Transportation Research Part E 67 (2014) 52–70

Contents lists available at ScienceDirect

Transportation Research Part E

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

The ship routing and freight assignment problem for daily frequency operation of maritime liner shipping

Dung-Ying Lin *, Yu-Yun Tsai

Department of Transportation and Communication Management Science, National Cheng Kung University, No. 1 University Road, Tainan City 70101, Taiwan

ARTICLE INFO

Article history:
Received 11 October 2013
Received in revised form 29 January 2014
Accepted 7 April 2014

Keywords:
Daily frequency
Maritime liner shipping
Lagrangian relaxation
Local search
Ship scheduling
Freight routing

ABSTRACT

To cope with excess capacity and improve service quality, maritime international liner carriers have recently adopted a new operational model known as daily frequency. In this new model, carriers provide daily pickup and delivery service to customers at major ports along the Pacific Rim. We investigate the ship routing and freight assignment problem for daily frequency operation of liner shipping. A solution procedure that incorporates a Lagrangian relaxation technique and local search was proposed. The numerical results show that Shanghai, Hong Kong and Singapore are ports that are ideal for carriers in establishing daily frequency operations along the Pacific Rim.

1. Introduction

International maritime liner shipping has undergone a fundamental change in its operational model in recent years. To provide sufficient capacity and better-quality service, major carriers ordered a large number of ships. However, due to the recent financial crisis, the market's expectation suddenly switched from an optimistic state to a pessimistic one, and the capacities taken on by these carriers became idle capacities. In addition, carriers typically assign ships of various types to meet customer demands at ports of various sizes. However, increasing the number of ports at which a ship stops could cause more delays. These delays can be the result of different factors, such as unstable weather, loading/unloading processes and waiting time during berthing. Consequently, the number of ports berthed by a ship is closely associated with the reliability of the service. To compound the situation, customers overbook ship space to mitigate the impact of ship delay, which drives waste of the valuable capacities of the carriers. To cope with the abovementioned issues, the leading carriers have proposed an alternative operational model known as daily frequency (Tai and Lin, 2013). In the operation model of daily frequency in the Pacific Rim, a carrier selects certain ports with higher customer demand as mega-hubs (e.g., Pusan, Shanghai, Hong Kong and Singapore) and dispatches the largest ships to pick up and to deliver shipments at these ports. The feeder ships carry shipments from smaller ports, such as Xiamen, to the mega-hubs.

Four primary features can be observed from this new operational model. First, the trend of ship maximization equips carriers with larger ships (e.g., ships over 10,000 Twenty-foot Equivalent Units (TEU)). The leading carriers use these ships to service the major ports. Because of the relatively short distance between destinations, these ships do not sail at full speed between mega-hubs and can accelerate between ports if the predefined schedule is delayed. In other words, the large ships

* Corresponding author. Tel.: +886 6 2757575x53226; fax: +886 6 275882.
E-mail address: dylin@mail.ncku.edu.tw (D.-Y. Lin).

http://dx.doi.org/10.1016/j.tre.2014.04.003
1366-5545/

can operate at higher speed when the schedule is delayed, which gives the carriers additional operational flexibility and provides customers with better service reliability. Second, due to the large fleet size, the leading carrier has sufficient fleet capacity to provide pickup and delivery services at the mega-hubs on a daily basis, which significantly improves the carrier's competitive advantage. Thus, the carrier can claim to deliver the cargo by a rather strict due date and promise to pay compensation to the customer according to the number of days delayed. This strategy not only appeals to additional customers to reduce supply chain costs (e.g., warehouse cost and inventory cost) but also consumes the carrier's idle capacity. Third, due to the large ship sizes and large volumes that they carry, the carriers can achieve economies of scale at the mega-hubs. Finally, because ships can operate at a lower speed, the new operational model can alleviate impact on the environment because ships traveling at lower speeds produce fewer emissions and create less pollution.

