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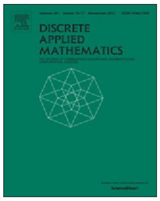

Scheduling cooperative gantry cranes with seaside and landside jobs

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ABSTRACT

We consider the problem of scheduling two identical rail mounted gantry cranes (twin cranes) working within a single storage area (block) at a seaport. The cranes, referred to as seaside crane and landside crane, cannot pass each other. Our focus is on peak times, where the minimization of dwell times of vessels at the berth is typically the major objective of port authorities. We allow the seaside crane to drop inbound containers at intermediate positions where the landside crane takes over and delivers the containers to their target slots. Earlier studies have shown that allowing the cranes to cooperate in this manner is beneficial, at least when there are no containers that are already stored in the block at the beginning of the planning horizon and that have to be delivered to the landside handover point by the landside crane within given time windows. In this paper, we analyze if the positive effect of letting the cranes cooperate persists when these latter jobs are present. This might have a critical impact, because these tasks are performed close to the landside whereas supporting the seaside crane is performed rather close to the seaside. We present complexity results and some general problem insights. Furthermore, we introduce lower bounds and develop heuristic procedures that apply these bounds. The performance of the algorithms is evaluated in computational tests.

1. Introduction

The use of standardized loading units that can be handled by different modes of transport has become one of the most time- and cost-effective ways of shipping cargo. Especially *containers* play an important role in modern freight business. The equipment required for handling containers is available almost all over the world. The number of containers handled is especially large at seaports. Large ports handle several ten thousand twenty-foot equivalent units (TEU) per day on average, so that sophisticated logistic processes at those seaports are of great importance for guaranteeing time- and cost-efficient transport.

The typical movement of an *inbound container*, i.e. a container arriving at the port with a ship, within a seaport can be described as follows. The container is unloaded by a quay crane and it is then passed to a reach stacker, a straddle carrier, an automated guided vehicle, or some similar device. It is then taken to one of dozens of *storage areas*, called blocks, for intermediate storage. A block is usually equipped with *gantry cranes*, which transport the container from a handover point located on the seaside to its designated storage position. When the container is ready to be loaded onto a train or to be picked

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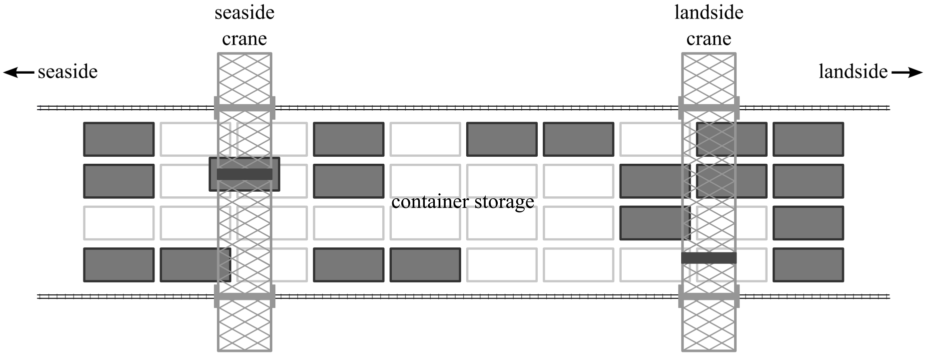

Fig. 1. Schematic layout of a twin system.

up by a truck, one of the block's gantry cranes transports the container to a handover point, which is usually located on the other side of the block, i.e. the landside. Then, again, the container is handled by some reach stacker or the like, and it is finally loaded onto a train or a truck. For the sake of completeness, it shall be mentioned that some containers that arrive by ship will be loaded onto another ship, which implies that these containers leave the block on the seaside (*transit containers*). *Outbound containers*, i.e. containers that arrive by train or truck and have to be loaded onto a ship, process the same steps in reverse order.

1.1. Problem setting and contribution

Our main focus in this paper lies on scheduling the gantry cranes working within a single block. A common configuration of a block features two identical rail mounted gantry cranes as depicted in Fig. 1. This layout is usually referred to as a *twin system* (see, for example, [11]). Based on this layout, we will refer to the cranes as the *seaside crane* and the *landside crane*, respectively. For a detailed description of the situation at the port of Hamburg, we refer to Speer et al. [15].

Each crane can move a container in three dimensions. First, the *spreader* allows for lifting and dropping the container. Usually, during lifting and dropping, no other movements of the container are possible. Second, each crane can move along *tracks*, allowing for traveling along the long (horizontal) side of the block. Whenever a crane moves in this direction, the spreader can concurrently move along the short (vertical) side of the block. As these two kinds of movements can be performed simultaneously, and as the block is very long but not very wide, spreader movements along the short side are almost never time critical. Therefore, vertical spreader moves will be neglected in our considerations, as it is often done in other approaches for container terminals (e.g. [8,12]).

The scheduling of twin cranes is usually embedded into higher scheduling tasks. Therefore, we assume that a designated storage position within the block is given for each container, so that capacity constraints or stacking constraints do not have to be considered. Furthermore, reshuffling of containers is not in the scope of our analysis, especially because the corresponding operations are commonly performed in off-peak times, while we focus on peak times.

The main challenge of a twin-crane configuration is that the cranes cannot pass each other as they share the same tracks, but working areas of both cranes must overlap because containers enter the block on one side and may leave the block on the other side. Thus, when scheduling the container moves to be performed by the cranes, *interference constraints* have to be taken into account.

The workload of the cranes varies significantly over time. It usually reaches its peak when a vessel is to be unloaded at the berth. Accordingly, our considerations will focus on this critical time period. Driven by cost requirements, the minimization of dwell times of vessels at the berth is the major objective of port authorities. Therefore, containers that have to be unloaded from a ship are assigned highest priority and the seaside crane stores containers in the block nonstop. It is a common procedure to let the landside crane perform other duties in the meantime, as, for example, delivering inbound containers to the landside handover point. However, it might be beneficial to let the cranes *cooperate*, i.e. let the landside crane support the seaside crane in storing inbound containers by allowing the seaside crane to drop inbound containers at intermediate positions, where the landside crane takes over and delivers the containers to their target slots. Briskorn et al. [4] raise the question whether this can considerably decrease the time required for storing a set of inbound containers. The authors find: "This [i.e. letting the cranes cooperate] is something for terminal operators to consider, seeing that it is not an uncommon policy in practice to assign only the seaside crane exclusively to stacking containers, while the landside crane is supposed to exclusively handle container transfers to the hinterland. Our study suggests that, at least if no hinterland traffic is currently to be handled, a lot of time can be saved if the landside crane helps out at the seaside during peak times". Even though their study shows that the commonly used procedure in practice bears potential for optimization, they study a scenario which might not be applicable in many cases. The landside crane might still have to deliver some containers that are already stored in the block at the beginning of the planning horizon to the landside handover point, or it may have to store containers that

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