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A collaborative agreement for berth allocation under excessive demand

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ABSTRACT

International seaborne trade has increased significantly during the last three decades, and this growth is expected to continue at similar rates. To address the growing demand, terminal operators aim to improve productivity with the minimum capital investment. This study extends an existing berth allocation policy, where demand can be diverted from a multi-user maritime container terminal to an external maritime container terminal at an additional cost. Furthermore, additional market based rules are introduced in the model for the vessel diversion decision making. The objective of the multi-user maritime terminal operator is to minimize the total vessel service cost. Due to complexity of the proposed mathematical formulation, a Memetic Algorithm is developed to solve the resulting problem. A number of numerical experiments are presented to evaluate efficiency of the new berth allocation policy and the solution algorithm. Results indicate that the suggested berth allocation policy yields substantial cost savings during high demand periods.

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1. Introduction

Maritime transportation is critical for the international trade with approximately 90% of the global trade volume carried by vessels (The Journal of Commerce, 2014). The World Shipping Council (2014) indicates that "*it would require hundreds of freight aircrafts, many miles of rail cars, and fleets of trucks to carry the goods that can fit on one large liner ship*". According to the data provided by the United Nations Conference on Trade and Development (UNCTAD, 2016), the overall international seaborne trade reached 10.05 billion tons in 2015. The containerized trade volumes increased by 2.9% from 2014 to 2015, while dry and liquid bulk cargoes increased by 2.9% and 4.3% respectively (UNCTAD, 2016). A similar growth is expected to continue. The majority of high value cargo and general consumption goods are shipped in a containerized form. Liner shipping companies, looking for transport efficiency and economies of scale, have increased the vessel size on most of the trade routes. The Journal of Commerce (2015a) highlights that CMA CGM placed an order for six vessels with 14,000 TEU capacity in the first half of 2015 after an earlier order for three 20,000 TEU vessels. Maersk ordered eleven 19,500 TEU vessels in the beginning of 2015, while MOL and OOCL placed orders for vessels with 20,000 TEU capacity. The number of megaships is projected to increase by at least 13% by 2020 (The Journal of Commerce, 2015a).

To meet the growing demand and serve the ever-changing carrier alliances, while facing capacity expansion limitations (e.g., lack of land, high cost of expansion, etc.), maritime container terminal operators have emphasized on the importance of planning and operations optimization as means to increase productivity (see for examples Lalla-Ruiz et al., 2012; De Armas et al., 2015; Yin et al., 2015; Li et al., 2016). A terminal capacity can be increased by upgrading the existing or constructing the new infrastructure but requires a significant capital investment (Petering and Murty, 2009; Cordeau et al., 2015). Alternatives to construction of the new infrastructure include improvement of conventional equipment and productivity by introducing new forms of technology (Emde et al., 2014), information systems (Henesey, 2004), and work organization (Paixão and Marlow, 2003). One approach that can increase productivity without the capital investment is better utilization of the existing berthing capacity between terminal operators through collaborative agreements (Canonaco et al., 2008; Cargo Business, 2014), which is similar to the alliance model adopted by liner shipping companies (The Journal of Commerce, 2016a, b). One may view such agreements, where vessels from different liner shipping

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companies can be served at different terminals of the same port, as the answer of port operators to the alliances, formed by liner shipping companies.

In this study, we build upon two existing berth allocation policies for a shared seaside capacity (Imai et al., 2008b; Karafa et al., 2011) based on a contractual agreement between two terminal operators, where a multi-user container terminal (MUT) operator can divert vessels to an external container terminal (ET). A set of additional market based rules is introduced in the proposed collaborative berth allocation model for the vessel diversion decision making. The problem is formulated as a non-linear mixed integer program. The objective of the proposed model is to determine the assignment of vessels (at MUT and diverted to ET) and minimize the total vessel service cost for the MUT operator. A novel Memetic Algorithm (Dokeroglu and Cosar, 2016; Koupaei et al., 2016; Qu et al., 2017) is developed to solve the problem. A set of local search heuristics is introduced to improve performance of the algorithm.

The rest of the manuscript is organized as follows. The next section discusses the relevant literature, followed by the problem description. The fourth section presents the mathematical model for the berth allocation policy, and the fifth section describes the solution algorithm. The sixth section presents results from the numerical experiments, performed in this study to evaluate the solution algorithm and the proposed MUT berth allocation policy. The last section concludes the study and outlines the future research directions.

