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Robust planning and disruption management in roll-on roll-off liner shipping

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ABSTRACT

This paper presents different strategies for handling disruptions in fleet deployment in roll-on roll-off liner shipping, which basically consists of assigning a fleet of vessels to predefined voyages at minimum cost. A new mathematical model of the problem is presented, including a set of robust planning strategies, such as adding slack and rewarding early arrivals. To solve real-life instances a rolling horizon heuristic is proposed. A computational study, where we also propose some recovery planning strategies, is conducted, and simulation results show that adding robustness significantly reduces the actual cost of the plan and the total delays of the voyages.

1. Introduction

This paper studies different strategies for handling disruptions in roll-on roll-off (RoRo) liner shipping. The RoRo segment of liner shipping is characterized by transporting cargo such as cars, trucks, farming equipment, and other types of cargo that contain wheels or can be placed on trailers, and thus can be rolled onto and off of the vessels. The vessels themselves are special purpose vessels, similar to gigantic ferries, where the rolling cargo is stacked on multiple decks onboard the vessels, with each deck having different height and weight restrictions.

This study is done in cooperation with Wallenius Wilhelmsen Logistics (WWL), which is one of the world's largest operators in the RoRo segment. The planning process undertaken by WWL can be divided into strategic, tactical, and operational levels of planning. At the strategic level decisions regarding which trade routes they should service, the frequency of service on these trade routes, and the composition of the fleet must be taken. Once this is decided, the company faces a fleet deployment problem (FDP) at the tactical level, where each vessel is assigned to service a sequence of trade routes, while taking the frequency requirements into account. Finally, at the operational level, decisions regarding stowage onboard the vessels, weather routing, and disruption management, is handled.

In this paper we focus on creating robust solutions to the FDP at the tactical level, in order to minimize the effect of disruptions at the operational level. In addition, we study recovery strategies that may be employed once a disruption has occurred that makes the existing plan undesirable. The FDP faced by WWL may be described as optimally assigning

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individual vessels to trade route voyages during a planning horizon stretching from a few months and up to a year. A trade route is a long distance maritime shipping route, and consists of a pre-determined sequence of port calls with sailing legs in between. E.g. a ship performing/sailing/servicing the trade route *Europe – North America*, visits a set of ports in Europe, where cargo is loaded, before sailing across the Atlantic to North-America where a set of unloading ports are visited, and the ship is emptied before starting on a new trade route voyage, possibly with some ballast (empty) sailing in between. According to monthly demand and contractual agreements, each trade route has to be serviced with a certain frequency, and a vessel completing one instance of a trade route once is denoted as a voyage. For each vessel, we thus get a schedule which consists of a sequence of voyages, combined with a start time for each voyage.

The term *fleet deployment* is defined by Perakis and Jaramillo (1991) as the "...allocation of ships to routes, their general scheduling, and the chartering of vessels, if any, to complement the owned fleet in the fulfillment of the transportation missions". Fagerholt et al. (2009) describe the FDP as determining an optimal way of servicing voyages defined for the planning horizon with the shipping company's fleet of vessels. Here, an optimal deployment is seen with respect to minimizing the costs. Most literature on the FDP studies the problem faced by container liner shipping companies. Gelareh and Meng (2010) present a nonlinear mathematical model for the FDP with speed optimization in container liner shipping. The model is linearized as a mixed integer linear programming model and solved for randomly generated numerical instances. In Meng and Wang (2010), the authors present a chance constrained programming model to solve the short-term liner ship fleet planning problem with cargo demand uncertainty for a liner container company. The demand uncertainty is modeled with a normal distribution, and for each liner route operated by the company, the chance constraints ensure that a minimum level of service is associated with each route. Wang et al. (2013) revisit the problem discussed in Meng and Wang (2010), but propose a joint chance constrained programming model, and show that the service level provided has significant effect on the total cost. Liu et al. (2011) formulate a joint optimization model for the container flow and fleet deployment problems. Finally, Wang and Meng (2012) present a cost minimization model for the FDP with container transshipment operations. The model allows containers to be delivered from its origin port to its destination port by the use of more than one vessel.

The FDP in container shipping separates itself from RoRo liner shipping in two respects: (1) The container shipping lines are cyclic with each ship assigned to a single service/line/port rotation for the entire planning horizon, while the trade routes in RoRo shipping usually go from one part of the world to another, and each ship is assigned to a sequence of voyages on different trade routes. (2) In container shipping they usually consider deployment of ship types, and not the specific deployment of individual ships. The latter also means that they are not taking into account the different initial positions the ships may have at the start of the planning horizon. This may be a reasonable assumption in container liner shipping due to (1), but is a too crude approximation in RoRo liner shipping.

To the authors' knowledge, Fagerholt et al. (2009) and Andersson et al. (2014) are the only studies that deal with the FDP in RoRo liner shipping. Fagerholt et al. (2009) present a very simplified model that is solved by a multi-start local search heuristic. Later, Andersson et al. (2014) extend their model, and propose a rolling horizon heuristic to solve an integrated fleet deployment and speed optimization problem. While studying the same problem as in this paper, their model differs from ours by simplifying the modeling of the cargo onboard the vessel. Their model has one cargo capacity per vessel, considers only one type of cargo, and has only one capacity restriction per voyage, thus implicitly assuming that all cargo transported on a voyage is onboard the vessel concurrently at some point during the voyage. The model presented in this paper divides the capacity of each vessel into groups dependent on the height and weight limits of each cargo deck, considers more than one type of cargo, and takes into account the fact that several loading/unloading regions may be visited on a given trade route. In addition, we model the variable speed of a vessel in greater detail, by allowing the speed of a vessel on a trade route voyage to differ from the speed on the subsequent ballast sailing.

The FDP is usually presented as a deterministic problem in the academic literature, however, in reality shipping companies operate in an environment that is highly uncertain and constantly changing. Hence, the execution of a predetermined fleet deployment plan is often subject to changes, or disruptions, caused by unforeseen events. According to Brouer et al. (2013), common events leading to disruptions in maritime transportation are strikes in ports, bad weather, congestion in passageways, and mechanical failures. Other, but less frequent events include piracy and crew strikes on vessels. All types of events may lead to disruptions, such as delays, or in some cases the need to charter an additional vessel. The occurrence of disruptions are common in a global shipping network; a study conducted by Notteboom (2006) showed that as many as 70–80% of the global shipping lines were disrupted in some way.

There are significant economic impacts associated with disruptions in liner shipping, and Kjeldsen (2012) highlights that this has an effect on two fronts. First, there are costs to the shipping company such as increased bunker cost, increased port costs, charter costs of extra ships and cargo space, and intangible costs (e.g., goodwill, loss of customers). Kjeldsen (2012) exemplifies this by showing that increasing the service speed of an 6600 TEU container vessel from 18 to 24 knots may increase fuel consumption by up to 130 tons per day. With the fuel prices of USD 650 per ton at the time the research was conducted, the higher speed costs USD 84,500 extra for each day it has to be maintained. In addition to the cost to the liner shipping company, there are significant costs associated for the customers whose cargo are onboard the vessels subject to disruption. Estimates given by Notteboom (2006) show that a vessel carrying 4000 TEUs traveling from the Far East to Belgium may lead to extra costs for its customers of at least EUR 57,000 per day it is delayed.

Yu and Qi (2004) classify approaches to handle disruption management into two stages: in-advance planning and real-time re-planning. The purpose of in-advance planning is to find an optimal plan while taking future uncertainties into account. This may be referred to as robust planning or robust optimization. Here, future uncertainties can be modeled by a