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An effective heuristic for solving a combined cargo and inventory routing problem in tramp shipping

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ABSTRACT

In this paper a vendor managed inventory (VMI) service in tramp shipping is considered. VMI takes advantage of introducing flexibility in delivery time and cargo quantities by transferring inventory management and ordering responsibilities to the vendor which in this case is a shipping company. A two-phase heuristic is proposed to determine routes and schedules for the shipping company. The heuristic first converts inventories into cargoes, thus turning the problem into a classic ship routing and scheduling problem. It then uses adaptive large neighborhood search to solve the resulting cargo routing and scheduling problem. The heuristic iteratively changes the cargoes generated to handle the customer's inventories, based on the information obtained from an initial solution. Computational results are presented, discussed and compared with exact solutions on large realistic instances. The results reveal the potential savings from converting traditional contracts of affreightment to an integrated VMI service. The factors that influence the benefits obtainable through VMI are also analyzed.

1. Introduction

Maritime transportation plays a major role in international trade today. More than nine billion tons of goods are carried by ships annually [24], having an estimated range from 65% to 85% of the total weight transported in international trade [7]. Maritime transportation is the obvious choice for heavy industrial activities where large volumes are transported over long distances since it has the lowest per unit cost of all transport modes [9]. This is exploited by industries related to a wide range of products from oil and chemicals to cars and foods.

There are many commercial shipping routes in the world. Even though the main routes are between continents, there are also major domestic routes along shorelines and between islands, for example in Greece, Indonesia, Japan, Norway, Philippines, and the USA.

Among the three basic modes of operation in maritime transportation (liner, industrial and tramp shipping) distinguished by Lawrence [15], we are interested in tramp shipping which is comparable to a taxi service and follows the available cargoes (a mix of mandatory contract cargoes and optional spot cargoes). Tramp shipping companies often engage in contracts of affreightment (COA) which describe obligations to carry specified quantities of cargo between specified ports within a given time frame for an agreed payment per ton. Some COAs have flexibility in the size of each cargo or shipment. Contracts between the shipping company and the cargo owner can be split into two main categories: *More-Or-Less-Owner's-Option* (MOLOO) and *More-Or-Less-Charterer's-Option* (MOLCO) [5]. In a typical contract, the quantity transported can vary up to $\pm 10\%$ or $\pm 20\%$ of the expected cargo quantity. In MOLCO contracts, the cargo owner has flexibility to determine the quantity, which is often not decided until the ship enters the loading port. In these situations, the shipping company planner must ensure that the ship assigned to this particular cargo has enough free capacity to carry the upper limit of the cargo quantity. However, in MOLOO contracts the ship owner decides the cargo quantity within the given interval. Sometimes, the planner can utilize this flexibility to achieve better fleet schedules and higher profits [11].

There are mainly two types of problems that have been considered in ship routing and scheduling problems; cargo routing and inventory routing [2]. In this paper we focus on a mix of these two which is described in detail in Section 2. Different variants of cargo routing problems have been targeted in the literature and various solution methods have been employed to solve them. For instance, Brønmo et al. [4] presented a multi-start local search heuristic for a ship routing and scheduling problem. Afterwards Korsvik et al. [14] proposed a tabu search heuristic and Malliappi et al. [17] developed a variable neighborhood search heuristic to solve almost the same problem. Recently Hemmati et al. [13]

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presented a wide range of benchmark instances for the ship routing and scheduling problem. They proposed an adaptive large neighborhood search heuristic to solve the problem.

The maritime inventory routing problem is also considered by many researchers [6,22,10,1,18,3]. Some of the works are based on real-life problems, for example Grønhaug et al. [12], who worked on a maritime inventory routing problem in the liquefied natural gas business and Christiansen et al. [8] who presented a case study from the cement industry. Recently, Stålhane et al. [23] introduced a new problem that combines traditional tramp shipping with a vendor managed inventory (VMI) service. They presented an arc-flow model describing the problem, a path-flow model which is solved using a hybrid approach that combines branch-and-price with a priori path-generation, and a heuristic path-generation algorithm. Their results show that replacing the traditional COAs with VMI services increases supply chain profit and efficiency. However, even with the heuristic path-generation algorithm, they are only able to solve small size instances in which only a few COAs have been replaced by VMI services. In addition, running times presented in their paper drastically increase from seconds to days by small increases in the problem size or even by increasing the number of replaced COAs. The method in [23] can only solve small instances, and it is therefore interesting to develop a method to solve realistically sized instances and to evaluate the contribution of introducing a VMI service for such instances.

Our contributions in this paper lies in (1) presenting a powerful novel heuristic to solve the problem introduced in [23] which enables the solution of realistically sized instances in reasonable time. In particular, we propose a heuristic algorithm which transforms the inventory management problem into a pickup and delivery problem with time windows; (2) introducing new realistically sized benchmark instances for a tramp shipping company offering VMI services; (3) presenting a computational study illustrating the performance of the heuristic; (4) analyzing the economic impact for the shipping company, and the supply chain, from replacing some of the traditional COAs with VMI services for realistically sized instances and also analyzing the factors that influence the benefits obtainable through VMI.

