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A decision support system for managing combinatorial problems in container terminals

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ABSTRACT

A container terminal is a facility where cargo containers are transshipped between different transport vehicles. We focus our attention on the transshipment between vessels and land vehicles, in which case the terminal is described as a maritime container terminal. In these container terminals, many combinatorial related problems appear and the solution of one of the problems may affect to the solution of other related problems. For instance, the berth allocation problem can affect to the crane assignment problem and both could also affect to the Container Stacking Problem. Thus, terminal operators normally demand all containers to be loaded into an incoming vessel should be ready and easily accessible in the yard before vessel's arrival. Similarly, customers (i.e., vessel owners) expect prompt berthing of their vessels upon arrival. However the efficiency of the loading/unloading tasks of containers in a vessel depends on the number of assigned cranes and the efficiency of the container yard logistic. In this paper, we present a decision support system to guide the operators in the development of these typical tasks. Due to some of these problems are combinatorial, some analytical formulas are presented to estimate the behavior of the container terminal.

1. Introduction

Container terminals generally serve as a transshipment between ships and land vehicles (trains or trucks). Henesey shows in [17] how this transshipment market is growing fast. Between 1990 and 2008, container traffic has grown from 28.7 million to 152.0 million of movements. This corresponds to an average annual compound growth of 9.5%. In the same period, container throughput went from 88 million to 530 million of containers, which represents an increase of 500%. The surge of both container traffic and throughput is linked with the growth of international trade in addition to the adoption of containerization as privileged vector for maritime shipping and inland transportation [1].

The efficient management of containers in port requires more analysis and development to ensure reliability, delivery dates or handling times in order to improve productivity and container throughput from quay to landside and vice versa. Extensive surveys are provided about operations at seaport container terminals and methods for their optimization [32,30]. Moreover, other problems are faced on planning the routes for liner shipping services to obtain the maximal profit [7]. Another important issue for the success at any container terminal is to forecast container throughput accurately [5]. Thus, they could develop better operational strategies and investment plans.

The main research on optimization methods in container terminals is related to reduce the berthing time of vessels. This objective generates a set of interrelated problems such as berth allocation, yard-side operation, storage operation and gatehouse operation. Usually, each one of these problems is managed independently of others due to their exponential complexity. However, these problems are clearly interrelated so that an optimized solution of one of them restrings the possibility of obtaining a good solution in another.

The overall goal collaboration between our group at the Technical University of Valencia (UPV), Valencia Port Foundation, and the maritime container terminal MSC (Mediterranean Shipping Company S.A.) is to offer assistance to help in planning and scheduling tasks such as the allocation of spaces to outbound containers, to identify bottlenecks, to determine the consequences of changes, to provide support in the resolution of incidents, to provide alternative berthing plans, etc.

In this paper, we focus our attention on three important and interrelated problems: the berth allocation problem (BAP), the Quay Crane Assignment Problem (QCAP) and the Container Stacking Problem (CStackP) (see Fig. 1). Briefly, the BAP and QCAP consist of the allocation of docks and quay cranes to incoming vessels under several constraints and priorities (length and depth of vessels, number of containers, etc.). On the other hand, when a

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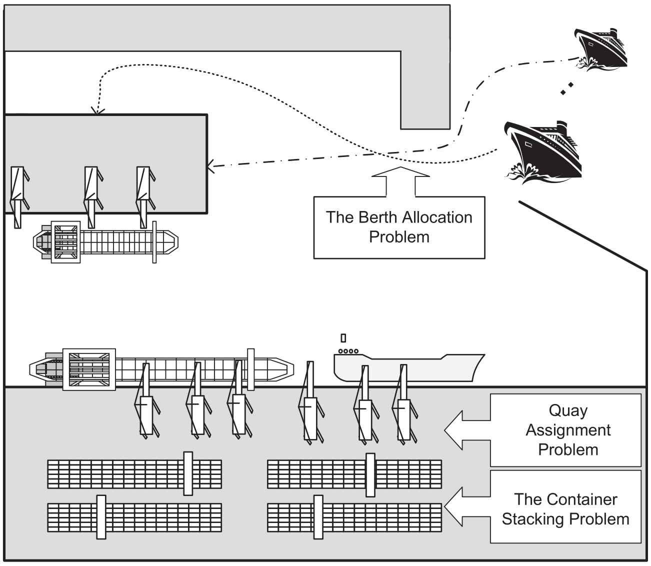

Fig. 1. Integrated remarshaling, berthing and quay crane allocation problems in maritime terminals.

vessel berths, export containers stacked to be loaded in the vessel should be on top of the stacks of the container yard. Therefore, the CStackP consists of relocating the containers so that the yard crane does not need to do re-handling work at the time of loading. These two problems are clearly related: an optimal berth allocation plan may generate a large amount of relocations for export containers; meanwhile a suboptimal berth allocation plan could require fewer rearrangements. Terminal operators should decide which solution is the most appropriate in each scenario.

