An arc-flow model for the job sequencing and tool switching problem with non-identical parallel machines

Khadija Hadj Salem[1], Arthur Kramer[1], Alexis Robbes[2]

[1] Mines Saint-Étienne, Univ Clermont Auvergne, CNRS , UMR 6158 LIMOS, Institut Henri Fayol, F-42023 Saint-Étienne, France
{khadija.hadjsalem,arthur.kramer}@emse.fr

[2] Université de Sorbonne, CNRS, UMR 7606 LIP6, 4 place Jussieu, 75005 Paris, France
alexis.robbes@lip6.fr

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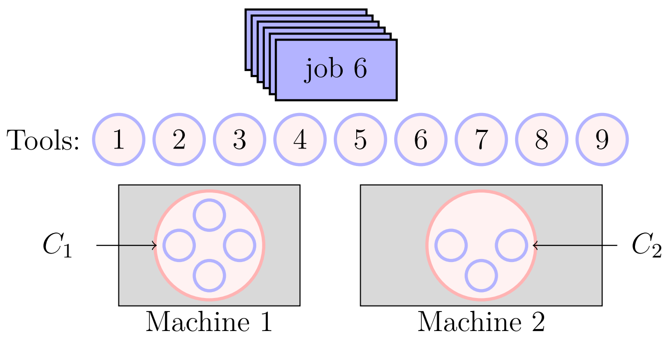
1 Problem description

In this paper, we consider the *Job Sequencing and Tool Switching Problem with Non-identical Parallel Machines* (SSP-NPM), which arises in a flexible manufacturing context. The SSP-NPM is a generalization of the classical Job Sequencing and Tool Switching Problem, first presented by [1] and [5], and proven to be NP-hard by [4].The SSP-NPM was first tackled by [3] throughout several constructive heuristics. After that, three different mixed integer linear programs (precedence-based, position-based and time index-based), with the aim of minimizing the objective functions related to job execution times (e.g., makespan, total flow time) and/or the number of tool switches, are proposed in [2].

Formally, the SSP-NPM can be defined as follows. Let us consider a set of jobs $\mathcal{J}$ that has to be scheduled in a manufacturing environment with a set of non-identical parallel machines $\mathcal{M}$, specified by machine-dependent processing and tool switching times. We will refer to p_{jm} the processing time of a job j on machine m characterized by a limited magazine capacity C_m. A job j can be processed on a machine m only if all of its required tools $t \in \mathcal{T}_j \subseteq \mathcal{T}$ are loaded in m during its processing. Since job requirements may be different, and the magazine capacities are limited, tool switches are needed to fully process all jobs. Let sw_m denote the time to switch one tool t on a machine m. Note also that the initial tool loading does not count as a tool switch, and that a tool switching on a machine m cannot be performed during the processing of a job in this machine. Then, the SSP-NPM requires to schedule the jobs to the unrelated parallel machine with limited capacity, so that the makespan is minimized.

An example of the SSP-NPM is given in Figure 1, where $|\mathcal{J}| = 6$ jobs, $|\mathcal{T}| = 9$ tools and 2 machines with different capacities $C_1 = 4$, $C_2 = 3$, and switching times $sw_1 = 1$ and $sw_2 = 2$.



(a)

j	1	2	3	4	5	6
	$\mathcal{T}_1$	$\mathcal{T}_2$	$\mathcal{T}_3$	$\mathcal{T}_4$	$\mathcal{T}_5$	$\mathcal{T}_6$
	1	1	2	1	3	1
	4	3	6	5	5	2
	8	5	7	7	8	4
	9		8	9		
p_{j1}	1	3	4	5	6	1
p_{j2}		4			3	1

(b)

FIG. 1: A schematic layout example of the problem environment.

2 An arc-flow model for the SSP-NPM

We model the SSP-NPM as an arc-flow (AF) model by using flows, that are associated with schedules, on a capacitated network. Our proposed model is composed by a continuous variable to represent the makespan and three sets of binary variables to represent job processing, tool loading and setup (tool switching) operations. Then, flow conservation constraints are used to impose that at most one job and C_m tools are considered at the same time per machine $m \in \mathcal{M}$. The remaining constraints are: (i) all jobs must be processed and (ii) can be processed on a machine only if all of its required tools are loaded at the same time on the same machine; (iii) a setup time between the loading of two different and consecutive tools is required; (iv) the number of tools available per machine is limited (one copy per machine).

An optimal solution of the example in Figure 1, obtained by applying the proposed AF model, is presented in Figure 2.

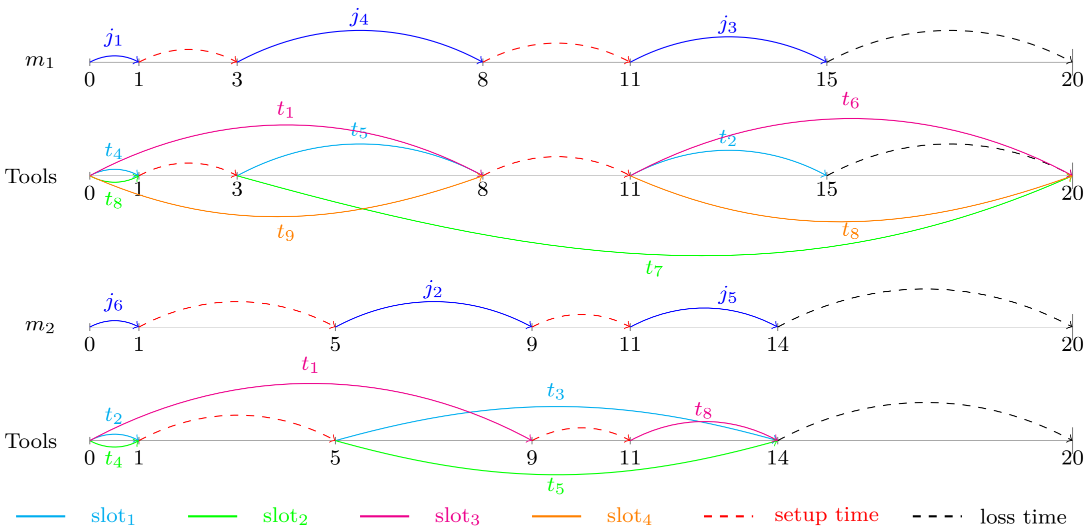


FIG. 2: An *AF* optimal solution (makespan = 15) of example in Figure 1:

3 Preliminary experiments and further research

We benchmark the proposed AF against the mathematical formulations presented in [2] on benchmark instances from the literature. Preliminary experiments show that the AF is able to successfully solve small-sized instances at optimality. Further research focuses on improving the AF model by proposing valid inequalities and preprocessing procedures to reduce the AF size and developing matheuristics/exact/decomposition methods to efficiently solve the SPP-NPM.

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