2. Overview of the relevant literature

Maritime container terminal operations and decision problems have kept the interest of numerous researches over the last two decades. A significant amount of research papers on berth allocation and seaside operations at maritime container terminals have been published to date, and for excellent reviews of those papers we refer the reader to Carlo et al. (2013) and Bierwirth and Meisel (2015). These survey studies presented a detailed description of the container terminal operations, overview of the international seaborne trade history, outline of the major decision problems, and classification of various scientific publications by different topics. There exist various studies that discussed collaborative agreements between liner shipping companies, including formation of alliances (Alix et al., 1999; Panayides and Wiedmer, 2011), selection of strategic alliance partners (Ding and Liang, 2005), liner shipping alliance stability (Yang et al., 2011), and comparison of collaborative vs. non-collaborative policies between liner shipping companies (Lei et al., 2008). However, only a limited number of papers focused on collaborative agreements between maritime container terminal operators and liner shipping companies and collaborative agreements solely between maritime container terminal operators.

Golias and Haralambides (2011) formulated a discrete dynamic berth allocation problem for maritime container terminals, where the terminal operator had various contractual agreements with liner shipping companies (i.e., different cost functions). The objective minimized the total cost of vessel waiting times and late departures, and maximized the total premiums from early departures. The authors applied an Evolutionary Algorithm to solve the problem. Computational experiments were performed for all the considered cost policies. Wang et al. (2015) proposed two collaborative mechanisms between the liner shipping company and maritime container terminal operators, serving ports of the given liner shipping route, at the tactical level. Both mechanisms enabled the liner shipping company to negotiate arrival time windows with the terminal operator at the given port of call. The first agreement considered the case when there was no transshipment moves, while the second one captured the case with transshipment moves at the given port of call.

Imai et al. (2008b), Karafa et al. (2011), and Peng et al. (2015) focused on modeling collaborative agreements between maritime terminal operators. Specifically, Imai et al. (2008b) studied a discrete dynamic berth allocation problem at MUT, where vessels with excessive waiting times were diverted for service at ET. The objective of the proposed mathematical model aimed to minimize the total service time of vessels at the external terminal. An Evolutionary Algorithm was developed to solve the problem. Computational experiments demonstrated that the proposed berth allocation policy would improve efficiency of operations at busy maritime container terminals especially during peak hours. Karafa et al. (2011) modeled a collaborative agreement, where vessels from a dedicated maritime container terminal could be diverted for service at MUT during pre-determined time windows. The objective of the presented model minimized the total vessel service cost. The authors applied an Evolutionary Algorithm to solve the problem for the realistic size problem instances. A set of numerical experiments, conducted in the study, demonstrated efficiency of the developed solution algorithm.

Peng et al. (2015) proposed a collaborative agreement for maritime bulk terminal operators, where the berthing space and the storage yard capacity could be shared among multiple terminals. The objective function of the proposed mathematical model aimed to minimize the total vessel service time. The problem was solved using an Evolutionary Algorithm. Numerical experiments demonstrated that the objective function values, suggested by the developed solution algorithm, were close to the optimal ones, which were obtained using CPLEX, for the small size problem instances.

This study extends the work, conducted by Imai et al. (2008b) and Karafa et al. (2011), and proposes the berth allocation policy where the following market based rules are introduced for the diversion decision making:

(1) The MUT operator diverts vessels based on a ***generalized cost function***, as it is unlikely that terminal operators will base the service decisions solely on vessel waiting times;
(2) For each diverted vessel the proposed model selects an optimal service time window (TW) and handling rate that ***minimizes the cost of diversion***; and
(3) Available capacity at ET is considered through a ***service TW constraint*** for any diverted vessel (i.e., the ET operator will accept a vessel only if its own customer service is not affected).

Next, we present a detailed problem description and discuss the proposed contractual agreement.

3. Problem description

This section of the manuscript provides a detailed description of the problem studied herein, including the following aspects: (1) terminal types and their layouts; (2) vessel arrivals; (3) contractual agreement description; and (4) service of vessels at ET.

3.1. Terminal types and their layouts

In this study, we consider a maritime port with two types of container terminals: (1) multi-user container terminals (MUTs) and (2) dedicated maritime container terminals (DCTs). DCT serves vessels from one liner shipping company, while MUT serves vessels from various liner shipping companies. Both terminals have discrete berthing layouts, where one vessel can be served at each berth at the time. Note that the latter terminal layout has been widely adopted in the berth allocation literature (Bierwirth and Meisel, 2015). However, the proposed berth allocation policy can be applied to maritime container terminals with continuous and hybrid berthing layouts as well.

3.2. Vessel arrivals

It is assumed that both MUT and DCT operators have the information regarding the expected vessel arrival times (i.e., the dynamic vessel arrival case). Uncertainty in vessel arrival time due to inclement weather conditions, disruptions that may occur at preceding ports of the liner shipping route, and potential alterations in the vessel schedules is not

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