INFLUENCE OF *NBMAX* AND TABU LIST IN THE SCHEDULING PROBLEM

Antonio Gabriel Rodrigues
Universidade do Vale do Rio dos Sinos
Av. Unisinos 950, São Leopoldo, RS, Brazil

Arthur Tórgo Gómez
Universidade do Vale do Rio dos Sinos
Av. Unisinos 950, São Leopoldo, RS, Brazil

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Abstract: Considering a Job Shop Scheduling Problems with tooling and due date constraints, experiments were made with a computational model based in Cluster Analysis and Tabu Search. Two minimization policies can be done in this model: swtiching instants and tardiness time. Previous experiments identify the conflict between these policies, as the positive influence of variation of TS parameters. This paper presents experiments considering the influence of the variation of TS paramenters *nbmax* (number of non-improving iterations performed by TS) and *tabu list size*.

1 INTRODUCTION

The Job Shop Scheduling Problem with tooling constraints (JST) can be defined as follows: there is a set of machines and a collection of parts to be processed on these machines. With each part type is associated a specific process plan, which consists in a sequence of operations. Each operation is defined by a machine type on which it must be processed, its processing time and the tools which are needed. A machine can process only one part at a time and they are continuosly avaliable. Each machine has a tool magazine with limited capacity. All parts to be processed are avaliable at processing time zero and each part can be processed by only one machine at a time. No individual operation can be pre-empted. Each operation needs a number of tools, which never exceeds the capacity of tool magazine. The classical objective is to minimize the *makespan*, the maximum of the completion times of all operations. Since the tool magazine have limited capacity, tool changes are needed. When a tool change occurs on a machine, some tools are replaced by others required for the next parts of the sequence on this machine. This time spent exchange tools is called *switching instant*(Hertz and Widmer, 1996).

In this paper we refer a Job Shop Scheduling Problem applied to a Flexible Manufacturing Cell (FMC), considering due dates and tooling constraints (refered here as JSTD). A FMC is composed by one workastation (CNC/DNC machine whith possesses a device for tool storage with restricted capacity), a material handling system and a computer center (Groover, 2001). We define a objective function F which permits the managing of the importance of due dates and switching instants in the Scheduling. A computational model based on simple Tabu Search and Cluster Analysis is used to generate a scheduling which minimizes F. Experiments performed with this model in previous works (Rodrigues and Gómez, 2005) showed the conflict between due dates and switching instants minimization. In the present paper, another experiments are made, in which the variation of TS parameters *nbmax* and tabu list size are analyzed.

2 COMPUTATIONAL MODEL

Are considered, additionally to the JSTD constraints (described in the previous item), the two assumptions: (*i*) once processed, any part can return to the system; (*ii*) the production turn is considered, so any part can be processed after the finish of the turn; A batch is considered a set of parts which can be processed in the workstation with the same set of tools. Between the processing of two batches, a switching instant is required. A switching instant lasts $\alpha + \beta r$ time units,

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where α is a fixed time due to removal of the tool magazine for the machine and clean the workspace area, β is a fixed time for each tool replacement and r is the total number of tools which must be replaced. In the presented model, it was used an approach suggested by Gómez (Gómez, 1996) where α and βr are considered two different decision variables in the objective function.

2.1 Techniques

To group parts into batches, Part Selection Problem (PSP) is studied. In this problem a set of parts must be grouped into subsets,called Part Families (PFs), according to some similarity. The PSP is represented using matrix formulation, a classical approach of Group Technology (TG). To solve this problem is used the Cluster Identification Algorithm (CIA) modified by Gómez (Gómez, 1996). Originally developed by Kusiak and Chow (Kusiak and Chow, 1987), the modified CIA organizes the rows and columns of the matrix A, generating a matrix B with part-tools clusters, where each cluster is a FP.

To solve the Job Shop Scheduling Problem, a Tabu Search (TS) approach was proposed (Glover and Laguna, 1997). TS is a meta-heuristic composed by a local search procedure associated with a memory structure which constraints the search to visit regions in the solution space already visited. This memory structure intents to make the search avoid the local optimals, performing a better exploration of the space.

2.2 Architecture

The computational model uses TS e modified CIA to find the schedule such the objective function $\digamma$ is minimized. The $\digamma$ function has the following decision varaiables:

- tardiness time (At): diference between due date and date of the completion of the part, expressed in minutes.
- tool replacement time (St): representing the βr time in the switching instants, expressed in minutes.
- tool removal time (Sp): representing the α time in the switching instant, expressed in minutes.

