A Multi-stage Approach Aimed at Optimizing the Transshipment of Containers in a Maritime Container Terminal

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Abstract. This paper addresses the management of container flows in a maritime container terminal. In this context, we propose a multi-stage approach that allows to provide a complete schedule of the container flows from their arrival within container vessels to their delivery to receiving companies. Our proposed approach is aimed at minimizing the total maximum waiting time of the companies after they have requested containers. The computational results indicate that there are some relations subjected to the involved resources that have to be considered when tackling this problem.

Keywords: Container transshipment · Maritime container terminal · Metaheuritics

1 Introduction

The multi-modal transportation involves the interconnection of several means of transport (*e.g.*, container vessels, trucks, trains, etc.). In this environment, maritime container terminals play a highlighted role. These facilities are open systems dedicated to the exchange of containers in multimodal transportation networks, allowing to move goods from their production sources towards their final destinations. However, the management of a given maritime container terminal is extremely complex due to the high volume of containers to handle, the number and the characteristics of the heterogeneous processes brought together within it, and the increasingly demand of reliable services.

For this reason, the availability of support systems that aid to achieve an efficient management of maritime container terminals is of essential interest in this transportation area. Thus, in order to tackle some of the most challenging issues for obtaining a support system, the main goals of this paper are *(i)* to analyse the main flows of containers in a maritime container terminal between the quay area and external companies that pick up the containers, and *(ii)* to propose a multi-stage approach aimed at modelling the transshipment of containers in a terminal.

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The remainder of this paper is organized as follows. Section 2 introduces an analysis of the main flows of containers arisen in maritime container terminals. Section 3 overviews the most highlighted papers found in the related literature. Afterwards, Sect. 4 introduces a multi-stage approach aimed at optimizing the transshipment of containers in a given maritime container terminal. Several computational experiments are presented and discussed in Sect. 5. Finally, Sect. 6 draws the main conclusions extracted from the work and proposes several lines for further research.

2 Maritime Container Terminals

The maritime container terminals are huge facilities found within multi-modal transport networks mainly dedicated to exchange containers among different transport modes. The layout of a terminal can be split into the following three different functional areas (Günther and Kim [10]):

- The *quay area* is the part of the port in which the container vessels are berthed in order to load and unload containers to/from them. The main seaside operations in maritime container terminals are studied in [14].
- The *yard area* is aimed at storing the containers until their subsequent retrieval. The main storage yard operations and several directions for further research are analysed in [2].
- The *mainland interface* connects the terminal with the land transport modes. The transport operations in container terminals are reviewed in [3].

The containers in a maritime container terminal arrive by means of container vessels, trucks, or trains. Once a container vessel arrives to the terminal, a suitable berth is assigned to it according to its particular characteristics (*i.e.*, draft, stowage plan, etc.) and all its containers are unloaded by means of the available quay cranes. Simultaneously, some containers can be loaded to be transported by the vessel towards another port in its shipping route. The loading and unloading operations are termed *transshipment operations* and have a great impact on the competitiveness of the terminal due to the fact that they determine the turnaround time of the vessels at the terminal.

Internal transport vehicles found at the terminal are aimed at moving containers from the quay cranes towards their storage locations on the yard, and vice-versa. The containers are stored on the yard of the terminal until their subsequent retrieval, which is determined by their loading time in vessels or the expected arrival time in private companies found outside the terminal.

The containers are moved between the terminal and the existing private companies found outside the terminal by means of external transport vehicles. The containers requested by the external transport vehicles can be picked up from the quay after the quay crane has unloaded them or from their current locations in the yard blocks. Once a container has been picked up by an external transport vehicle can be directly transported towards its destination private company outside the terminal. It is worth mentioning that, due to space and security restrictions, only a maximum number of external transport vehicles can be simultaneously in the terminal.

The optimization objective studied in this paper is the minimization of the waiting times of the private companies requesting containers. This can be formally expressed as follows:

$$\min \sum_{e \in E} wt(e), \tag{1}$$

where E is the set of existing private companies and $wt(\cdot)$ is the maximum waiting time of a company after requesting containers.

3 Related Works

The container transshipment management at maritime container terminals involves, at a first stage, the berthing of container vessels and the storage of their containers on the yard. In this regard, the quay and yard operations play an outstanding role due to their direct impact on the overall management of transshipment flows.

The main logistic problem at the seaside is the so-called Berth Allocation Problem (BAP). Its goals are assigning and scheduling incoming vessels to berthing positions along the quay. As indicated in [12], this problem has a relevant impact on the container terminal performance. The reason is found in that a bottleneck derived from a poor schedule of its resources may be translated into a delay of the remaining logistic operations at the terminal.

Once the vessels have been berthed, their containers are unloaded [7] and moved towards the yard, where they are stored in the yard blocks until their subsequent retrieval [9]. However, the space on the yard is a scarce resource, and therefore suitable stacking strategies are required. This way, a continuous flow of goods in the supply chain is kept. Optimization approaches have been proposed in [11] and [1] among others with the aim of satisfying the container requests of a container terminal.

