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Scheduling co-operating stacking cranes with predetermined container sequences☆

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ABSTRACT

With the proliferation of multi-gantry automated stacking cranes, the already difficult crane scheduling problem in container terminals has become even more challenging. In this paper we present an efficient algorithm that can solve a sub-problem that arises in this context, namely the prioritization of crane gantry movements once transportation tasks have been assigned. We tackle this problem for both, twin crane setting and crossover crane setting, and develop graphical models and strongly polynomial algorithms accordingly. A series of experiments is carried out where it is shown that the method can produce optimum solutions with exceptionally small run times.

1. Introduction

Automation has been a central agenda item for port operators and equipment manufacturers over the last 20 years. Seen as the key to significant performance improvements and cost savings, there have been many efforts to automate several terminal operation aspects. Automated Stacking Cranes (ASCs) represent a major success story from this period and have allowed terminal designers to increase the number of containers processed and stored with less cost and space requirements.

Typically containers are stored in blocks. Each block may be maintained by one or multiple gantry cranes. These span the whole storage block in width and move on tracks installed alongside the block. As opposed to straddle carriers and rubber tyred gantry cranes, which are not automated, ASCs are fixed to a certain block within the container storage area. That is, they manage containers only within the storage area and, consequently, have to hand over the containers to transport devices or receive containers from them (typically automated guided vehicles or ship-to-shore cranes on the seaside and trucks on the land side).

Since some or all types of vehicles deployed in the terminal may be unable to lift containers independently it would be essential to fix a time in the planning horizon where both, vehicles and gantries, would meet at the same place to exchange containers. In practice this requires the presence of a sophisticated scheduling technique that is able to determine a series of crane movements that are coordinated with other terminal activities. While several scheduling algorithms for ASCs have been developed in the past, see Dorndorf and Schneider [4] and Vis and Carlo [14] for example, they often overlook the

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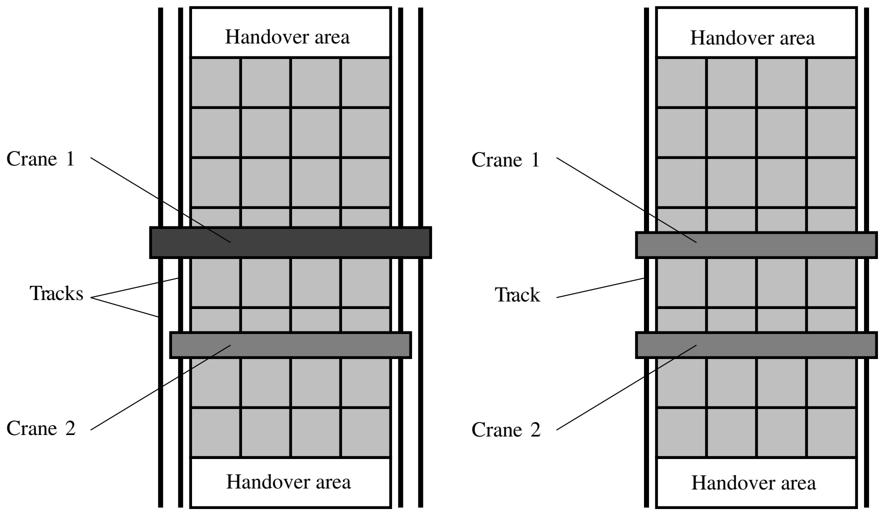

Fig. 1. Crossover cranes (left) and twin cranes (right).

potential problems that arise from the presence of two or more gantries in the same stack. The study discussed in this paper is part of a greater effort to comprehensively address crane scheduling.

Scheduling problems for ASCs typically require several decision components to be made. Usually, a set of transport jobs is given for the planning horizon under consideration. A transport job corresponds to a single container to be picked up at the origin, moved, and released at the destination. The origin is given naturally by the current position of the container and we assume the destination to be predetermined. The decision components, then, can be described as follows.

1. We need to decide which job is done by which crane in case there is more than one.
2. Given an assignment of jobs to cranes we need to decide the sequence of jobs for each crane.
3. Given the above decisions the actual point of time of each operation has to be determined. This involves, in case there are multiple cranes, resolving conflicts between cranes' operations. Typically this means that whenever two cranes cannot execute certain operations in parallel we have to decide which crane gets the right of way. The type of operations which can be executed in parallel depends on the crane design.

Throughout this paper we focus on the third decision assuming that the first two decisions have been made already. We focus on two different settings with two cranes each serving a single container block, namely crossover cranes and twin cranes. On two opposing sides of the block there are dedicated handover areas for exchanging containers with other transport devices. Fig. 1 depicts both settings looking from above. A pair of crossover cranes consists of a larger crane (Crane 1) and a smaller crane (Crane 2) using different tracks. This allows both cranes to pass each other, i.e. both cranes may serve both ends of the block. However, while the larger crane's spreader is releasing or lifting a container in a certain row the smaller crane can neither travel across this row nor perform a release or lift in the same row. In twin configurations the cranes have similar or identical gantry, use the same tracks, and, therefore, cannot pass each other. As a result, the two cranes are destined to exclusively serve the opposing ends of the block, with careful planning required when they need to operate in the middle sections.

This rather narrow problem setting can be motivated easily. First, since the aspect of avoiding collisions is rarely considered in the literature on a detailed level we may take an arbitrary schedule provided by one of the existing approaches and reoptimize the priorities without modifying the sequences of operations assigned to both cranes. Furthermore, the algorithm can be used as a component of a metaheuristic approach for holistic crane scheduling (i.e. that also addresses the allocation of jobs to cranes), with the methodology presented here being responsible for deciding movement priorities and accurately resolving any potential conflicts. A natural representation scheme used in a metaheuristic would be to have a sequence of containers for each crane implying the sequence of transport jobs as processed by cranes. Clearly, these sequences do not fully specify a schedule which is implementable since the third decision component is not represented. There are two options at hand. First, we may extend the representation scheme used in the metaheuristic framework in order to represent priorities, as well. It is likely that we end up with a representation scheme having several sections differing in their semantics. Moreover, redundancy can hardly be avoided. The second option is to design an efficient module deciding about priorities in traffic and to employ it to "interpret" individuals specified by sequences of operations. Then, each individual corresponds to many schedules and the module allows us to find the optimum schedule among those represented. This reduces the size of the search space (in comparison to the first option), reduces redundancy, and supports a representation scheme with a uniform structure.

The contribution of this paper is threefold. First, we give a graphical representation of an optimization problem with respect to the third decision component. This representation gives valuable insights into the structure of the problem which