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Routing optimization for multi-type containerships in a hub-and-spoke network

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ABSTRACT

This paper considers the ship routing optimization problem in a hub-and-spoke network. A routing optimization model for multi-type containerships with time deadlines is established, and the target is to minimize the total cost, which consists of the total travelling cost, total service cost and total waiting cost. The model is set up through an improved genetic algorithm. The study data are from the Pearl River Delta region of China, which include 1 hub port and 29 feeder ports and have a population of 30 million. Result shows that when the iteration time reaches 190, the total cost comes to 521 thousand yuan near the optimal value. There are 6 routes, including 3 containerships of 100 TEU, 2 containerships of 150 TEU and 1 containership of 200 TEU. At the same time, in the single-type containerships case, there are 7 routes, and when the iteration time reaches 120, the total cost comes to 573 thousand yuan, which is close to the optimal value. Comparing the two cases, it shows that the model for multi-type containerships with time deadlines is reasonable, and the algorithm is practicable. In the last, three factors, which may affect the total cost to carry out sensitivity analysis are chosen. It shows that time deadline, containership capacity and cargo handling capacity of each port have significant influence on the total cost. It is also shown that the total cost for multi-type containerships is always less than that for the single-type containerships.

1. Introduction

Ocean shipping is a major transportation mode of international trade. As an important capital investment for a shipping company, the daily operating costs of a ship can be thousands of dollars. Therefore, significant improvements of the economic performance of a fleet of ships may be expected from proper routing and scheduling (Fagerholt, 2001). The large-scale trend for containerships leads to the development of hub-and-spoke network. When considering a maritime hub-and-spoke network, we usually select the major ports as hub ports based on their location and the demand of freight shipping, and consider the other ports as feeder ports. The services among hub ports are mainly provided by large

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containerships, while the services between a hub and its feeder ports are often provided by small feeder ships (Hsu and Hsieh, 2007).

Liner ship fleet is developing quickly due to the huge world trade. This also leads to the forming and developing of the spoke line transportation, since the large-scale containerships cannot reach the small ports. For shipping companies, facing the competition in global market, they should not ignore the optimization for feeder ship schedule. Therefore, it is an important strategic issue to design the containership routes rationally so as to improve the service efficiency, and to save the transportation cost.

The pickup and delivery problem is to design a set of routes for a fleet of m identical vessels stationed at a central depot to service the transportation requests of n customers (Savelsbergh and Sol, 1995). In this paper, we consider such a pickup and delivery problem, in which the m vessels are stationed at a hub port and the n customers are feeder ports. The vessels start from the hub port and deliver some containers to certain feeder ports, at the same time they pick up some other containers from the feeder ports, and then return to the hub port before their time deadline.

The paper is organized as follows. Section 2 gives a brief review on the investigations of containership routing and scheduling. A detailed description of problem is given in Section 3. Section 4 introduces the formulation of the model. In Section 5, we improve the genetic algorithm to solve the optimal routes and containership types, which minimizes the total transportation cost. Section 6 describes an application case, which is a practical problem faced by a shipping company doing business in the Pearl River Delta region of China. In Section 7, we perform sensitivity analysis to investigate the influences of containership types and time deadlines on the problem. Conclusions are given in the last section.

2. Literature review

There is abundant literature concerning the problem of vessel routing and scheduling. Meanwhile, with the development of containership transportation and feeder transportation, more and more scholars pay their attention to the containership routing optimization problem, especially the ship routing optimization problem in a hub-and-spoke network. Cho and Perakis (1996) generated a set of candidate routes and applied the linear programming to select the optimal set of routes for containerships. Fagerholt (1999) proposed a set-partitioning model for determining optimal fleet size and corresponding weekly routes. Their work built the foundation of this field. Baker and Ayechew (2003) considered the application of a genetic algorithm to the vessel routing problem, in which customers of known demand were supplied from a single depot. Bendall and Stent (2001) developed a scheduling model for a highly speed containership service. They gave a new algorithm for solving the scheduling problem of containership. Chen and Zeng (2010) proposed a bi-level genetic algorithm based method to solve the optimization of container shipping network and its operations under changing cargo demand and freight rates, which was a mixed-integer non-linear programming problem (MINP) with an objective of maximizing the average unit ship-slot profit at three stages. The unbalance of global trade leads to the empty container repositioning problem. Reinhardt and Pisinger (2012) treated the network design and fleet assignment problems, and established a mixed integer linear programming model to minimize the overall cost. To better reflect the real-life situation, they took into account the cost of transhipment, route dependent capacities, and butterfly routes.

When it comes to the ship routing optimization problem in a hub-and-spoke network, most researches mainly focused on liner transportation. Hsieh and Chang (2001) investigated the routing of ship liners by using a hub-and-spoke network model. Sambracos et al. (2004) used the VRP formulation for the operational needs of a ship fleet allowing exploration of problems of higher dimensions with respect to fleet size, demands sites and loads and gave a more comprehensive account with respect to cost and fleet efficiency and utilization. Hsu and Hsieh (2007) formulated a two-objective model to determine the optimal liner routing, ship size, and sailing frequency by minimizing shipping costs and inventory costs. Their model not only provided a tool to analyze the trade-off between shipping costs and inventory costs, but also provided the flexibility on the decision-making for container carriers. Suban and Twrdy (2008) gave a detailed analysis of the maritime transportation between the hub port in the Mediterranean and its feeders in northern Adriatic. They established a two-level programming model with pickup and delivery to simulate the feeder system in the north Adriatic. Takano and Arai (2009) proposed a genetic algorithm for designing a hub-and-spoke network for container transport. Their hub-and-spoke problem was based on a fixed number of hubs, and each spoke was connected to a single hub. The locations of the hub ports were part of the decision. They tested a few different values for the number of hub ports. They used their method on a case with 16 Asian ports in addition to Rotterdam and Los Angeles. Gelareh et al. (2010) proposed a mixed integer programming formulation for hub-and-spoke network in a competitive environment. They solved the model by combining an accelerated Lagrangian method with a heuristic. In order to optimize a liner shipping system and to meet the requirements of liner service with fixed schedules, Yang et al. (2011) established a mixed-integer nonlinear model for fleet planning based on the multi-call liner route pattern. Andersson et al. (2011) considered a maritime pickup and delivery problem with time windows and split. They presented an arc flow formulation of the problem, and also suggested a solution method. Meng and Wang (2011) proposed a liner shipping service network design problem with combined hub-and-spoke and multi-port-calling operations and empty container repositioning, then developed a mixed integer liner programming model for the realistic Asia-Oceania shipping operation problem, and showed that the proposed model can be efficiently solved by CPLEX.

Some scholars considered the pickup-and-delivery problem in spoke network. As we know, scheduling is one of the main bottlenecks, which restricts the quality and efficiency of