On the other hand, a relevant problem arises in the land-side, the route planning problem, which can be split into two stages: the design of service networks (tactical), whose goal is to find the best set of services dealing with transport and logistics, and the transport programming or operational planning (operational), which determines the best service under scenarios with available resources and imposed constraints. Most inter-modal problems described in the literature follows the first format (*i.e.*, design and planning of networks and flow), aimed at finding the best combined transport route in an inter-modal transport network. These problems are solved and modelled as a shortest path problem, since their objective is to find the best path given specified starting and ending points, and doing stops at diverse nodes. See the works [4,5], and [15] for further discussion.

4 Optimization Approach

The flow of containers around a maritime container terminal in their way towards receiving companies can be addressed by a multi-stage approach, as discussed

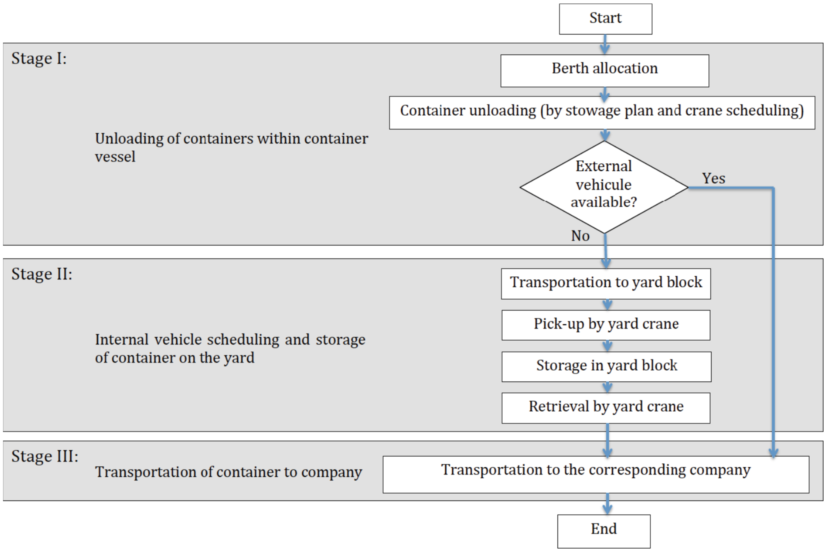

Fig. 1. Diagram of the multi-stage approach

in the following. This is depicted in Fig. 1. Those container vessels arriving to port must be adequately berthed along the quay in order to load and unload their containers while minimizing their waiting times. Thus, at Stage I, the vessels are allocated and the transshipment containers to be loaded and unloaded from/into are scheduled by the quay cranes according to their stowage plans. An efficient Tabu Search algorithm with a Path-Relinking-based restarting strategy (Lalla-Ruiz *et al.* [13]) is used at this stage.

Moving containers from the terminal to the companies requires to manage a fleet of external transport vehicles. With this goal in mind, a heuristic approach is proposed. This approach allows to assign each container to one of the available external transport vehicles with the aim of minimizing the total transportation times of containers to companies. This way, each container unloaded from a vessel is assigned to a vehicle to be transported to its destination company as shown in Stage III. In those cases in which there is not external transport vehicle, the container must be stored in one of the yard blocks and follow the process shown in Stage II.

As above mentioned, in some cases, containers cannot be delivered immediately to their destination companies, and then they have to be temporarily stored on the yard of the terminal. In this case, each container is moved to the yard by one of the internal vehicles of the terminal and stored in a yard block by means of the stacking cranes. The management of the storage and retrieval operations in blocks is known as Stacking Problem (SP). Its objective is to minimize the number of relocation movements performed by the stacking cranes at the yard. A heuristic algorithm [8] to solve this problem is used. The rationale behind our heuristic is to exploit those time periods in which the stacking cranes are idle in order to arrange the stored containers according to their retrieval orders.

5 Computational Experiments

This section is devoted to assess the performance of the multi-stage approach proposed in this paper. The influence of the different elements of the maritime container terminal in the companies waiting time has been studied, and the correct behaviour of our approach has been checked. The approach has been implemented using the programming language Java Standard Edition 7.0. All the computational experiments have been carried out on a PC equipped with Ubuntu 13.10, a processor Intel Core 2 Duo 3.16 GHz, and 4 GB of RAM.

Some parameters, such as number of containers nC, number of companies nE, number of berths nB, and number of arriving vessels nV, have been taken into account to generate scenarios with different features. These scenarios have been executed changing some other parameters values, such as number of quay cranes of a berth b denoted as $qc(b)$, number of internal vehicles $nKin$, number of external vehicles $nKout$, and maximum number of internal vehicles simultaneously allow inside container terminal.