The importance of these decision variables in the final schedule can be managed through the assignment of weights to them. The objective function was developed considering two dimensions: physical dimension (Part Families) and time dimension (scheduling). Considering: N the total amount of parts; L the number of setups in s; U the number of switching tools in s; Dv_i the due date of part i; Ds_i the completion date of part i; Tr the time to removal the tools e prepare the workstation for new parts, in minutes; Te the time to replace one tool in minutes.

Minimize

$$\digamma(p,f) = P_1 \cdot At(p,f) + P_2 \cdot Sp(p,f) + P_3 \cdot St(p,f) \tag{1}$$

Where

$$At(p,f) = \sum_{i=1}^{N}(Dv_i - Ds_i) \quad \text{such } (Dv_i - Ds_i) \geq 0, \; i \in \{1,\ldots,N\} \tag{2}$$

$$Sp(p,f) = Tr \cdot \sum_{i=1}^{L} Sp_i \quad \text{such } Sp_i \geq 0, \; Tr \geq 0, \; i \in \{1,\ldots,L\} \tag{3}$$

$$St(p,f) = Te \cdot \sum_{i=1}^{U} St_i \quad \text{such } St_i \geq 0, \; Te \geq 0, \; i \in \{1,\ldots,U\} \tag{4}$$

$$P_1 \geq 0, P_2 \geq 0, P_3 \geq 0 \tag{5}$$

The computational model was developed in four modules: (*i*)Part generator, (*ii*) PF generator, (*iii*) Initial Solution generator and (*iv*) TS-based module. More datails about the computational model can be seen in previous works (Rodrigues and Gómez, 2005).

3 EXPERIMENTS

The variation of weights of the objective function was analyzed in previous papers (Rodrigues and Gómez, 2005). A summary of the results are replicated here. Based on these results, new experiments were made, considering the influence of *nbmax* and tabu list size in the objective function.

3.1 Summary of Previous Experiments

The previously performed experiments were made with objective of the managing of the three decision variables of the $\digamma$ function, presented in the item 2. The parameters of the experiments performed were:

(*i*) a set of 10 parts and 9 tools; (*ii*) the magazine capacity is 4 tools; (*iii*) the time spend for each tool replacement is 4 minutes; (*iv*) the time for tool removal is 5 minutes; (*v*) the production period (turn) is defined as 480 minutes; (*vi*) the tabu list initially stores 10 forbidden moves; (*vii*) and *nbmax* number is defined as 100 iterations. Initially was defined a non-tendentious solution (NTS), in which all the decision variables have the same contribution in F. The values of the weights of decision variables are: $At = 17.27 \cdot Sp$ and $At = 9.89 \cdot St$.

Once defined the NTS solution, experiments with variation of the weights of F were made. The methodology used was: one of the three weights of F were increased and the other two were made constant with the values of the NTS solution. There were made experiments which represents three different minimization policies (minimizing Sp, St and At). The same behavior (reducing of St and increasing of At) occurs when Sp is minimized. Using the above TS parameters, the increasing of this weight did not contribute to generating a schedule with less tardiness. Thus, other experiments were performed, in which *nbmax* and tabu list size are varied. The results of this lasts experiments are showed in table 1.

Table 1: Tabu list size and *nbmax* variation for solution that $At = 10$.

nbmax	tabu list	At	St	Sp
200	100	355	30	56
300	150	397	25	44
400	200	355	30	56
500	250	397	25	44
600	300	355	30	56
700	350	344	30	56
800	400	361	30	56
900	450	397	25	44
1000	500	397	25	44

As the values of At become smaller with the increasing of TS parameters, the values of St and Sp became high, confirming the conflict between switching instants and tardiness. New experiments are made in a manner to determine better the influence of the variation of these parameters in At minimization.

3.2 Experiments with *Nbmax* and Tabu List Size

In the new experiments, the tabu list size and *nbmax* size are varied one at each time. The initial solution was generated using Part Family rule (FAM) dispacthing rule. The initial sequence of parts for these experiments is $\{3, 4, 5, 1, 7, 9, 2, 6, 8, 10\}$. Other parameters are the same of the previous experiments. The value (in minutes) of each decision variable using the FAM rule is: $St = 40$, $Sp = 20$ and $At = 1026$.

