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# An efficient algorithm for solving a new mathematical model for a quay crane scheduling problem in container ports

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ABSTRACT

This paper presents a novel, mixed-integer programming (MIP) model for the quay crane (QC) scheduling and assignment problem, namely QCSAP, in a container port (terminal). Obtaining an optimal solution for this type of complex, large-sized problem in reasonable computational time by using traditional approaches and optimization tools is extremely difficult. This paper, thus, proposes a genetic algorithm (GA) to solve the above-mentioned QCSAP for the real-world situations. Further, the efficiency of the proposed GA is compared against the LINGO software package in terms of computational times for small-sized problems. Our computational results suggest that the proposed GA is able to solve the QCSAP, especially for large sizes.



## 1. Introduction

The use of containers in maritime transportation is rapidly increasing during last decades. A container terminal plays an essential role in a port as a intermodal interface, in which container vessels dock on berths, load outbound (export), and unload inbound (import) containers. The main productivity of a container terminal can be measured in terms of two factors: (1) Ship operations where containers are discharged from and onto a ship; and (2) receiving and delivery operations where containers are transfered to and from outside trucks (Kim & Park, 2004). The planning process of ship operations consists of berth planning, quay crane (QC) or work scheduling, and discharge and load sequencing. During the process of berth planning, the berthing time and the berthing position of a container ship on a wharf must be determined. A QC schedule specifies the service sequence of bays in a ship by each QC and the time schedule for the services. Input data for QC scheduling consists of a stowage plan of a ship, the ready time of each QC, and a yard map showing the storage locations of a containers bound for the ship. Finally, during discharge and load sequencing, the discharge and load sequence of individual containers are determined based on a QC schedule. This paper addresses the QCSAP, which is pertinent to the second stage of ship operarion planning.

By considering that the main objective of a QC scheduling problem is to minimize the makespan of vessels. Kim and Park (2004) presented a mathematical model for a QC scheduling problem. We extend their model incorporating with QC assigment problem, namely QCSAP. We apply this extended model for a container terminal located at the south of Iran, called Shahid Rajaei Terminal. In the case of any delay in the total known charge or discharge time, the container terminals must pay the related cost, called Demoraje, to vessels. Furthermore, they receive the cost of earliness in the total completion time, called Dispatch. Thus, makespan of container vessels is the latest completion time among all handling tasks of the container vessel, which is a critical success factor. On the other hand, the use of each quay crane has a fixed and variable cost for each unit of time. In this paper, we propose and develop a new mixed integer programming (MIP) model for the quay crane scheduling and assignment problem to vessels optimizing the efficiency of container terminal operations.

There are many different decision problems involved in a container terminal operation, such as berth allocation, storage space allocation, quay crane (QC) scheduling, QC allocation, location assignment, yard crane scheduling, trailer routing problem, and so on. All these decisions affect on each other. The QC scheduling problem is one of the significant issues in container terminal operations. The main goal of this problem is to determine the sequence of loading and unloading operations in such a way that the completion time of a ship operation is minimized, similar to the parallel machine scheduling problem. However, the QC scheduling

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problem has several unique characteristics that are different from typical parallel machine problems. For example, when loading and unloading operations are performed at the same ship-bay, the discharging operation must preceed the loading operation. When unloading operations are performed in a ship-bay, tasks on a deck must be performed before tasks in the hold of the same ship-bay. Thus, there are precedence relationships among clusters, whose relationships must be observed during a ship operation. Thus, certain peirs of tasks cannot be performed simultaneously when the location of the two clusters corresponding to the tasks are too close to each other. Becouse two adjacent QCs must be apart from each other at least one ship-bay in order to simultaneously perform their tasks without interference. If containers must be picked up or dropped off to the same location in a yard, these two tasks may not be performed simultaneously. It causes interference among yard cranes that transfer containers corresponding to two tasks.

The literature can be divided over the various problems in the container terminal as follows: (1) arrival of the ship; (2) unloading and loading of the ship; (3) transport of containers from ship to stack; and (4) stacking of containers. The most important problem in the first problem is the berth allocation problem (BAP). Imai, Nagaiwa, and Tat (1997) introduced a model minimizing the sum of port staying times of ships as well as minimizing dissatisfaction of ships in terms of the berthing order. Imai, Nishimura, and Papadimitriou (2001) introduced both static and dynamic BAPs. They developed a heuristic based on Lagrangian relaxation. Nishimura, Imai, and Papadimitriou (2001) extended the dynamic BAP proposed by Imai et al. (2001) to treat some physical restrictions on berthing ship such as water depth and berth length. They employed a genetic algorithm (GA) to find the approximate solution for the given problem.