In this paper, we investigate the ship routing and freight assignment problem for daily frequency operation of liner shipping. The problem is formulated as a mixed integer program with a large number of operational constraints. Commonly used commercial optimization packages are incapable of solving this problem efficiently, especially if problems with realistic sizes are considered. Therefore, we developed a solution procedure that incorporates an effective Lagrangian relaxation technique and intelligent local search such that the solution space of this complicated program can be explored efficiently. Unlike the conventional Lagrangian relaxation scheme that relaxes the capacity-related constraints, we relaxed the delayed-cost-related constraints such that the searching procedure can converge to a good solution more rapidly. From a practical point of view, in a daily frequency operational model, the carriers attempt to dispatch additional ships into service so that they can service customers at major ports on a daily basis. Therefore, capacity is abundant, and the relaxation of capacity constraints is not of significant aid in the solution search procedure. We demonstrate that the proposed solution scheme is able to solve realistic problems that are beyond the reach of the widely used optimization packages.

The remainder of the paper is structured as follows. Section 2 provides a critical overview of the recent developments in the field of maritime freight shipping and related fields of research. Section 3 presents a mathematical model of the ship routing and freight assignment problem. Section 4 describes the proposed solution procedure, a Lagrangian relaxation based heuristic, to find the solution of the mathematical model described in Section 3. In Section 5, the proposed method is applied empirically to networks with various sets of parameters to demonstrate efficacy. The final section concludes the paper and suggests potential directions for future research.

2. Literature review

In the early 1980s, relatively little work was devoted to ship routing and scheduling problems. Compared with the widely studied vehicle routing problem (VRP), the ship routing problem received less attention because of its low visibility, lack of structure, higher uncertainty, volatile market without barriers to entry and conservative industry (Ronen, 1983). Ronen (1983) reviewed the work in this area in early 1980 and provided a general classification of the research, namely transportation models (e.g., Baumol and Wolfe, 1958; Naslund, 1970), liner shipping (e.g., Olson et al., 1969), tramp shipping, industrial operations (e.g., Flood, 1954; Mckay and Hartley, 1974; Laderman et al., 1966; Rao and Zionts, 1968) and other models. Additionally, the major differences between the VRP and ship routing/schedule problem were described as well (e.g., ships do not necessarily return to their origins, ship destinations may be changed at sea, etc.). Following this work, Ronen (1993) provided an updated overview of related work in the field of ship routing and scheduling in 1980s and 1990s. However, the relative scarcity of publications in this field has not changed significantly. Most of the published work in the previous era contains models based on integer programming and linear programming with the objective function of minimizing total cost. However, newer issues drew attention in 1990s, e.g., fleet size, fleet mix, fleet deployment (e.g., Rana and Vickson, 1988; Koenigsberg and Meyers, 1980; Larson, 1988), inventory routing (e.g., Trudeau and Dror, 1992; Miller, 1987) and optimal cruising speed (e.g., Ronen, 1982; Brown et al., 1987), etc. Christiansen et al. (2004) attempted to overview the research in the area of ship scheduling/routing from a different perspective. This group summarized the research on strategic planning (e.g., fleet planning) and tactical and operational planning (e.g., industrial, liner and tramp shipping). Trends in the following decades included carrier collaboration, computer-aided decision support systems, development of software/hardware and supply chain management, among others, yet liner shipping has not been investigated widely (Christiansen et al., 2004). Recently, an overview of the ship-scheduling problem was published by Christiansen et al. (2013) in which four basic models in this field were critically reviewed and examined. In the review, liner shipping was further classified into network design (e.g., Agarwal and Ergun, 2008), fleet deployment (e.g., Gelareh and Meng, 2010) and other related problems. Similarly, industrial and tramp shipping were classified into fleet size and composition (e.g., Hoff et al., 2010), cargo routing and scheduling (e.g., Al-Khayyal and Hwang, 2007), maritime inventory routing and supply chain problems (e.g., Andersson et al., 2010). Sailing speed (e.g., Notteboom and Vernimmen, 2009), bunkering and refueling (e.g., Kim et al., 2012), offshore logistics (e.g., Shyshou et al., 2010), and lightering and stowage (e.g., Huang and Karimi, 2006), and related issues that arose in the last decade were reviewed in the same work.

Although research on ship routing/scheduling has blossomed in the last decade, the liner network design problem, combined ship routing/scheduling and port management are important topics for which only the surface has been scratched by recent research.

To review the work related to the current research, we focus the remainder of the literature review on the ship scheduling problems in liner shipping. Agarwal and Ergun (2008) studied the ship scheduling and cargo routing problem. A greedy heuristic, a column generation algorithm and a Benders decomposition algorithm were developed to solve the proposed mixed