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Two Formulations for non-Interference Parallel Machine Scheduling Problems

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Abstract: This article deals with a job scheduling on two cranes subject to non-interference constraints. It is based on a real case at a distribution center of steel coils, where two cranes sharing the same rail must load a sequence of trucks, which has a defined demand of coils. The problem is mathematically modeled as a parallel machines with ordering variables and with time index variables. The proposed formulations are computationally tested among different instances. Based on the results, we discuss which formulation might work best for these problems.

Keywords: Mathematical Approaches for Scheduling, Warehouse Management Systems, Optimization and Control, non-Interference Constraints.

1. INTRODUCTION

This work is based on a real case at a distribution center of steel coils where two cranes must load a sequence of trucks. As the cranes share the same rail, they are subject to non-interference constraints. We formulate this problem as a parallel machine problem were two mathematical models are developed to describe it. As done by Keha et al. (2009) for single machine, here we compare the computational performance of two different mixed integer programming (MIP) models defined by their decision variables.

We consider that, once the cranes start processing the truck, its demanded coils must be completely fulfilled without interruption. The loading order of the coils is not considered so, once a truck j starts, it prevents other trucks to be processed if it has coils in some row in between the area bounded by the rows of the coils from j. For example, considering Q_j the set of coils that must be loaded in truck j; l_i the storage row of the coil i; $r_j^{min} = min_{i \in Q_j}(l_i)$, and a $r_j^{max} = max_{i \in Q_j}(l_i)$. Then any truck $f \neq j$ that has at least one coil in between the rows r_j^{min} and r_j^{max} can not be processed while the truck j is loaded.

From the foregoing, differently than observed in the revised works, we propose two formulations to solve the cranes scheduling problem subjected to non-interference constraints. In our cases these constraints are a function of the truck's bounding area and do not treat the interference in the product's level.

Each truck has a defined load demand, such as specifications of how many and of which coils should be loaded into it. These parameters are obtained by the lot sizing problem of the dissertation of da Silva Neto (2013), who studied the same scenario.

The reminder of this paper is organized as follows. Section 2 review the existent literature. Section 3 presents the notations and the MIP models of the proposed approaches. Section 4 shows the instances generated and compares the performance of the MIP models by executing computational experiments. Finally, in section 5, the paper is concluded and implications are provided.

2. LITERATURE REVIEW

The non-interference problem discusses the case in which machinery such as cranes, reclaimers and stackers, share the same rail and may interfere in each other's displacement. These kind of problems often appears at logistical centers, such as depots, warehouses and stockyards.

The scheduling problem with non-interference constraints are also present mainly at the port terminals scenery, for the operation of quay cranes and yard cranes, as one can see from the works of Kim and Park (2004), Lee et al. (2008) and Chung and Choy (2012), and of Ng (2005) and Li et al. (2009), respectively. According to Kim and Park (2004) and Bierwirth and Meisel (2010), the quay cranes scheduling problems with non-interference constraints differ from the parallel-machine problems due to precedence constraints of unloading and loading of vessels and the presence of interference on the displacement of the cranes.

The non-interference constraints were firstly treated in the quay crane-scheduling problem model of Kim and Park (2004) who study the problem of scheduling the loading of containers on a single ship. The work consider the location of the quay cranes and their release date. The authors formulate a MIP model with linear ordering variables and propose a branch-and-bound (B&B) and a GRASP heuristic.

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Bierwirth and Meisel (2010) develop a survey in which quay crane scheduling problems at port terminals is treated. The authors suggest a classification scheme for the problems addressed and conclude that, despite the multitude of models found, the trend is to integrate port terminal problems.

According to Bierwirth and Meisel (2009) and Bierwirth and Meisel (2010), in most of the researches about sequencing of cranes the common optimization criterion is to minimizing the makespan. The authors conclude that the non-interference constraints are present in the majority of the studies, although they are fewer when considered the safety margin of the cranes displacement. The crane attributes, such as travel speed and availability are also quite neglected.

In this scenario, the cranes scheduling problem can also be treated by simulation to evaluate the given scheduling schemes. Bielli et al. (2006), for example, develope a simulation framework able to evaluate alternative ship loading and unloading operations and different resource allocation procedures. Zeng and Yang (2009) develop a simulation-optimization method to schedule loading or unloading containers in terminals. The optimization algorithm searches the solution space and the simulation evaluates the robustness of the obtained solutions.

Some crane scheduling problem are also treated for warehouse of steel coils, although there are few studies in this scenario, as the works of Zäpfel and Wasner (2006), Tang et al. (2014) and Xie et al. (2014). Zäpfel and Wasner (2006) and Tang et al. (2014) deal with a single crane scheduling problems, while the last one consider the multiple cranes with interference. Differently than studied in this paper, these works consider that the row and the level of each coil in the warehouse is known and that the shuffling operations may occur. Shuffling operation consists of the removal of coils that blocks the demanded coils and that are in a lower level. However they do not consider that the trucks have defined coils demands and that the truck must be processed without preemption. They also do not consider the area bounded of each truck by the rows of its coils.

