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Biased random key genetic algorithm for the Tactical Berth Allocation Problem

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ABSTRACT

The Tactical Berth Allocation Problem (TBAP) aims to allocate incoming ships to berthing positions and assign quay crane profiles to them (i.e. number of quay cranes per time step). The goals of the TBAP are both the minimization of the housekeeping costs derived from the transshipment container flows between ships, and the maximization of the total value of the quay crane profiles assigned to the ships. In order to obtain good quality solutions with considerably short computational effort, this paper proposes a biased random key genetic algorithm for solving this problem. The computational experiments and the comparison with other solutions approaches presented in the related literature for tackling the TBAP show that the proposed algorithm is applicable to efficiently solve this difficult and essential container terminal problem. The problem instances used in this paper are composed of both, those reported in the literature and a new benchmark suite proposed in this work for taking into consideration other realistic scenarios.

Introduction

The competition between sea-freight container terminals has hugely grown due to the increased transport of goods along the main maritime routes of containers and the important economic role played by the container ports in countries and regions. According to a United Nations Conference on Trade And Development (UNCTAD) study [30], the average container traffic growth in the last two decades is around 10%. This growth of containers traffic leads to port terminals to manage a larger number of incoming ships at a competitive price. In order to achieve this goal, container terminals are forced to improve their management capabilities and resources utilization with the objective of enhancing productivity to compete with other port terminals. For this reason, an inefficient utilization of some key-factor resources like berths and quay cranes (QCs) might be translated into a delay of the yard-side and land-side operations, resulting in lower global productivity of the container terminal.

From a general point of view, the loading and unloading processes in a container terminal consist of several phases as indicated by Steenken et al. [36], Stahlbock et al. [35] and Monaco et al. [25]. Whenever a ship arrives to the port, it is allocated to a specific berth, where a set of quay cranes are required to perform its loading and unloading operations. The unloaded containers are stored on the yard in order to continue their route by trains, trucks or other ships. Meanwhile, the allocated ship may be loaded with transshipment containers which will continue their route to other container terminals. The processes described above present a high dependence among the tasks and operations that are carried out in them. Concerning the operations of the Tactical Berth Allocation Problem studied in this paper, the ships are allocated in berthing positions and the time of their stay in port depends on the number of quay cranes assigned for serving them. In this regard, the quay crane productivity depends on the number of ships assigned to it, while the berths productivity depends on the waiting time and service time of the ships. According to Expósito et al. [12], most of the time spent by a container ship in a terminal is used to perform the loading and unloading tasks by quay cranes. Given this important relationship between these operations, and as indicated by Bierwirth et al. [4], integrating both logistic problems is a common task in the management of container terminals. Their effective resolution will suppose important savings for the container terminal due to the fact that the

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berthing operations are one of the tasks with the highest impact on the service costs.

Regarding modern container terminals, one of the most important problems is the coordination between the storage of transshipment containers and the loading and unloading of ships. When terminal managers attempt to address this problem they also pursue at the same time to reduce the unnecessary use of transport resources. Furthermore, they also consider the direct dependence of the processes involved, specially with the allocation of cranes as they are responsible for the loading/unloading of containers. In this concern, as the number of cranes assigned to ship docked at a determined berth is reduced, the stay of the ship at port lengthens. This can cause a deviation of the berthing position or scheduling of an incoming ship that needs to pick up some transshipment containers deposited at that berth. The consideration of this issue and its appropriately resolution would suppose an improvement in container traffic management, thus the transshipment traffic comprises an increasing proportion of the maritime terminal total traffic. Moreover, this improvement in the management results in an advantage that is frequently taken into account in the decision making of the shipping lines and shippers since the terminal transshipment capacity is a decisive characteristic as indicated by Bevskovnik et al. [3].

This paper proposes a new alternative to solve the TBAP involved processes (berth and quay allocation) jointly. The proposed method is based on the development of a biased random key genetic algorithm (BRKGA). Its goal is to provide a high-quality solution in short computational times with the aim of providing terminal managers a useful tool which will make berth and quay crane allocation decisions more suitable and efficient. The effectiveness of the approach has been assessed by comparing its results with the best-known algorithmic methods reported in the related literature. Furthermore, in order to test the efficiency of the BRKGA algorithm in different scenarios, a set of new instances is proposed.

The rest of the paper is organized as follows. A literature review is provided in *Literature review*. The TBAP description is presented in *The Tactical Berth Allocation Problem*. The algorithm proposed in this paper is introduced in *Biased random key genetic algorithm*. *Computational results* section is devoted to summarize the computational experiments carried out in this work. Final section describes the conclusion.

