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Simulation-based optimization for housekeeping in a container transshipment terminal

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ABSTRACT

An important activity in container transshipment terminals consists in transferring containers in the yard from their current temporary positions to different positions closer to the point along the berth from which the containers will be boarded on departing vessels. This housekeeping process aims at speeding-up discharge and loading operations and, thus, relieving congestion. This paper introduces a heuristic procedure to manage the routing of multi-trailer systems and straddle carriers in a maritime terminal. A simulation model embedded in a local search heuristic allows a proper evaluation of the impact of different vehicle schedules on congestion and throughput. Computational experiments performed on test instances derived from real-life data show that important improvements in routing distance and vehicle waiting time can be obtained compared to the use of standard scheduling policies.

1. Introduction

The recent contraction in trade resulting from the present economic downturn has somewhat eased and, according to the IMF – International Monetary Fund, world trade is expected to increase by 3.6% in 2013 [1]. Since the amount of goods transported by sea accounts for approximately 90% of the world's total freight volume, the availability, low cost and efficiency of maritime transport via container will remain vital to the functioning of the global economy.

Although a high barrier to entry generally applies for the new players in the international container shipping industry, those already in the market will in any case have to spare no efforts to capture favorable business and turn adversity into opportunity. To do so, they will need to respond to the growing demand for their services by emphasizing the development of their core business and strengthening their competitiveness. In particular, container terminal operators will need to efficiently provide flexible, yet slim handling and storage solutions to their clients, while keeping productivity and quality up to standards.

In this sense, a major limit on the efficiency of container terminal operators is certainly represented by congestion. Congestion carries with it loss of time, rise of cost and drop in quality of service for both shipping companies and terminal operators, as well as significant deterioration of the overall terminal performance. According to a macroeconomic perspective, congestion arises when the actual demand of the shipping companies exceeds the actual capacity of the terminal facility. From an operational point of view, it can be caused by a number of factors pertaining to the container logistics chain such as the availability of limited resources, the lack of synchronization among different types of equipment dedicated to container handling and transfer and, above all, the occurrence of unforeseen events which are normally not accounted for in the terminal's organization, resource management and activity scheduling. Practically, as is well summarized in [2], various bottlenecks can be identified along the port-calling chain. A vessel that is heading from open sea to a seaport may experience congestion consecutively in the following places or corridors, depending on the location and structure of the port: maritime access route, locks, berths, discharge/loading, storage, customs inspection, hinterland discharge/loading, and hinterland connections.

In the present study, we consider the standpoint of a container terminal devoted to pure transshipment (i.e. container transfer occurs from one vessel to another rather than from vessels to train or truck units). Our contribution to keeping the terminal's productivity and quality up to standards by lessening the congestion arising at the main intra-terminal bottlenecks (i.e. berthing, discharge/loading and storage processes) is centered on the so-called housekeeping process.

Housekeeping consists in transferring a container on the yard from a temporary position to a final position with the latter being closer to the point along the berth from which the container will be boarded on a departing vessel. The object of this operational

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procedure is to speed-up discharge/loading operations. As a practical consequence, terminal productivity will increase by minimizing service delays and profits will rise by preventing the payment of extra charges for not achieving the level of service granted to clients. Shipping companies will also benefit from the implementation of this operational procedure by keeping their vessels on schedule while traveling from one port to another.

To our knowledge, the housekeeping process has not received much attention in either theoretical or empirical research. Besides [3,4], in which a queuing-based representation of the housekeeping process is proposed for a real container terminal and solved by discrete-event simulation, housekeeping is often mentioned only in a marginal way as a possible choice lying behind yard operating rules and, in particular, behind intelligent yard stacking [5–7]. Our work aims at filling in this modeling gap.

In this paper, both discrete-event simulation and local search are exploited to support housekeeping decisions in a complex, dynamic and stochastic environment. On one hand, simulation-based approaches have been widely used to model various planning problems arising in container terminals. Many examples can be found with reference to yard layout [8–12], container stacking [6,7,13,14], vehicle dispatching [3,12,15–19], alternative transfer systems [9,10,20] and inter-terminal transport [21], where the latter exhibits similar characteristics to the housekeeping process considered in this paper, including the type of vehicles deployed and the need of managing them effectively.

On the other hand, although they sacrifice a complete representation of the uncertainty and congestion phenomena inherent to the housekeeping process, deterministic optimization algorithms have the ability of identifying optimal or near-optimal solutions to simplified deterministic problems. To benefit from both approaches, we thus resort to *Simulation-based Optimization* (SO) [22].