The rest of the paper is organized as follows. Section 2 describes the routing and scheduling problem of a tramp shipping company which offers VMI services. In Section 3 an *iterative cargo generating and routing* (ICGR) heuristic is presented. Numerical experiments appear in Section 4. Finally, conclusions are drawn in Section 5.

2. Problem description

A regular tramp ship routing and scheduling problem is commonly classified as a maritime version of the pickup and delivery problem with time windows and consists of routing a given fleet of ships to service a set of cargoes. Each cargo consists of a given quantity and has to be transported from a pickup port to a delivery port within given time windows. In maritime transportation there is usually a mix between contracted cargoes that the shipping company must transport, and a set of optional (or spot) cargoes that the company may transport if it is profitable and there is sufficient capacity in the fleet. The fleet of ships is heterogeneous with the ships having different cargo capacities, speeds, and cost structures. In addition, the ships are located at different positions, either in a port or somewhere at sea, at the beginning of the planning horizon.

Often the contracted cargoes of shipping companies are based on COAs, however, as argued in [23], these COAs may, in some cases, be replaced by a VMI service. VMI services are based on a business model where a third party logistics provider, here a shipping company, has taken on the responsibility of inventory management at both supplier and customer sites. This service permits the customer to focus on its core business and outsource the inventory management processes. The use of VMI has several positive effects on the supply chain performance, such as decreasing the inventory holding costs, reducing stock outs, increasing competition and improving the service level.

In this paper, we consider a combined cargo routing and inventory management problem faced by a shipping company that offers VMI services to some of its customers, i.e. some of the COAs are replaced by VMI services. Thus, the company is engaged in transporting the remaining COAs and optional spot cargoes, as well as offering VMI services to some of its customers. Each VMI service consists of transporting a single product from one storage where the product is produced to another one where the product is consumed and the shipping company must ensure that the inventory level of both storages stay within their limits throughout the planning horizon.

The problem consists of a set of transportation tasks, $C=\{1,\ldots,N\}$, that may be partitioned into three disjoint sets: the set of inventory pairs where COAs have been replaced with VMI services, the set of mandatory cargoes representing the remaining COAs, and the set of optional cargoes. The problem may be defined on a graph $G=(\mathcal{N},\mathcal{A})$ where $\mathcal{N}=\{1,2,\ldots,2N\}$ is the set of nodes, and $\mathcal{A}$ is the set of arcs. With each transportation task $i\in C$ there are associated two nodes, the pickup node i and the delivery node $(N+i)$. Similar to the transportation tasks, the nodes may also be divided into three disjoint sets: the set of nodes which are associated with inventory pairs $\mathcal{N}^I$, the set of nodes associated with mandatory cargoes $\mathcal{N}^M$, and the set of nodes associated with optional cargoes $\mathcal{N}^O$. The set of arcs, $\mathcal{A}\subseteq\mathcal{N}\times\mathcal{N}$, consists of the feasible movements of a ship between the nodes.

During a given planning horizon, going from time 0 to T, the inventory level of the storage associated with inventory node $i\in\mathcal{N}^I$ must lie between an upper and a lower limit ($\underline{S}_i$and $\overline{S}_i$). The initial inventory level is denoted S_i, and a production (if positive) or consumption (if negative) rate R_i, is also associated with each inventory node. Inventory pairs may be serviced at most $\overline{M}_i$ times during the planning horizon to keep the inventories within their limits. It is assumed that there are lower and upper limits ($\underline{Q}_i$and $\overline{Q}_i$) on the loaded and unloaded quantities and that the associated handling time in port is quantity-dependent. The cargo quantity associated with node $i\in\mathcal{N}^C\cup\mathcal{N}^O$ that must be transported between the pickup and delivery port is denoted by Q_i.

The combined cargo routing and inventory management problem consists of designing routes and schedules for the fleet of ships. The problem also aims at determining the quantities handled at each inventory node without exceeding the storage's inventory limits. The objective of the problem is to maximize the profit of the shipping operations which is the difference between revenues and costs. Revenues come from servicing the inventory and mandatory cargoes and also from the optional cargoes that are serviced, while the costs are associated with the sailing performed by the fleet of ships. A feasible solution considers the ship capacities, time windows for service at ports, and precedence and pairing of visits to the pickup and delivery nodes of a given transportation task for each ship. In addition, a feasible solution must ensure feasible upper and lower limits on the cargo quantity loaded or unloaded at each visit to an inventory node, and that all inventory levels stay between their limits. For a mathematical model of the problem, we refer the readers to [23].

3. Iterative cargo generating and routing heuristic

To solve the routing and scheduling problem of a tramp shipping company offering VMI services an iterative two-phase