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Routing and fleet deployment in liner shipping with spot voyages

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ABSTRACT

The routing, scheduling and fleet deployment is an important integrated planning problem faced by liner shipping companies which also lift load from the spot market. This paper is concerned with coordinating the decisions of the assignment of ships to contractual and spot voyages, and the determination of ship routes and schedules in order to maximize profit. We propose a new model for representing voyages as nodes of a directed graph which is used to build a mixed integer programming formulation. Besides contractual and spot nodes, another type of node is put forward to represent a combination of a contractual voyage with one or more spot voyages. In addition, the concept of dominated nodes is introduced in order to discard them and reduce the effort of the search for an optimal solution. A set of test problems has been generated taking into account real world assumptions. The test problems are solved by an optimization software and computational results are reported. The results show the potential of the approach to solve test problems of moderate size.

1. Introduction

There are generally three modes of operation in maritime transportation shipping: *industrial*, *tramp* and *liner* (Lawrence, 1972). The industrial shipping is common in mining companies and oil companies that own or control the ships and seek to transport their cargo at minimum cost. In tramp service, the ship operator does not have a fixed route or schedule and searches for cargo to transport from any port to any port in order to maximize its profit. In general, the cargos consist of bulk goods such as cereals, coal, ore, wood, gases, oil and chemicals. On the other hand, a liner shipper offers a regular service that consists of a sequence of ports to visit and a departure time, thus seeking to attract cargos.

Liner shipping became an important industry in the 1870s and since the Calcutta Conference in 1875, it has been characterized by collusive agreements, called ship conferences, which denote formal agreements between liner companies on a route, always setting (possibly discriminatory) prices, and sometimes pooling profits or revenues, managing capacity, allocating routes, and offering loyalty discounts. The explanations for the existence of ship conferences fall into two categories: monopolizing cartels and destructive competition (Sjostrom, 2004).

Liner companies offer service to shippers in the form of long-term contracts (one year or more), short-term contracts (one month up to 6 months) and spot market contracts for particular shipments at a price determined at the time of the

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transaction. For example, the revenue split from the Maersk Line (Maersk, 2013), the world's largest container shipping company, in 2013 was: 41% for contracts longer than 3 months, 23% for contracts between 1 and 3 months, 26% for the spot market with contracts with less than 1 month, and 10% from other sources which include chartered-out ships.

Liner shipping is the foundation for global commerce, transporting about 16% of the world's goods loads in tons (UNCTAD, 2011). Such goods are high-value ones, i.e., either manufactured or semi-manufactured goods that correspond to about 60% of world seaborne trade by value (WSC, 2014). The main types of ships used in liner services are: container, roll-on/roll-off (Ro–Ro), general cargo and multi-purpose (Clarksons, 2014). A liner shipping company provides regular transportation services on a given set of trade routes, each specifying a set of ports between two (or more) intercontinental regions. Each trade route entails one or more voyages that are to be sailed during a given horizon.

A voyage consists of a sequence of loading and unloading port calls, starting with the port where the ship loads its first cargo and ending where the ship unloads its last cargo. We present the case of empty sailing between the last port call of one voyage and the first port on the next voyage (Christiansen et al., 2007), which occurs when two consecutive voyages are made in distinct geographical regions. However, when a voyage starts in the same region where the previous voyage terminates, the ship may not become empty, and this case can also be handled by our approach. The characteristics of voyages are stipulated in a contract of affreightment between the shipper and the liner shipping company. Each contractual voyage requires its departure time, the estimated duration, the freight rate, the agreed ports to be visited for loading and/or unloading, and the minimum and/or maximum quantity of goods of specified nature between the ports. Another type of voyage is the spot voyage that involves a contract to move a single cargo from one port to another port in the near future.

This paper addresses the integrated problem of routing, scheduling and fleet deployment of voyages, which is an important problem in liner shipping with a time horizon of 3–6 months. The routing and scheduling problem comprises the determination of sequences of voyages to be performed by the ships and the inclusion of timing to a ship's route, such as a time window to start service at the first port of a voyage and a corresponding waiting time. Since a voyage consists of a set of port calls, the time window for starting service at each port cannot be explicitly defined. The fleet deployment problem is a tactical problem which determines the number and type of ships, and the assignment to the contractual and spot voyages in order to maximize the total profit.

We propose a new model for representing contractual and spot voyages as nodes of a directed graph which is used to build a mixed integer programming formulation. Besides contractual and spot nodes, another type of node is introduced to represent a combination of a contractual voyage with one or more spot voyages. Based on the attributes of contractual voyages, the concept of dominated nodes is introduced in order to discard them and reduce the effort of the search for an optimal solution. The CPLEX software is used to solve the mixed integer programming formulation and obtain an optimal or a feasible solution for randomly generated test problems.

The remainder of the paper is organized as follows. Section 2 presents a literature review and Section 3 contains a detailed description of the problem. Section 4 shows the construction of nodes that represent contractual and spot voyages of a directed graph with arcs representing sequences of voyages. Section 5 develops mixed integer programming models for the problem without and with spot voyages. Section 6 describes the computational experiments and, finally, conclusions are presented in Section 7.

2. Literature review

The extensive surveys by Ronen (1983, 1993) and Christiansen et al. (2004, 2013) are general relevant references because they cover four decades of the evolution of research literature on ship routing and scheduling problems, as well as related planning problems, including the fleet deployment problem. Meng et al. (2014) provide a review from the last 30 years on the containership routing and scheduling problems in liner shipping at the strategic, tactical and operational planning levels. Kjeldsen (2011) develops a classification scheme with 18 characteristics for problems of ship routing and scheduling in liner shipping. Tran and Haasis (2013) conduct an extensive survey of network optimization in container liner shipping focusing on three major categories: container routing, ship assignment and scheduling, and network design. The literature on maritime transportation has been increasing significantly due to the growth in the world fleet and trade that has led to large and complex problems.

Perakis and Jaramillo (1991) introduce the fleet deployment problem with decision variables given by the number of ships to be assigned to given routes and formulate it as a linear programming problem. In the same year, Jaramillo and Perakis (1991) suggest an integer programming formulation with a computational example. Powell and Perakis (1997) extended the model of (Perakis and Jaramillo (1991) by adding the ship lay-up costs to the objective function.

The work developed in the following two papers is related to ours in the sense that they deal with the fleet deployment problem in liner shipping with spot voyages. Fagerholt et al. (2009) address a problem of fleet deployment, routing and scheduling problem for a Ro–Ro liner company. First, they identify contractual voyages with high probability of occurrence of spot cargos. Then ships with larger capacities are assigned to such voyages in order to accommodate the estimated minimum contracted cargo and the additional quantity from the spot market. Norstad et al. (2015) deal with a problem of fleet deployment and scheduling for a given set of routes of a Norwegian liner shipping company. The problem requires that the voyages of a trade route should be fairly evenly spread (a clause in the contract of affreightment), which has been specified as a minimum acceptable time between two consecutive voyages. Imbalance in the supply and demand is common in liner shipping companies, i.e., more voyages starting in a region than ending up there. In order to try to avoid sailing with no cargo