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Multi-crane scheduling in steel coil warehouse

Xie Xie [a,*], Yongyue Zheng [b], Yanping Li [a]

[a] Key Laboratory of Manufacturing Industrial and Integrated Automation, Shenyang University, Shenyang, Liaoning 110044, China
[b] Liaoning Institute of Standardization, Shenyang, Liaoning 110004, China

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ABSTRACT

This paper considers a multi-crane scheduling problem commonly encountered in real warehouse operations in steel enterprises. A given set of coils are to be retrieved to their designated places. If a required coil is in upper level or in lower level without being blocked, it can be picked up directly to its designated place; else, the blocking coils need to be picked up to another position first. Our problem aims to determine which positions for blocking coils to be shuffled to, and a joint transportation sequence of required coils to the designated places and blocking coils to be shuffled as soon as possible by multi-crane carrying these coils simultaneously.

For describe the studied problem clearly, we first formulate it as a mixed integer linear programming (MILP) model. Then some feasible and optimal properties for assigning cranes to avoid collisions in possible positions are identified. Since a special case of our problem is demonstrated strongly NP-hard, we further propose a heuristic algorithm. A lower bound to the problem is developed and the performance of the heuristic algorithm is analyzed from the worst case point of view. Finally, computational experiments are used to evaluate the average performance of our proposed methods and the results show that the proposed heuristic algorithm is capable of generating good quality solutions.

1. Introduction

In this paper, we study a multi-crane scheduling problem that arises from steel coil warehouse in iron and steel enterprises, as shown in Fig. 1. Some finished or semi-manufactured coils have been stored in the warehouse waiting to be picked up for customers or for their next production lines. As practical storage technological requirement, coils have been stored on pre-specified positions in two levels. If a required coil is in the upper level or in lower level without being blocked, it can be picked up directly to designated place. If a required coil in the lower level is blocked by one or two un-required coils, it can not be moved directly to a position until all the blocking coils are picked up to other empty positions. For convenience in description, a blocking coil which is moved to an empty position is called a shuffling operation. A required coil which is moved to its designated place is called a transportation operation. In either a shuffling operation or a transportation operation, the coil concerned needs to be lifted up from its current position, moved to another position and then dropped off. The whole process is performed by expensive equipment: traveling crane, and is considered as a loaded move for the crane. After the crane drops off a coil, the empty crane can move to another coil to perform the next loaded move. As illustrated in Fig. 2, each crane mounted on a single bi-directional track moves from one place to another place means that its pickup equipment (hoist) accompanies the crane to move not only along the parallel tracks, but also run along the supported parallel bridges, both run in simultaneity. In the following, we treat the hoist as crane for simplicity.

This paper aims to determine which positions for blocking coils to be shuffled to, and a joint transportation sequence of required coils to the designated places and blocking coils to be shuffled as soon as possible by multi-crane carrying these coils simultaneously. That is, we deals particularly with a joint multi-crane scheduling for transporting all required coils and shuffling all blocking coils so as to minimize the last required coil to its designated place (*makespan*). The effective coordinated scheduling of cranes may help to supply coils for downstream production in time, increase crane utilization ratio and thus will improve steel productivity.

This problem is frequently encountered in the real-world warehouse of iron and steel enterprise which stores finished coils and semi-manufactured coils, such as hot-rolling back warehouse, hot-galvanize material warehouse, acid pickling material warehouse and acid-rolling back warehouse. Similar problems also exist in other warehouses, such as stack yard in container terminal and material warehouse in dockyard. However, to the best of our knowledge, there are few researches on crane scheduling in steel warehouse, especially on this joint scheduling of transportation and shuffling operations.

* Corresponding author. Tel.: +86 2462269908.
E-mail address: xiexie8118@gmail.com (X. Xie).

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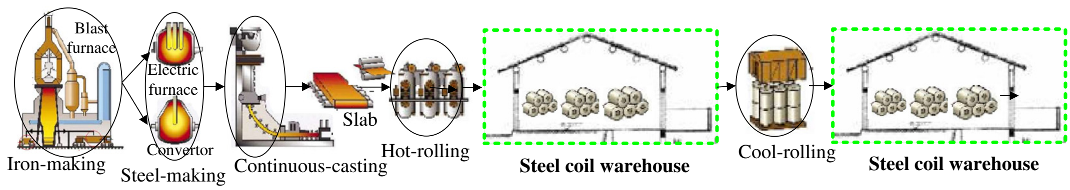

Fig. 1. Production and logistics flow chart in iron and steel enterprises.

