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Minimizing the makespan for the MPM job-shop with availability constraints

N. Zribi*, A. El Kamel, P. Borne

École Centrale de Lille, Cité scientifique-BP 48, 59651 Villeneuve d'Ascq Cedex, France

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Abstract

In this paper, we deal with the Job-shop with Multi-Purpose Machine scheduling problem with Availability Constraints (JMPMAC). In the first part, we propose a heuristic, based on priority rules to solve the assignment problem. A local search algorithm is then introduced to improve this assignment solution. In the second part, we introduce a genetic algorithm to solve the sequencing problem. Finally, a new lower bound is developed for the problem to evaluate the quality of solutions.

Keywords: Scheduling; Assignment; Availability constraints; Genetic algorithm; Local search

1. Introduction

In the scheduling literature, it is usually assumed that machines are available during the whole planning horizon. However, in many realistic situations, e.g. in typical industrial settings, machines may be unavailable for processing jobs after a breakdown or during a preventive maintenance activity. In fact, in manufacturing systems, machines are periodically submitted to reconfiguration, control or setup operations.

The problem of job-shop with multi-purpose machines arises in the area of flexible manufacturing systems. Machines are equipped with different tools and called multi-purpose machines. A job can be processed on any machine equipped with the needed tool.

Moreover, we assume that the machines are unavailable during given periods. We consider the deterministic model where the unavailability periods, corresponding to preventive maintenance tasks, are known in advance. We also assume that preemption of operations is not allowed. More precisely, an operation O_{ij} of job J_i on machine M_k starts only if its execution can be finished before M_k becomes unavailable. The problem considered here is a generalization of the classical job-shop problem and the multi-purpose machine problem studied in Jurisch (1992), where machines are available all times.

As compared to the literature dedicated to classical scheduling problems, studies dealing with limited machine scheduling problems are rather rare. Availability constraints have been firstly introduced in single machine (Adiri et al., 1989; Leon and Wu, 1992) and parallel machines (Schmidt, 1984, 1988). Lee (1996, 1997, 1999) extensively investigated flow-shop scheduling problems with two machines. In particular,

*Corresponding author. Tel.: +33 3 20 33 54 85.
E-mail address: nozha.zribi@ec-lille.fr (N. Zribi).

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the author defined the resumable, non-resumable and semi-resumable models. An operation is called resumable if it can be interrupted by an unavailability period and completed without penalty as soon as the machine becomes available again. If the part of the operation that has been processed before the unavailability period must be partially (respectively, fully) re-executed, then the operation is called semi-resumable (respectively, non-resumable). Recently, flow-shop scheduling problems, with two machines and resumable jobs, have been treated in Blazewicz et al. (2001) and Kubiak et al. (2002). Besides, the job-shop problem under availability constraints has also been considered. Indeed, in Aggoune (2002) the author proposed a branch and bound algorithm with lower bound based on two-job decomposition for the job-shop problem with heads and tails and unavailability periods. However, to the best of our knowledge, the Job-shop with Multi-Purpose Machine scheduling problem with Availability Constraints (JMPMAC) has not been considered yet. The problem is strongly NP-hard since the problem without unavailability periods is already strongly NP-hard (Jurisch, 1992). Hence, in this paper we propose a heuristic method to solve this problem.

The paper is organized as follows: the second section presents the specifications of the JMPMAC. In Section 3, we give a lower bound for the JMPMAC. Then in Section 4 we describe the assignment technique introduced to pre-optimize the makespan. In Section 5, we propose a genetic algorithm to solve the sequencing problem. Finally, numerical experiments and some conclusions concerning this research work are given.

2. Problem formulation

The MPM job-shop with availability constraints may be formulated as follows: there are n jobs $J_1, \ldots, J_n$ to be processed on a set of m machines $R = (M_1, \ldots, M_m)$. Each machine M_r can process at most one job at a time. Each job J_i consists of a sequence of n_i operations that must be accomplished according to its manufacturing process. Each operation O_{ij} $(i = 1, \ldots, n; j = 1, \ldots, n_i)$ can be performed by any machine M_r in a given set $\mu_{ij} \subset R$ for p_{ij} time units. Each operation is non-preemptive, i.e. it must be accomplished without interruption. Each job J_i has an earliest starting time denoted by r_i.

Moreover, we assume that machine M_r is unavailable during given periods corresponding to preventive maintenance. The starting times and durations of these tasks are fixed and known in advance. We all note by K_r the number of maintenance tasks on machine M_r. A_{rl} and D_{rl} represent, respectively, the starting and the finishing time of the lth maintenance task on machine M_r.

The objective is to find a schedule, defined by the starting time S_{ij} and the completion time C_{ij} of each operation O_{ij}, with a minimum makespan (max C_{ij}).

According to the terminology, concerning the machine availability introduced in Schmidt (2000), the JMPMAC can be denoted by $J(\mathrm{MPM})$, $\mathrm{NCwin}|C_{\max}$, where NCwin means that unavailability periods are arbitrarily distributed on machines.

The scheduling problem in $J(\mathrm{MPM})\mathrm{NCwin}|C_{\max}$ can be decomposed in two subproblems:

- A routing subproblem that consists in assigning operations to machines.
- An operation scheduling subproblem associated with each machine to minimize the makespan. This is a job-shop scheduling problem with availability constraints $J, \mathrm{NCwin}|C_{\max}$.

Since the unavailable intervals differ from machine to another, the assumption of identical machines is greatly weakened and the routing problem becomes more complicated. Thus, in order to reduce the complexity of the problem, we propose a two-phase algorithm to construct a schedule minimizing the makespan for the $J(\mathrm{MPM}), \mathrm{NCwin}|C_{\max}$. In the next section, we propose a lower bound for the makespan to evaluate the quality of the developed approach.

3. Lower bound for the $J(\mathrm{MPM}), \mathrm{NCwin}|\mathrm{C}_{\max}$

In this section, we present a lower bound denoted by LB_{JMPMAC}.

Definition 1. To each operation O_{ij}, we associate an earliest starting time r_{ij} expressed by the following formula:

$$\begin{cases} r_{i,1} = r_i \ \forall 1 \leqslant i \leqslant n, \quad r_{i,j+1} = r_{i,j} + p_{i,j} \\ \quad \forall 1 \leqslant j \leqslant n_i - 1 \quad \forall 1 \leqslant i \leqslant n. \end{cases} \tag{1}$$

Proposition 1. *$C^*_{\max}$ denotes the makespan of the optimal solution*:

$$C^*_{\max} \geqslant \frac{R_m + \sum_{i,j} p_{ij} + \sum_{1 \leqslant k \leqslant m} \sum_l (t - A_{kl})^+ - (t - D_{kl})^+}{m}, \tag{2}$$