Xie et al. (2014) formulate the problem as a mixed integer linear programming (MILP) model to minimize the makespan. They consider non-interference constraint and the safety distance between the cranes. The authors also propose a heuristic based on some feasible and optimal properties identified for assigning cranes without causing interference. It can solve all instances almost instantly and it is able to generate good quality solutions.

3. MODEL FORMULATION

3.1 Notation

Before describing the problem it is important to consider that the coils are the items, the trucks are the jobs and the cranes are the machines. Without loss of generality, it is assumed that the cranes and the rows are indexed sequentially from left to right in increasing order. Each machine is considered to be always available to process jobs over a period of sequencing and they are not subject to disruptions, such as breakdowns, maintenance, among others. We also assume that each job must be completely processed without preemption, and are available at time zero.

We are given a set of items $\mathcal{B}$ that must be shipped by the set of machines $\mathcal{M} = \{1, 2\}$. $Q_j \subseteq \mathcal{B}$ is the set of items that must be loaded by these machines on job $j \in \mathcal{J}$, where $\mathcal{J}$ is the set of trucks available. The items $i \in \mathcal{B}$ have machine dependent processing times $p_{im} = p_0 + u_i^m$, where $m \in \mathcal{M}$, and p_0 represents the retrieval time of the coils, which is the same for all of them. Before explaining u_i^m, we assume that each item i has its row positions in the shed given by l_i and that the trucks have to be positioned in l^m if it is processed by machine m. Then u_i^m is given by the sum of the idled travel time from position l^m to position l_i and of the loaded travel time from the position l_i to l^m. The machine dependent processing time can also be computed to jobs $j \in \mathcal{J}$ by $p_{jm} = \sum_{i \in Q_j} p_{im}$, and it is valid when considering the no idle time between the processing of coils from the same truck. Each job j is associated a r_j^{min} and a r_j^{max}, as presented earlier. The parameter w_j is the weight, or priority factor, of a job j and Δ is the safety operational distance of the cranes. G is a very large integer given by the time horizon H, where $H = \sum_{i \in \mathcal{B}} max_{m \in \mathcal{M}}(p_{im})$ and $\bar{G}$ is a large integer given by the amount of rows in the shed. The problem is to find completion times C_j for all jobs $j \in \mathcal{J}$ with respect to the constraints such that the total weighted completion time is minimized.

3.2 Formulation

For the fisrt formulation, we consider binary linear ordering variables, such as in the works of Rocha et al. (2008) and Lee et al. (2008). The variables s_{fj} are equal to 1 when job f precedes job j, and equal to 0 otherwise; and y_{jm} are equal to 1 when crane m process truck j, and equal to 0 otherwise. The start time of the truck j is computed by $t_j \geq 0$.

The problem then can be modeled as:

$$Min \sum_{j \in \mathcal{J}} w_j * (t_j + \sum_{m \in \mathcal{M}} p_{jm} y_{jm}) \quad (1)$$

$$\sum_{m \in \mathcal{M}} y_{jm} = 1, \; \forall j \in \mathcal{J} \quad (2)$$

$$\begin{aligned} t_f \; + p_{fm} &\leq t_j + G(1 - y_{fm}) + G(1 - y_{jm}) \\ &+ G(1 - s_{fj}), \; \forall f \in \mathcal{J}, \; \forall j \in \mathcal{J} \mid f \neq j, \; \forall m \in \mathcal{M} \end{aligned} \quad (3)$$

$$\begin{aligned} t_j \; + p_{jm} &\leq t_f + G(1 - y_{fm}) + G(1 - y_{jm}) + G s_{fj}, \\ &\forall f \in \mathcal{J}, \; \forall j \in \mathcal{J} \mid f \neq j, \; \forall m \in \mathcal{M} \end{aligned} \quad (4)$$

$$\begin{aligned} t_f \; + \sum_{m \in \mathcal{M}} p_{fm} y_{fm} - t_j + G s_{fj} > 0, \\ \forall f \in \mathcal{J}, \; \forall j \in \mathcal{J} \end{aligned} \quad (5)$$

$$\begin{aligned} t_f \; + \sum_{m \in \mathcal{M}} p_{fm} y_{fm} - t_j - G(1 - s_{fj}) \leq 0, \\ \forall f \in \mathcal{J}, \; \forall j \in \mathcal{J} \end{aligned} \quad (6)$$

$$\begin{aligned} \bar{G}(s_{fj} \; + s_{jf}) \geq y_{jm} r_j^{max} - y_{fm+1}(r_f^{min} - \Delta), \\ \forall f \in \mathcal{J}, \; \forall j \in \mathcal{J} \mid f \neq j, \; \forall m \in \mathcal{M} \end{aligned} \quad (7)$$

$$y_{jm} \in \{0, 1\}, \; \forall j \in \mathcal{J}, \; \forall m \in \mathcal{M} \quad (8)$$

$$s_{fj} \in \{0, 1\}, \; \forall f \in \mathcal{J}, \; \forall j \in \mathcal{J} \quad (9)$$