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Liner ship route schedule design with port time windows

Shuaian Wang *, Abdurahim Alharbi, Pam Davy

School of Mathematics and Applied Statistics, University of Wollongong, Wollongong, NSW 2522, Australia

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ABSTRACT

This paper examines a practical tactical liner ship route schedule design problem, which is the determination of the arrival and departure time at each port of call on the ship route. When designing the schedule, the availability of each port in a week, i.e., port time window, is incorporated. As a result, the designed schedule can be applied in practice without or with only minimum revisions. This problem is formulated as a mixed-integer nonlinear nonconvex optimization model. In view of the problem structure, an efficient holistic solution approach is proposed to obtain global optimal solution. The proposed solution method is applied to a trans-Atlantic ship route. The results demonstrate that the port time windows, port handling efficiency, bunker price and unit inventory cost all affect the total cost of a ship route, the optimal number of ships to deploy, and the optimal schedule.

1. Introduction

Liner shipping mainly involves the transportation of containerized cargos (containers) such as manufactured products, food, and garment (Øvstebø et al., 2011). Unlike tramp shipping, liner shipping services have fixed sequences of ports of call and fixed schedules, i.e., arrival and departure times at each port of call (Karlaftis et al., 2009; Norstad et al., 2011; Rakke et al., 2011). Liner services are announced in advance to attract potential customers. For example, Fig. 1 shows a liner service named Atlantic Gulf Mexico Service (AGM) provided by Orient Overseas Container Line (OOCL, 2013). The ports of call and schedule are published in the website of OOCL. Customers can arrange the delivery of their cargo based on the available date of the cargo at the origin port and the expected arrival date at the destination port.

Liner shipping operations are similar to public transport services (Yan et al., 2013; Liu et al., 2013). Schedule design for a liner service (ship route) is a tactical-level planning decision that is made every three to six months. To design a schedule of a ship route, the first factor to be considered is the service availability of the ports. Since a port needs to provide services for a number of liner shipping companies and a number of ships, it cannot guarantee the availability of services whenever a ship arrives. For instance, a port may be able to provide services on Monday, Tuesday, and Friday, and is fully occupied on Wednesday, Thursday, Saturday, and Sunday. We use the term "port time window" to refer to the time in a week that a port can provide services to ships. Hence, schedule design is subject to the constraint of port time windows. Moreover, because of the fast growth of container trade and the long time required for the construction/expansion of port capacity, ports tend to be more congested. Another factor for port unavailability is that some ports do not provide services at all times due to social and cultural reasons. As a result, it is important to consider the availability of ports in schedule design. Otherwise the designed schedule may be infeasible in reality.

* Corresponding author. Tel.: +61 2 4221 5770.
E-mail addresses: wangshuaian@gmail.com (S. Wang), afma987@uowmail.edu.au (A. Alharbi), pjd@uow.edu.au (P. Davy).

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Port Rotation

Westbound: Le Havre - Antwerp - Rotterdam - Bremerhaven - Charleston - Miami - Veracruz - Altamira
Eastbound: Veracruz - Altamira - Houston - Miami - Le Havre - Antwerp - Rotterdam - Bremerhaven

Transit Time (Days)				
Europe to USA/Mexico (Westbound)				
From \ To	Charleston (Mon)	Miami (Wed)	Veracruz (Sun)	Altamira (Tue)
Le Havre (Mon)	15	17	21	23
Antwerp (Tue)	13	15	19	21
Rotterdam (Thu)	11	13	17	19
Bremerhaven(Fri)	10	12	16	18

Transit Time (Days)				
Mexico/USA to Europe (Eastbound)				
From \ To	Le Havre (Sun)	Antwerp (Tue)	Rotterdam (Wed)	Bremerhaven (Fri)
Veracruz (Mon)	20	22	23	25
Altamira (Wed)	18	20	21	23
Houston (Fri)	16	18	19	21
Miami (Mon)	13	15	16	18

Fig. 1. AGM service provided by OOCL (2013).

The design of schedule is also influenced by other factors because different schedules result in different ship costs, bunker costs, and inventory costs. Liner services are usually weekly, which means that the round-trip journey time (weeks) of a ship route is equal to the number of ships deployed on it (Alvarez, 2009). As a result, sailing at a higher speed will reduce the round-trip journey time, thereby the number of ships required and the ship cost. However, a higher speed implies a higher bunker cost: the daily fuel consumption of ships increases approximately proportional to the sailing speed cubed (Ronen, 2011). At the same time, a higher speed leads to a shorter transit time of containers from origin to destination, and thereby a lower inventory cost (Notteboom, 2006). Consequently, in schedule design a liner shipping company must balance the trade-off between ship cost, bunker cost, and inventory cost, subject to the port time window constraints.

1.1. Literature review

According to reviews of Christiansen et al. (2004), Christiansen et al. (2013) and Meng et al. (2014), most studies on liner shipping operations focus on network design, ship deployment, and container routing with fixed schedules or without considering the schedules, e.g., Fagerholt (1999), Shintani et al. (2007), Gelareh and Meng (2010), Meng and Wang (2010), Bell et al. (2011), Meng and Wang (2011), Reinhardt and Pisinger (2012), Dong and Song (2012) and Brouer et al. (2013a). In the scarce literature related to the design of ship schedules, at the tactical level, Mourão et al. (2001) analyzed a small hub-and-spoke network consisting of two routes, i.e., a feed route and a main route, and one origin-to-destination pair of ports, by assuming that all containers must be transshipped at the hub port in the feeder route. They examined the schedules of the two ship routes, and compared each alternative on the basis of the inventory costs of the containers to be shipped. Qi and Song (2012) designed an optimal containership schedule for a liner ship route to minimize the total expected fuel consumption. The time spent at port was treated as a random variable, and a certain level of service, in terms of the probability that the containership would arrive at a port no later than the published arrival time, had to be maintained. Wang and Meng (2012b) designed a robust schedule for a liner ship route in which uncertainties in port operations and schedule recovery by fast steaming were captured endogenously. Wang et al. (2014) developed a dynamic programming approach to design a schedule for a single ship route with port time windows. However, they assumed that each port on the ship route can only be visited once, whereas in reality many ship routes have ports that are visited twice. Wang and Meng (2011) investigated the schedule design and container routing problem in a general liner shipping network with many ports and many ship routes. However, the sailing speed is not a decision variable. Wang and Meng (2012a) extended the work of Wang and Meng (2011) by incorporating the optimization of speed. Neither Wang and Meng (2011) nor Wang and Meng (2012a) have considered the port time windows.

At the operational level, Yan et al. (2009) developed a container routing model from the perspective of a liner shipping company with the objective of maximizing operating profit while considering the arrival time of ships at ports. They performed a case study utilizing operating data from a major Taiwanese marine shipping company. Brouer et al. (2013b)