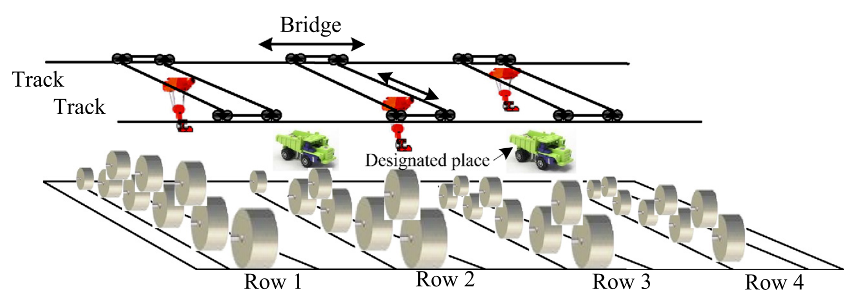

Fig. 2. Coil storage in a block of steel coil warehouse.

Up to present, researches associated with crane scheduling in steel warehouse were merely attempted to investigate a sequential approach for a single crane scheduling problem without simultaneous consideration of interrelated transportation and shuffling operations. Zapfel and Wasner (2006) studied a single crane scheduling problem for storing incoming coils and retrieve coils required in a distribution centre of steel coils. They viewed the problem as a classical job shop scheduling problem and formulated the problem as a nonlinear integer programming model which is hard to solve. A local search based heuristic is proposed and tested through computation. For storing and retrieving steel items with known arrival and retrieval dates, Rei, Kubo, and Pedroso (2008) focused on a single crane scheduling problem to minimize the number of crane movements. The items are stacked one on top of another in a similar way to container stacking. A simulation based heuristic is proposed to solve the problem. Also, for a single crane scheduling problem, Tang, Xie, and Liu (2009) mainly employed a sequential approach for assigning furnaces first to steel stacks to be processed and then scheduling the crane to move the furnaces around in a steel annealing system. There is no shuffling operation involved. Although Tang, Xie, and Liu (2013) considered a joint sequence of transportation and shuffling operations in steel warehouse and provided a heuristic algorithm with its worst-case performance analyzed, they still studied the case of a single crane scheduling.

Owing that our problem concerns the utilization of material handling equipment for warehouse storage, it may be viewed as one of the warehousing operation management problems. Intensive researches were attempted in the area of warehousing operation management problems. Interested readers may refer to van den Berg and Zijm (1999) for a discussion of warehousing systems and a classification of warehouse management problems, and de Koster, Le-Duc, and Roodbergen (2007) for a review of studies on warehouse design and control issues. Among those classifications, most relevant to our problem is order picking. Order picking is the process of retrieving products from the storage area in response to specific customer orders. Researches on ordering picking can be mainly classified into three categories: determining picker routes through the warehouse, assigning items to storage locations and batching items from different customer orders for picking in the same routes. Among these, the picker routing problem is more related to our problem. Ratliff and Rosenthal (1983) first presented a polynomial computation time algorithm for order picking tour construction, considering horizontal travel time and as a special case of the traveling salesman problem (TSP). Ascheuer, Grotschel, and Abdel-Hamid (1999) modeled the picker route problem as an online asymmetric TSP, considering both horizontal and vertical travel time. Further studied by using an intelligent agent-based model, Kim, Graves, Heragu, and Onge (2002) solved an order picking problem where there are separated storage areas each having a dedicated picker, goods are stored at multiple locations and the picking location of the goods can be selected dynamically. Pan, Shih, and Wu (2012) formulated the picking model as a queuing network and proposed a heuristic storage assignment policy that considers both the travel time and the waiting time simultaneously by minimizing the average order fulfillment time. Considering batching precedence-constrained customer orders problem, Matusiak, Koster, Kroon, and Saarinen (2013) investigated a joint order-batching and picker routing problem by using simulated annealing method to avoid unnecessary routing. However, these order picking problems do not involve shuffling decisions which is a main concern in our problem.

Researches involving shuffling activities on multi-crane scheduling usually result from the context of managing container in container terminal (such as quay crane scheduling (QCS), as well as, yard crane scheduling (YCS)). However, the way of stacking of containers is different from the way of stacking steel coils. Coils cannot be stacked one on top of another like containers. Each upper-level coil has to be supported by two coils below it. This special way of stacking makes the problem quite different. To minimize the number of shuffles needed, Kim and Hong (2006) mentioned a branch and bound procedure and presented a heuristic for determining the storage positions for shuffled containers during the process of retrieving a given sequence of export containers. Wan, Liu, and Tsai (2009) developed a linear integer programming model for the container retrieval and shuffling problems and also presented heuristics for handling container storage and retrieval dynamically. To minimize the weighted sum of the number of container movements and the crane working time, Lee and Lee (2010) presented a three-phase heuristic for retrieving containers in a given sequence Given the storage configuration and a sequence of containers to be retrieved, Lee and Hsu (2007) proposed an integer programming model for pre-marshalling containers with minimum number of