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Cooperative twin-crane scheduling

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ABSTRACT

This paper treats the crane scheduling in a container port where two cooperative gantry cranes (denoted as twin cranes) jointly store import containers arriving from the seaside in a storage yard. We aim to minimize the makespan while non-crossing constraints among cranes need to be considered and preemptive container moves are allowed, i.e., the seaside crane sets down a container in some intermediate position where the landside crane takes over and delivers the container to its final storage position in the yard. Elementary complexity proofs are provided and efficient heuristic solution procedures are introduced and tested.

1. Introduction

With more and more containers arriving on container vessels of ever increasing capacity (e.g., see [1]) strong pressure is put on port operators to implement efficient handling processes. Therefore, it is not astounding that optimizing the container flow in ports with operations research methods has received considerable attention among practitioners and researchers alike (see [28,27]). In this context, an important optimization problem is the scheduling of twin cranes in the stacking yards of container ports. These yards constitute the interface between sea- and landside and intermediately store import and export containers to be exchanged between vessels and barges on the seaside as well as trucks and trains serving the landside. A widespread layout of a single block within a storage yard (also denoted as the *twin system*, see Kemme [20]), which we presuppose throughout this paper, is depicted in Fig. 1.

The container flow through such a yard block is briefly summarized in the following. Once arrived on a container vessel from overseas or on a short-sea barge, an import container is unloaded by a quay crane and handed over to a yard truck or some automated guided vehicle (AGV). This vehicle delivers the container to the seaside access point of the container yard where it is taken over by the seaside gantry crane and delivered to its intermediate storage position in the container yard. Once the truck tasked with delivering the container to its next destination in the distribution process has arrived, the landside crane retrieves the container and hands it over at the landside access point. Naturally, export containers arriving from the landside and to be loaded on a ship follow this workflow in reverse order.

In our yard setting we presuppose two identical gantry cranes, the twin cranes, which are, for instance, applied in Portsmouth, Virginia (see [11]). For their horizontal movement along the yard, these cranes share a special rail track, so that they cannot overtake each other and non-crossing constraints need to be considered when scheduling crane movements.

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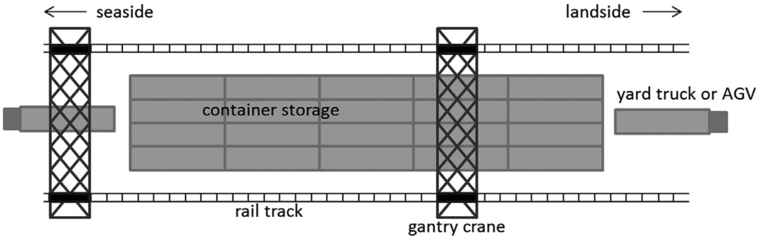

Fig. 1. Schematic layout of a yard block in a container yard.

Given these potential obstructions among cranes a widespread and simple rule for determining the division of labor is to let one crane exclusively serve the seaside and the other the landside (see [8,14,26]). Then, the one thing remaining for deriving a valid scheduling policy is a right-of-way rule (e.g., the seaside crane is generally prioritized) for resolving conflicts among cranes. We denote this basic crane scheduling policy as the *non-preemptive policy*.

The non-preemptive policy works well whenever the workloads of sea- and landside are well balanced. On the landside this premise may be somewhat fulfilled, because either individual preferences (see [17]) or an appointment system applied at the terminal (see [22]) levels the arrival times of trucks over time. However, on the seaside the workload varies considerably over the day. As containers stemming from and dedicated to the same vessel are often stored together in the same yard block [28,10], a huge number of import containers is to be stored in the respective yard block right after such a vessel arrives. Once the ship is unloaded, an additional large amount of export containers is to be retrieved by the seaside crane in order to reload the vessel. When applying the non-preemptive policy during these peak hours, the seaside crane is loaded to capacity while the landside crane runs idle.

Given an unbalanced workload it, thus, seems advisable to let the twin cranes cooperate and share the seaside workload. Cooperation can be realized by letting the seaside crane interrupt an import move and store the container in some intermediate storage position in between the seaside access point and a container's dedicated (final) storage position, so that the landside crane can take over to complete the container move. On the downside, the better division of labor comes at the cost of a more sophisticated crane scheduling problem. As before, the movement of cranes needs to be coordinated, so that collisions are ruled out, and the storage sequence of containers is to be determined. Additionally, for each import container it has to be decided whether the seaside crane executes the complete storage move alone or a hand-over position for a cooperative job processing is to be determined. This paper investigates the preemptive crane scheduling problem and aims to minimize the makespan of storing a given set of import containers arriving from seaside. Note that in some practical settings, container sequences are predetermined, e.g., by a fixed arrival sequence of AGVs or a given stowage plan. Thus, we also treat the case where container sequences are not alterable.

Existing research mainly treats non-preemptive crane scheduling in container yards. The research effort in this direction is, for instance, summarized by the in-depth review papers of Steenken et al. [28], Stahlbock and Voß [27], and Kemme [19]. Different approaches have been developed covering various non-preemptive scheduling problems for a transport system equivalent to the one treated in the paper at hand, see, e.g., Boysen et al. [5,8,12,24,31]. However, to the best of the authors' knowledge only the paper of Zhou and Wu [32] is also dedicated to solution procedures for preemptive crane scheduling in container yards. They presuppose that all containers have to be moved through the complete block from the landside to the seaside access point, so that each move inevitably has to be split among both cranes. However, given a container's average dwell time of three to five days in storage ([28], p. 22), such a unified view of storage in and retrieval from the yard results in an unrealistically long planning horizon. Thus, we restrict our view on import containers having a predetermined storage position within the yard, where, however, each move may (but need not) be preempted and handed over between the twin cranes at an intermediate storage position. Furthermore, we provide some elementary complexity proofs of the resulting crane scheduling problem yet missing in the literature.

Related crane scheduling approaches, that do not allow a preemption of jobs but at least enable some workload sharing among cranes by defining rehandles, i.e., boxes to be removed from containers actually to be retrieved, and relocation moves, i.e., relocating boxes closer to their dedicated hand-over point, as separate jobs are, for instance, provided in [23,9].

The remainder of the paper is structured as follows. First, Section 2 describes our preemptive crane scheduling in detail. Then, an analysis of computational complexity is provided (Section 3). Some heuristic scheduling procedures are introduced in Section 4 and tested in a comprehensive computational study in Section 5. Finally, Section 6 concludes the paper.

2. Problem description

For defining our preemptive crane scheduling problem (PCSP) we consider a single yard block consisting of some storage positions, two identical twin cranes, and two access points from sea- and landside, respectively. The storage positions are arranged along a single straight line and numbered according to their succession on the line, so that we have $s = 1, \ldots, S$ storage positions or slots for storing containers. Without loss of generality we assume that the line goes from left to right,