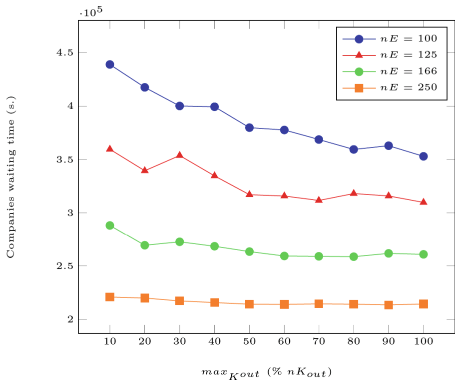

Fig. 2. Average companies waiting time according to a percentage over a maximum number of external vehicles ($max_{K^{out}}$).

For the first experiment, we have checked the influence of the number of external vehicles simultaneously allowed inside the terminal ($max_{K^{out}}$) over the companies waiting time. Figure 2 shows the behaviour of the companies waiting time when the percentage of external vehicles allowed inside the terminal $max_{K^{out}}$ increases. Each line corresponds to a different number of companies $nE = \{100, 125, 166, 250\}$, and the number of containers nC has been fixed to 500.

As can be seen in Fig. 2, the rank of the waiting time is different based on the number of companies to which containers belong, going from 4 days to 2 days. It has been possible to verify that the higher the percentage, the smaller the companies have to wait.

Moreover, there is a certain stability in terms of companies waiting time obtained when a percentage is reached. In this regard, this stability is achieved earlier when the number of external vehicles increases, since the percentage of allowed vehicles in the terminal is calculated on the basis of the total number of external vehicles. Hence, the higher the total number of external vehicles, the larger the number of external vehicles allowed inside terminal, and therefore the better the results in terms of the companies waiting time. This way, when the total number of external vehicles is very high there is no difference between allowing 10 % or 100 % of them inside terminal. With this kind of graphic it is possible to determine which is the limit number of external vehicles allowed inside terminal for which no significant improvement occurs in terminal performance according to the particular characteristics of the studied terminal.

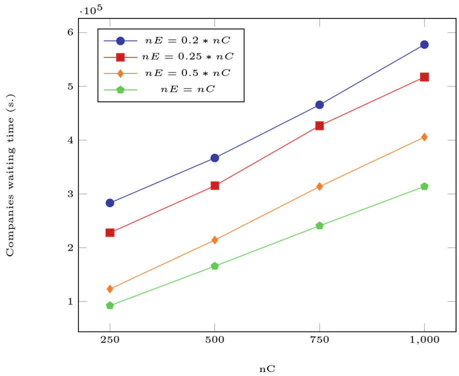

Fig. 3. Average waiting time of companies according to the number of containers (nC)

The second experiment has been made in order to assess the influence of the number of required containers over the companies waiting time. Figure 3 represents the increment of companies waiting time when the number of required containers increases. In the figure, each line corresponds to a number of companies, $nE = \{0.2 * nC, 0.25 * nC, 0.5 * nC, nC\}$, which depends on the workload in terms of the number of containers $nC = \{250, 500, 750, 1000\}$.

As can be checked in the figure, the increment over the companies waiting time increases with the number of containers. This increment is quasi-linear which makes sense taking into account the increase of containers within a terminal with the same characteristics. Moreover, in those cases where the number of companies is small, the companies waiting time is higher and vice-versa. This is agree with real-scenarios since the higher the number of companies, the larger the number of external vehicles hired by them for picking-up the containers.

Furthermore, other important factor in a maritime container terminal is the number of available internal vehicles. For this reason, in the last experiment the effect of this parameter in the waiting time of companies is evaluated. Table 1 report the waiting time of companies regarding the number of internal vehicles. Each column in the table represent the different number of companies considered. As can be seen, the higher the number of vehicles, the lower the waiting time. In this regard, the reduction is more relevant in terms of objective function value when the number of companies increases. That is, when the number of companies is high, the number of external vehicles is also high, so it is more likely that an external transport vehicle may carry a container directly to a company without requiring the use of any internal vehicle.

Table 1. Average waiting time of companies according to the number of internal vehicles (nK_{in}) and number of companies (nE)

	nE			
nK_{in}	100	125	250	500
5	393152.39	324464.09	221071.60	167157.47
10	366842.52	315150.17	214457.18	166005.43
15	361079.06	307337.74	215206.25	165432.28
20	360385.22	304778.57	215020.96	164726.63

6 Conclusions and Further Research

In this work, we analyze the flow of containers in a maritime container terminal from their arrival into container vessels to their delivery to receiving companies. During this complete process, we have recognized three main stages and, hence, proposed a multi-stage approach for providing a complete schedule. The computational experiments carried out suggest that the performance of the proposed multi-stage approach corresponds with expectations while it provides a complete schedule of the resources involved in the management of container flows.

Moreover, through our propose approach terminal managers are also able to analyse the impact that some resources have over the terminal from the viewpoint of the companies. This feature provides them a support when taking strategic decisions such as increasing the number of either internal vehicles or quay cranes, extending the quay to include more berths, etc.

In future works, on the basis of the contributions presented in this paper, we will focus on the introduction of dynamism related to the arrival of the vessels and the movement of containers.

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