (about 50%–60% according to Notteboom 2006; Golias et al. 2009; Wang and Meng 2012c). A number of studies have emerged in the last few years examining the impact of vessel speed reduction on shipping's