In order to provide a computer-based decision support system, we integrate a set of intelligent techniques for solving these problems concurrently in order to achieve a mixed-solution that combines optimization of BAP, QCAP and CStackP. To this end, we developed a heuristically-guided planner for generating a rehandling-free intra-block remarshaling plan for container yards (CStackP problem). Due to the fact that this is a time consuming task, we present in this paper an analytic formula to estimate the number of reshuffles needed to solve this problem. Then, we present a meta-heuristic approach for solving the BAP + QCAP as an independent problem. Afterwards, we integrate solutions obtained from BAP + QCAP and StackP systems, so that terminal operators should ultimately decide which solution is the most appropriate in relation to a multi-objective function: to minimize the waiting times of vessels and to minimize the amount of relocations of containers.

These techniques will be very useful for terminal operators due to berth allocation is especially important in case of ship delays because in this case a new berthing place has to be allocated to the ship whereas containers are already stacked in the yard [30] and a remarshaling plan remains necessary to minimize the berthing time.

2. Integrating BAP, QCAP and CStackP

As we have pointed out, both the CStackP and the BAP + QCAP are well-known problems and several techniques have been developed to solve them separately. However, few systems have been developed to relate and optimize both problems in an integrated way. Some works consider berth and yard planning in a common optimization model [2,4,10], but they are mainly focused on storage strategies. Moreover, only some works integrate the BAP with the QCAP. Giallombardo et al. [12] try to minimize the yard-related house-keeping costs generated by the flows of containers exchanged between vessels. However, there also exists a relationship between the optimization of maritime and terminal-sides operations (BAP, QCAP, CStackP, etc.). Fig. 2 shows an example of three berth allocation plans with the corresponding quay crane allocations and a block of containers to be loaded in the vessels. Containers of type A, B and C must be loaded in vessels A, B and C, respectively. In the first berth allocation plan, the order of vessels is A–B–C and the quay crane allocation is two cranes, three cranes and one crane, respectively. The second berth allocation plan is C–B–A. In this case the quay crane allocation is three, two and one, respectively. Finally, the third berth allocation plan is B–C–A and two quay cranes are allocated to all vessels. Each configuration generates a different waiting time for berthing and different handling times, and the port operator probably selects the best solution to optimize these (BAP and QCAP) problems. However the best solution of these two problems could generate a large number of reshuffles in the yard so the question is straightforward: what is a better solution? Perhaps a solution that optimizes the BAP + QCAP could not be the more appropriate for the CStackP (and vice versa).

Given a waiting queue of vessels to be allocated and a given state of the containers in the container yard, each solution for the BAP + QCAP ($SBAP_i$: a feasible sequence of mooring and a feasible quay crane allocation), requires a different number of container's re-locations in the associated CStackP solution ($SCStackP_i$) in order to put on top the containers to be loaded according to the order of berthing. We can associate a cost to each $SBAP_i$ + $SQCAP_i$ related to the total weighted waiting time and handling time of vessels of this berthing order (T_w). Likewise, we can associate a cost to each $SCStackP_i$ as the number of required container relocations. Therefore, we can qualify the optimality of each global solution (Sol_i) of BAP + QCAP and CStackP as a lineal combination of the quality of each partial solution:

$$Cost(Sol_i) = \alpha * Cost(SBAP_i + SQCAP_i) + \beta * (SCStackP_i) \quad (1)$$

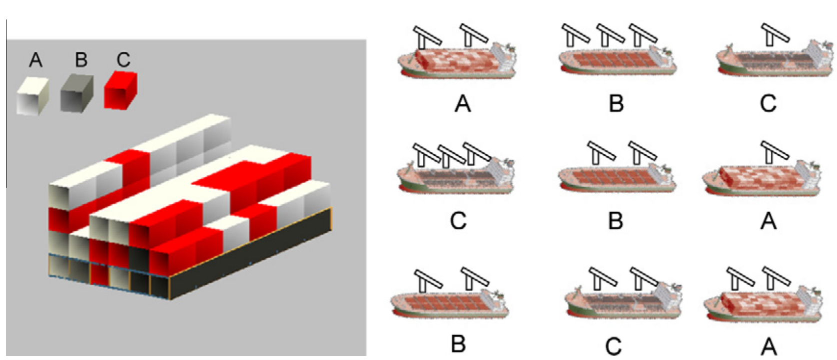

Fig. 2. Different alternatives of BAP and QCAP.