Literature review

Several studies about maritime container terminals focus their attention on the strategic, tactical and operational problems in a container port. Some of these studies are those presented by Murty et al. [27], Vis et al. [39], Stahlbock et al. [35], Steeken et al.[36], Günter et al. [15] and Crainic et al. [8]. Some problems related to the TBAP can be highlighted: Berth Allocation Problem (BAP), that consists of assigning ships to berths over the time horizon, and Quay Crane Allocation Problem (QCAP), that consists of assigning quay cranes to ships with the purpose of serving them. A summarized state of the art of these problems and their integrations is presented by Bierwirth et al. [4], where a classification according to the way in which the integration of these two problems is performed is introduced.

The Berth Allocation Problem has been extensively studied in the literature. Due to the diversity of maritime terminal layouts, research has produced multitude of considerations for the BAP. Concerning the arrival time of the ships, two types of problems can be considered, the static version (SBAP) presented by Imai et al. [19] and the dynamic version (DBAP) presented by Imai et al. [20]. In the first case, ships are in port before the planning horizon begins, whereas in the second case, ships can arrive at any moment of the planning horizon. The SBAP can be solved in polynomial time since it can be reduced to a classical assignment problem which is known to be polynomially-solvable (Pinedo [32]). The SBAP is extended to the dynamic version by Imai et al. [20]. Due to the difficulty of accurately finding an optimal solution, these authors develop and present a heuristic using the sub-gradient method with a Lagrangian relaxation. Monaco and Sammarra [25] present a stronger formulation for the model proposed by Imai et al. [20] and present a Langrangian relaxation with a non-standard multiplier adjustment method for solving it. Nishimura et al. [28] extend this problem with the consideration of different water depths. Lalla et al. [22] present an effective and efficient Tabu Search strategy with Path-Relinking for solving this problem. Moreover, Imai et al. [21] include ships priorities.

Concerning spatial constraints, the Berth Allocation Problem can be classified as discrete, continuous or hybrid (see Bierwirth et al. [4]). The discrete case presents a quay divided into sections referred to as berths (see Imai et al. [20], Cordeau et al. [7], Nishimura et al. [28], Hansen et al. [16]). In the continuous case, there is no division of the quay, so that an incoming ship can be assigned to the quay taking into account its spatial measures (see Lim [24], Park et al. [31], Wang et al. [40]). In the hybrid version of the BAP, the quay is divided into berths, but a ship can occupy more than one berth (some examples can be found in the work presented by Cordeau et al. [7], Imai et al. [18], Cheong et al. [5]).

Cordeau et al. [7] introduce two formulations for the DBAP, in which both discrete and hybrid quay are considered. In order to solve them, two Tabu Search heuristics are presented. Moreover, Hansen et al. [16] take into account the costs for waiting and handling as well as earliness or tardiness of completion with the purpose of including priorities. There is also a handling cost associated to each berth that would vary depending on which berth is used. A Variable Neighbourhood Search algorithm is then developed for its resolution, which attains the optimal solution in the vast majority of cases.

The Quay Crane Allocation Problem (QCAP) constitutes a problem that has hardly received attention from researchers. However, it becomes important when it is integrated into the BAP, since the service time of the ships depends on the number of quay cranes assigned to them. Several studies that tackle the integration of both Berth Allocation and Quay Crane Allocation Problems can be found in the literature. The most influential papers related to the Tactical Berth Allocation Problem are described below. Imai et al. [18] propose a model for simultaneous berth-crane allocation that minimizes the total service time and develop a genetic algorithm for its solution. In their study, they do not consider the relationship between the handling time and the number of cranes. Therefore, a ship will start to be served only when a predetermined number of cranes becomes available. Otherwise, the ship will have to wait until they are available. Zhang et al. [41] consider the allocation of discrete berths and quay cranes for ships arriving at container terminals. For this purpose, a mixed integer programming model is presented and solved by a sub-gradient optimization algorithm. In this integrated model, the berth and quay crane allocation problems are simultaneously solved under the consideration of coverage ranges of the quay cranes and limited adjustments of the quay cranes allocated during loading and unloading. Liang et al. [23] address the operational problem of determining the berthing position and the number of quay cranes assigned to the ships. They aim to minimize the sum of the handling, waiting and delay times for every ship. Due to its difficulty they propose a genetic algorithm to find an approximate solution. Raa et al. [33] present a model for the integration of the BAP and QCAP at an operational level where ships priorities, preferred berthing locations and handling times are taken into account.

While the majority of the literature works related to the integration of the BAP and QCAP are focused on an operational level, only