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The continuous Berth Allocation Problem in a container terminal with multiple quays

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ABSTRACT

This paper extends the study of the continuous Berth Allocation Problem to the case of multiple quays, which is found in many container terminals around the world. Considering multiple quays adds a problem of assigning vessels to quays to the problem of determining berthing times and positions for each incoming vessel.

This problem has not been considered in the literature at the operational level addressed in this study. In order to solve it, we have developed first an integer linear model and then a genetic algorithm which works on sequences of vessels that are decoded by a constructive algorithm. A local search procedure helps to improve further the solutions produced by the genetic algorithm.

We have conducted an extensive computational experiment, adapting existing instances to the case of multiple quays. We have also adapted our genetic algorithm to the case of a single quay and tested it on previously reported instances, showing its superior performance compared with existing approaches. Finally, we have developed a random instance generator for the problem with multiple quays, enabling us to conduct a systematic study of the factors affecting the complexity of the problem.

1. Introduction

Container terminals appeared in the late 1960's as a consequence of the traffic of specialized container ships between Europe and the USA. The use of containers has become widespread due to their important advantages: less product packing, less deterioration, and much greater productivity in the different handling phases. Moreover, it makes the intermodal transportation of goods much easier, because the transfer from vessels to rail or road is simplified. Consequently, the number and size of container terminals have continuously increased. In 2013, the total volume of container loading/unloading operations surpassed 650 million *TEUs* (*Twenty-foot Equivalent Unit*) (UNCTAD, 2014). Ports like Shanghai and Singapore moved more than 30 million TEUs. In Europe, Rotterdam moved almost 12 million, followed by Hamburg with more than 9 million. In Spain, the largest volume of container traffic was that of Algeciras, with 4.5 million, and Valencia, with 4.3 million TEUs. Overall, the percentage increase in the decade 2001–2010 was 206%.

The productivity of these busy container terminals is highly dependent on the terminal handling system, as well as on the efficient berth allocation of calling vessels. In this paper we study the *Berth Allocation Problem (BAP)*, which consists of allocating to each vessel a berthing position and a time to perform its loading/unloading operations. Depending on the spatial structure of the terminal, several types of problems can be distinguished. Basically, we can differentiate between discrete and continuous cases. In the *discrete* case, the quay is divided into fixed sections and each section can be occupied by at most one vessel, irrespective of its length. In the *continuous* case, the quay is not divided and a vessel can berth at any position at the quay, depending only on the position of other vessels. Considering a continuous quay adds flexibility but also increases the complexity of the problem.

Up to now, in all previous studies dealing with the continuous BAP, the quay has been considered a single continuous line of a given length. However, when we started to study this problem, we discovered that one of the terminals in the port of Valencia (Spain) consists of two quays, and considering it as a single line did not seem a good approximation. Looking at terminal layouts all over the world, we found many other terminals with several

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quays. In Singapore, Keppel terminal is divided into four quays and Tanjong Pagar and Brani terminals into three. Maher and APM terminals in the Port of New York and New Jersey (USA) have two quays each, while Terminal 1 of Jebel Ali Port (Dubai) has three quays. Many other examples can be observed in other ports. It could be argued that algorithms designed for single quay terminals can be adapted to the multiple quay case. Nevertheless, addressing the problem as it really is, with multiple quays, can lead to better algorithms and, more importantly, will allow us to include more realistic characteristics. Conditions such as the fact that a given vessel cannot moor at a given quay for technical or contractual reasons, or the assignment of different costs for mooring at different quays, are easily added to algorithms specifically designed for terminals with multiple quays.

This paper extends the dynamic and continuous Berth Allocation Problem to the case of multiple quays. Considering multiple quays to moor a set of calling vessels adds a problem of assigning vessels to quays to the basic problem of deciding the time and position for each vessel at the quay. While the basic problem can be represented in a single space–time diagram, the problem with multiple quays requires a multiple space–time representation, as can be seen in Fig. 1, in which each space–time diagram shows the distribution of the vessels assigned to each quay. The horizontal axis shows the time, in hours, and the vertical axis the length, in meters. The first quay has a length of 800 m and 5 vessels are berthed. Quay 2 has 600 m and 3 vessels, while quay 3 is 1000 m long and 4 vessels have been assigned to it. Each vessel is represented by a rectangle, whose length is the handling time and whose height represents the vessel length.

