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AN EFFICIENT SIMULATION-BASED OPTIMIZATION ALGORITHM FOR A CRANE SCHEDULING PROBLEM IN A STEELMAKING SHOP

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ABSTRACT

This study addresses a crane scheduling problem in a steelmaking shop, where cranes are responsible for transporting ladles with molten steel between machines. To meet production schedules, the coordination between cranes and machines is crucial, performing the transportation of ladles at appropriate times. Also, multiple cranes share a common track, interference between them must be avoided. To address this problem, we propose an efficient algorithm based on iterative simulations. Several dominance rules are developed to reduce the solution space and accelerate the convergence of the algorithm. Experimental results show that our approach can derive high-quality solutions within a short time.

1 INTRODUCTION

In a steelmaking shop, molten steel is initially poured into a container, called a ladle, and processed in a series of machines. Ladles are transported between machines by overhead cranes on a common track. Cranes unload each ladle from a source machine, travel to the target machine, and load the ladle onto the target machine. Each unloading or loading operation is defined to a single task, and according to the production schedule, each task has a release time and due date (Li et al. 2020). Each crane can only handle a task at a time, and it is necessary to prevent any collision between cranes. To coordinate the movement of ladles within the production schedule, the efficient scheduling of cranes is essential (Peterson et al. 2014). Our goal is to find the optimal task assignments and execution sequence to minimize the tardiness of tasks.

We first develop a simulation model to produce various crane schedules and assess their performance. Utilizing this model, we generate distinct solutions and evaluate their objective values iteratively, finally deriving improved schedules. To enhance the effectiveness of our approach, we design several dominance rules capable of reducing the solution space. Experimental results show that dominance rules significantly improve our approach, enabling us to attain high-quality solutions within a short computational time.

2 SIMULATION-BASED SOLUTION APPROACH

In our approach, a solution is represented as a sequence of task-crane pairs, where a pair indicates an assignment of the task to the crane. With a solution, we utilize a simulation model to generate a crane schedule, while avoiding collisions. In the simulation, each crane executes its assigned tasks according to the sequence outlined in the solution. In cases where crane interference arises, priority is given to the crane positioned earlier in the sequence. All tasks are performed at the earliest start time considering the release time, travel time, and interference of cranes. By above procedures, we can identify feasible crane trajectories and evaluate the objective value of the resulting schedule.

To form a solution, we sequentially assign tasks to cranes, making a sequence of pairs. At each decision point, we identify candidate pairs for all tasks and their nearest cranes, and select one based on specific priority rules, such as first in first served (FIFO) and earliest due date (EDD). Given the fast execution of the simulation model, to generate diverse solutions, we make some modifications to above rules. For pair candidates, we establish selection probabilities considering release times and due dates. Higher probabilities are assigned to pairs with earlier release times or due dates of corresponding tasks. With probabilities, we can sample various sequences of pairs, resulting in numerous distinct solutions. These solutions are then evaluated by the simulation, ultimately leading us to obtain enhanced schedules.

To accelerate our solution approach, we design two categories of dominance rules. Task dominance rules are employed to eliminate dominated tasks from the pool of task candidates. When considering two tasks among the candidates, we compare the schedules that would eventually be generated when one task is added to the solution prior to the other, and vice versa. If one of these solutions proves to be dominant over the other, there is no need to further explore the solution space by adding the dominated task first to the solution. Pair dominance rules operate on a similar principle to task dominance rules.

3 EXPERIMENTAL RESULTS AND CONCLUSION

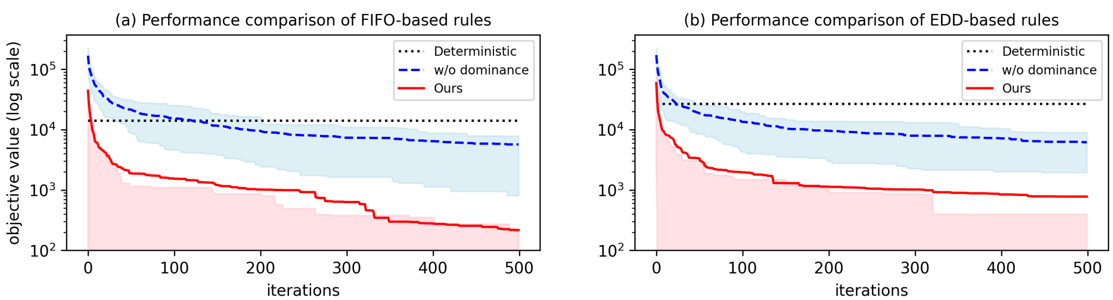

Figure 1: (a) Performance of rules based on FIFO (Left). (b) Performance of rules based on EDD (Right)

Figure 1 illustrates the comparative performance of our approach and baseline methods on 100 instances generated using the parameters based on real factory data. For comparison, we also test deterministic and probabilistic dispatching rules without any dominance rules. The probabilistic rules, including ours, are executed over 500 iterations. The shaded area represents the first to third quartiles. As depicted in Figure 1, our approach achieves superior solutions much faster than others under both FIFO and EDD rules. For the computational time, our approach takes about 80 seconds for each instance.

We conclude that our simulation-based optimization algorithm yields high-quality solutions within a short computational time. From a real-world application perspective, our algorithm can derive solutions within few seconds, signifying its effective usability in practical field scenarios.

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REFERENCES

Li, J., A. Xu, and X. Zang. 2020. "Simulation-based solution for a dynamic multi-crane-scheduling problem in a steelmaking shop". *International Journal of Production Research* 58(22):6970–6984.

Peterson, B., I. Harjunkoski, S. Hoda, and J. Hooker. 2014. "Scheduling multiple factory cranes on a common track". *Computers & Operations Research* 48:102–112.