Mathematical modeling of single and multi-unit process planning problem in a reconfigurable environment

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1 Introduction

A reconfigurable manufacturing system (RMS) is one capable of changing its functionality or capacity by changing the type of product manufactured or the throughput of production. Since its introduction, RMS emerged as one of the promising manufacturing paradigms and changed how we perceived different manufacturing activities, such as scheduling and process planning.

Process planning can be defined as the activity of converting a product design into manufacturing steps, consisting of operations sequence and the parameters where these operations will be processed. We can identify two types of Process planning: single-unit (SUPP) and multi-unit (MUPP). The difference is that in the MUPP, we generate multiple process plans for multiple units executed sequentially instead of just one in the SUPP case. The SUPP problem has been abundantly studied in the literature, either in conventional manufacturing systems or in reconfigurable ones [2] [1]. On the other hand, MUPP problems received little interest, especially in the RMS context; we can mention from a few [3].

The main contributions of this paper are as follows: *i)* Developing a mathematical model for SUPP and MUPP problems, *ii)* Proposing a tradeoff approach called Repetitive-SUPP (R-SUPP), *iii)* Evaluating the mathematical models performance.

2 Mathematical models

The SUPP in RMS problem can be described as follows. There's a set of reconfigurable machine tools (RMTs) on a shop floor with a predefined layout. Each RMT can use a set of tools and may exist in multiple configurations, wherein each configuration provides a set of available tool approach directions (TADs). Each part produced at the shop floor has a set of known features. Each feature comprises a group of operations requiring a specific tool and TADs. The process planner needs to select what machines to use and assign operations to them and determine the sequence of execution of the operations with respect to the precedence constraints between operations and TADs and tools requirements, etc. The obtained solution is called a process plan. Table 1 presents an example of a solution. We can interpret it from left to right column by column. The first column indicates that we process first operation OP1 of feature F1 on machine M2 configuration C3 with tool T1; next, OP1 of F2 is processed on M1 with configuration C2 and tool T1, etc.

Feature	F1	F2	F1	F1
Operation	OP1	OP1	OP2	OP3
Machine	M2	M1	M2	M1
Configuration	C3	C2	C2	C1
Tool	T1	T1	T5	T3

TAB. 1: A Solution representation

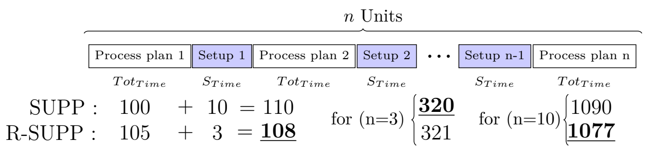
Unlike other models in the literature, we use one main decision variable P, that contains six indices for the position s, feature k, operation u, machine j, configuration l, and tool q ($P^{k,u}_{s,j,l,q}$). So for instance, the first column of the example in table 1 is presented as $P^{1,1}_{1,2,3,1} = 1$. Even though this modeling approach might seem messy or complex, it will be easier to introduce changes and new constraints to the original model without losing its linearity.

The models also contain auxiliary decision variables that depend on P and represent machine, configuration and tool changes. The Multi-unit model is a generalization of the single-unit one, where we add an extra index i of units and the necessary changes to reset the machines after one unit's process plan to the next one. For the R-SUPP, the basic idea is to solve a SUPP with the awareness of repeating that process n times; this is done by adding the machine, configuration, and tool changes done when going from the end of the process plan to its beginning, to the objective function.

3 Results

The preliminary tests on the models showed the obvious intuition that the SUPP model performs better in computational time, and MUPP performs better in terms of solution quality (since it guarantees the optimality of a multi-unit solution). On the other hand, the R-SUPP couldn't surpass the SUPP approach in terms of computation time or solution quality. This is partially due to the fact that the instances tested from the literature didn't favor such an approach, but additional tests are still required. Figure 1 represents an example of a solution where even though the R-SUPP model performs better when considering the sum ($Tot_{Time} + S_{Time}$), it performs worse when $n = 3$ and better for the case $n = 10$ Since the Tot_{Time} gets repeated n times and S_{Time} repeated $n - 1$ times.

FIG. 1: Difference between the SUPP and R-SUPP results.



The mathematical modeling approach still needs to be benchmarked with other solution methods proposed in the literature and further instances with different parameters.

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