In order to solve this problem we have worked in two complementary directions. We first developed an integer linear model with the objective of minimizing the sum of all operational costs involved. That includes the usual waiting and delay costs for each vessel and also the cost of assigning vessels to quays and, for each vessel, the cost of deviation from its desired berthing position at the quay. In a second phase we developed a genetic algorithm in order to solve problems of realistic size in short computing times. The BAP allows a natural representation using sequences of vessels that can be used by the genetic operators to evolve them towards high quality solutions. Vessel sequences are decoded by using a fast constructive algorithm. The solutions obtained by the genetic algorithm are further improved by a local search procedure.

The integer linear model and the genetic algorithm have been tested on a set of instances generated by adding more quays to the one-quay instances of Park and Kim (2002). Nevertheless, in order to assess the performance of the proposed algorithms, we have also solved the one-quay instances of Lee, Chen, and Cao (2010) and Cordeau, Laporte, Legato, and Moccia (2005), adapting our algorithm to one quay and using the objective function proposed in each study. The results show that our genetic algorithm outperforms both the GRASP algorithm by Lee et al. (2010) and the Tabu Search algorithm by Cordeau et al. (2005). We have also developed a random instance generator in which all the parameters (number and length of quays and vessels, arrival and departure times, relative importance of costs) can be controlled, thus allowing us to study the effect of each element on the complexity of the problem.

The rest of the paper is organized as follows. After the literature review in Section 2, in Section 3 we describe the characteristics of the problem and then in Section 4 we present the mathematical formulation for the continuous dynamic *BAP* with multiple quays. In Section 5 we present our metaheuristic solution approach, describing first the elements of the genetic algorithm, then the constructive algorithm for decoding the sequences, and finally the local search procedure. Section 6 presents the numerical experiments with the integer formulation and the genetic algorithm. Finally, in Section 7 we draw some conclusions and discuss future work.

2. Related work

Berth allocation is considered one of the key issues in a container terminal. Therefore, it is not surprising that the many variants of the problem have been the object of extensive research in recent years. In their first survey (Bierwirth & Meisel (2010)) reviewed 53 papers published from 1994 to 2008, while in their second survey (Bierwirth & Meisel, 2015) they review 79 new papers that have appeared since 2009. These surveys cover all types of Berth Allocation Problems, classified by the spatial layout (discrete, continuous, or hybrid), the temporal attributes of the vessels (static, dynamic, with due dates), the types of handling times (fixed, depending of the position at the quay, depending on the number of quay cranes assigned, depending on the quay crane schedules) and the measures of performance, including different

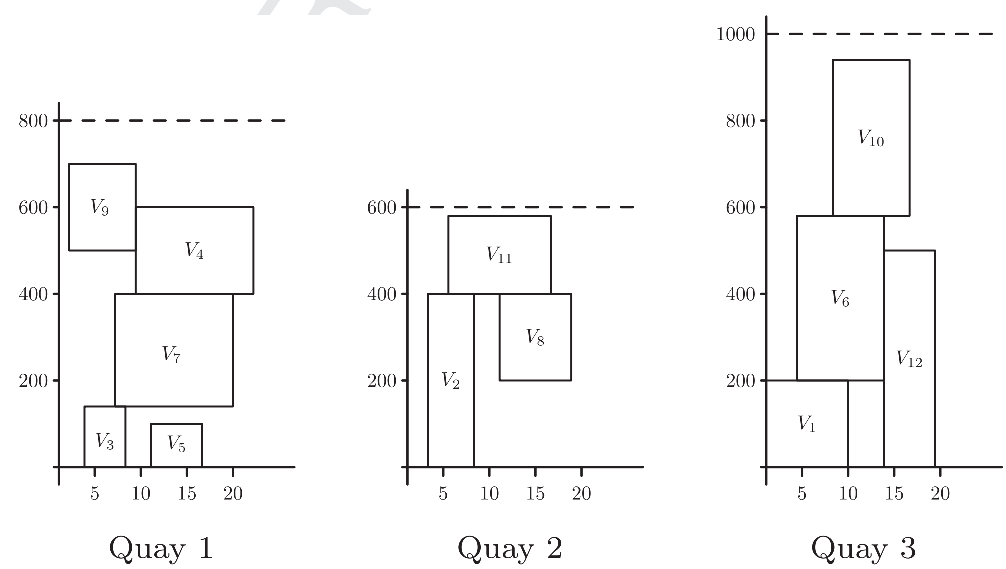

Fig. 1. A BAP solution with 3 quays and 12 vessels.