SO is a practical solution method based on the idea of embedding a simulation engine within an optimization algorithm to deal with hard combinatorial optimization problems arising in dynamic processes characterized by sources of randomness. The optimization algorithm is aimed at generating an initial feasible solution and then exploring the solution space until no further improvements of the performance measures are obtained or until the allocated computation time budget is exhausted. The use of the simulation engine is required in the evaluation process because the cost function cannot be evaluated by simply giving values to the decision variables in a closed-form formula.

The rest of the paper is organized as follows. The housekeeping process is described in Section 2 while a mathematical formulation of the problem is provided in Section 3. The SO solution approach is then presented in Section 4. This is followed by computational results in Section 5 and by conclusions in Section 6. Finally, further details on the simulation model are provided in the Appendix.

2. Problem description

A housekeeping operation consists in transferring a container from one storage location to another with the aim of speeding up discharge/loading operations and avoiding congestion. This is possible because the latter storage position is supposed to be reasonably closer to the berth area along which the container will undergo future boarding on a pre-assigned departing vessel. Depending on the structure and the organization of the facility, a container requiring housekeeping can be transferred from a common front area to a final storage position on the yard as illustrated by Fig. 1a or between yard positions as illustrated by Fig. 1b.

From here on, we will refer to the housekeeping implementation depicted in Fig. 1b which mirrors precisely how housekeeping is carried out in our facility of interest: the container terminal located at the port of Gioia Tauro in Southern Italy. This terminal, which is almost entirely devoted to pure transshipment, features a very extensive horizontal yard layout (approximately 1,000,000 m^2). Rather than transfer cranes, the yard is equipped with 110 *straddle carriers* (SCs), i.e. very flexible and productive container handling equipment bearing an operational flexibility to both lift and transfer containers between the yard and the quay at a high speed. Due to the dimensions and organization of the container yard, transfer operations are very time consuming. As a result, resorting to housekeeping becomes a very logical choice to be taken when aiming at speeding-up the container discharge/loading cycle. Practically speaking, in the above container terminal, in which the yard is divided into blocks, the housekeeping process concerns the simultaneous transfer of a batch of containers from a source block to a destination block. This generally occurs just a matter of hours before the vessel on which containers are meant to be boarded is scheduled for departure.

A step-by-step description of the housekeeping process is given in the following and summarized by Fig. 2, according to which one can easily identify the pertaining congestion points. A request for housekeeping is performed by means of a transfer system; if the assigned system is unavailable, the container to be housekept waits in its current position on the yard and, thus, plays a role in creating potential congestion points that affect the overall housekeeping work schedule. Once available, the transfer system must access a specific row (or column) of the source block in order to retrieve the target container. For security reasons, no vehicle is allowed to access a row if container stacking/retrieval operations are already occurring in that row, as well as in the adjacent ones. Hence, transfer vehicles queuing in front of a block are another factor likely to contribute to congestion. Once access is granted to the row, the transfer system must also provide for handling: it requires time to reach the stack with the target container, eventually shuffle other containers located on top and perform the actual pick-up operation. Then, container transfer from the source block to the destination block follows and depends on the distance lying in between the blocks. Stacking operations are initiated at the destination block only if the transfer system gains immediate access to the row of interest; otherwise, the transfer vehicles must queue with the loaded container(s) in front of the block. Again, congestion is likely to occur. Once access is granted to the vehicles, container stacking within the row closes the housekeeping work cycle.

The logic behind housekeeping is quite clear. However, whether or not to perform housekeeping operations depends on the distance to cover when transferring a discharged container from its current position along the quay to its storage location on the yard. Let d be this distance. If d is less than a fixed threshold, then a *direct transfer* occurs, meaning that the container is definitely transferred to the yard position or slot in which it will remain until rescheduled for departure on another vessel. In the specific terminal under analysis, direct transfer is implemented with human operated SCs and, for our convenience, we refer to this as D-SCs. If d is greater than the aforesaid threshold, then containers will be stacked in a temporary position on the yard and undergo *indirect transfer* or housekeeping only afterwards. In this case, different types of transfer systems are used: SCs providing for housekeeping and referred to H-SCs are used over short distances, whereas multi-trailer systems (MTSs) over long distances. MTSs combine (i) SCs dedicated to container discharge/loading from/on MTSs and referred to M-SCs and (ii) tractor units to haul the trailers from one yard block to another. The number of trailers used by an MTS can affect the way to carry out the working cycle of the housekeeping process. To fix ideas, one may consider the configuration in which five trailers are used against three trailers. In the first case, the time required by the SCs to discharge/load a multi-trailer is certainly greater than the second. Thus, to avoid an unacceptable idle time for the associated tractor, the same tractor may be assigned to two different multi-trailers such that while