Imai, Nishimura, and Papadimitriou (2003) introduced the service priority of the ship in dynamic berth allocation circumstances. They first attempted to utilize the Lagrangian relaxation; however, they found that the relaxed problem is reduced to the quadratic assignment problem (QAP), which is difficult to solve in the polynomially bounded computation time. Consequently, they applied a genetic algorithm for this problem. Imai, Nishimura, Hattori, and Papadimitriou (2007) solved the berth allocation problem at indented berths for mega-containerships by a GA.

In the above-mentioned problem of the second problem, more useful and important subjects are Stowage planning for container and the crane scheduling problem. We present a model for crane scheduling problem in this paper.

Kim and Park (2004) presented a mathematical model for a QC scheduling problem. This study proposed a branch and bound (B&B) method to obtain the optimal solution of the QC scheduling problem and a heuristic search algorithm, called greedy randomized adaptive search procedure (GRASP), to overcome the computational difficulty of the B&B method. Daganzo (1989) first discussed that the limitation in the length of a berth must be considered simultaneously during the crane scheduling. However, more emphasis was placed on schedules of QCs than that of the berth which is the main issue of this study. Regarding the crane-scheduling problem, he suggested an algorithm to determine the number of cranes in order to assign to ship bays of multiple vessels.

Li, Cai, and Lee (1998) considered the berth-scheduling problem to be a scheduling problem for a single processor (i.e., berth) that can simultaneously perform multiple jobs (vessels). They suggested various algorithms based on first-fit-decreasing (FFD) heuristics and tested the algorithms by a simulation study. Bish (2003) considered a container terminal loading/unloading containers to and from a set of ships, and storing the containers in the terminal yard. The problem is (i) to determine a storage location for each unloaded container, (ii) to dispatch vehicles to containers, and (iii) to schedule the loading and unloading operations on the cranes in such a way that the maximum time to serve a given set of ships is minimized. At last, he proposed a heuristic algorithm based on formulating the problem, referred to a transshipment problem.

Cordeau, Gaudioso, Laporte, and Moccia (2005) considered the quay crane scheduling problem to minimize the vessel completion time and the crane idle times. They proposed a branch-and-cut algorithm to solve this problem. Lee, Wang, and Miao (2008) studied QC scheduling with non-interference constraints and they proposed a genetic algorithm to obtain near-optimal solutions. Jung and Kim (2006) proposed genetic algorithm and simulated annealing methods to schedule loading operations when multiple yard cranes are operating in the same block. The loading scheduling methods considered interferences between adjacent yard cranes. It attempts to minimize the makespan of the yard crane operation. They considered the container handling time, the yard crane travel time, and the waiting time of each yard crane, when evaluating the makespan of the loading operation by yard cranes. Kim and Kim (1999) investigated a routing problem of straddle carriers in port container terminals. They proposed a beam search algorithm to minimize the total travel distance of these carriers in the yard.

Kia, Shayan, and Ghotb (2002) used a simulation model to investigate and evaluate the performance of a container terminal considering its handling equipment and terminal capacity. Kim, Kim, Hwang, and Koc (2004a) studied an operator-scheduling problem of a real-case container terminal in Korea. They used commercial software to present an efficient scheduling of operators of handling devices. Kim, Won, Lim, and Takahashi (2004b) proposed a control framework for automated container terminals. They presented an architectural design of control software and a simulation-based test-bed for testing various control rules of the control software, in which automation of handling equipment and operation in port container terminals was utilized. Kim and Bae (1998) proposed a methodology to convert a current bay layout into a desirable layout by moving the fewest possible number of containers and in the shortest possible travel distance. They presented three mathematical models for the bay matching, the move planning, and the task sequencing problems minimizing the completion time of the re-marshaling operation.

The rest of this paper is organized as follows: the extended quay crane problem (QCP) is formulated in Section 2 and the proposed GA is developed in Section 3. Computational results are reported in Section 4 and finally Section 5 covers the conclusion.

## 2. Mathematical model

Vessels can be processed simultaneously by several QCs. The processing time of a vessel will be longer than scheduled if an insufficient number of QCs is assigned to the vessel. This will delay in the departure of the vessel. However, we cannot assign too many QCs to vessels because of the number of QCs constraint. So, in this paper, we consider the optimal allocation and schedule of a given number of QCs to vessels planned to arrive in the planning horizon. Zhang, Liu, Wan, Murty, and Linn (2003) considered a fixed planning horizon with the rolling-horizon approach (RHA) for a storage space allocation problem (SSAP), as shown in Fig. 1.

In most real cases, there are dynamic situations in ports where vessels always move in and out. We cannot assume that the number of active vessels are fixed because many vessels after unload/load processes leave the port in a given time horizon and other vessels are replaced with them. Therefore, we cannot present a fixed schedule for a planning horizon. This plan assumes that all vessels arrive and leave the port at the beginning and end of the planning horizon, respectively. However, the above situation never happens in real cases. In this case, a