The values of the weights used in the new experiments are: $At \cdot 100$, $St \cdot 10$, $Sp \cdot 18$. In the first type of experiments, tabu list size was varied, while $nbmax = 1000$. The best result was found at TS interaction 1712, with $At = 311$, $St = 56$, $Sp = 30$ and tabu list with size = 500. In the figure 1 shows the behavior of At in the experiment and the iteration where it was found the better result.

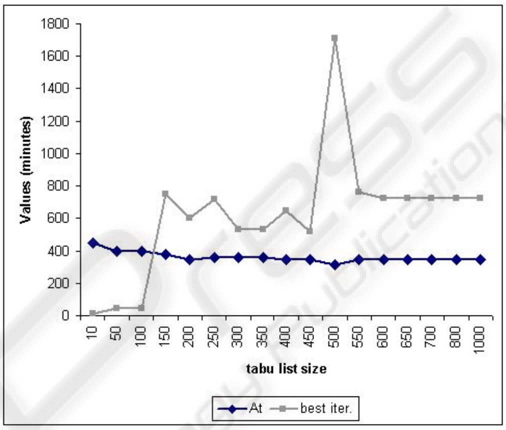

Figure 1: Values of At considering variation of tabu list size and iteration when it was found the best result.

A second type of experiment was performed, Using the best value of tabu list size in the experiment presented above. In this experiment NBMAx was varied and the same better solution was found in the TS iteration 1712, with $nbmax \geq 900$. Figure 2 shows At and the best iteration behavior.

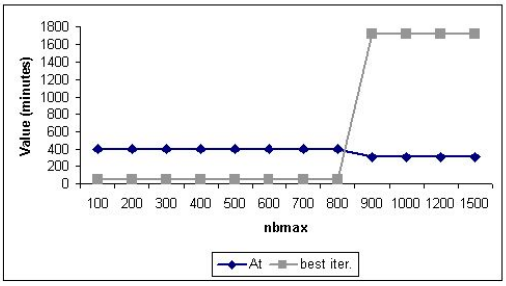

Figure 2: Values of At considering variation of *nbmax* and iteration when it was found the best result.

Comparing the variation of two graphs, it can be noticed that tabu list size determines the search reach to the better results for At, considering a high *nbmax* number. The increasing of these parameters reduces de At value significantly, but increases the amount of memory used by the model and the running time. In the next item, comparsion is made between TS parameters of previous works and new TS parameters used in the presented experiments.

3.3 Comparing Results

Table 2 shows a comparsion among initial FAM solution, NTS solution ($At \cdot 1$, $St \cdot 10$ and $Sp \cdot 18$) and the solutions obtained with 3 minimization policies weights in previous works (Rodrigues and Gómez, 2005).

Table 2: Comparsion among initial solution and policies of minimization considering $nbmax = 100$ and tabu list size = 10.

Minimizing	decision variables			best iteration
	St	Sp	At	
St	28	20	891	7
Sp	32	20	709	7
At	56	30	451	16
NTS	32	20	709	7
FAM	40	20	1026	-

The initial solution (FAM) groups parts with same PF, forming a sequence with minimum switching instants time (20 minutes). The increasing of Sp cannot improve F and the tool replacement time remains the same. The St minimization results in less tool replacement time and a higher tardiness value, according to the previous experiments. The At minimization reduces 575 minutes the tardiness time ($\cong 56\%$), increasing the tool removal and tool replacement time.

Table 3 shows the impact of the variation of TS parameters in the decision variables of F, considering the initial, solution, NTS solution and minimization policies.

Table 3: Comparsion among initial solution and policies of minimization. BI = best iteration; TL = tabu list size; NB = $nbmax$.

Min	Desision variables			BI	TL	NB
	St	Sp	At			
St	28	20	891	7	50	500
Sp	32	20	624	70	50	100
At	56	30	311	1712	500	1000
NTS	32	20	397	43	50	100
FAM	40	20	1026	-	-	-

The increasing of tabu list size doesn't contribute for improvement of any decision variable in St minimization. Its influence is low in Sp minimization, reducing the tardiness time in 85 minutes. With the NTS solution, the variation results in a better At time, while St and Sp remain the same value. It was needed a higher variation of TS parameters to find a better result of At, when its minimization is considered.

4 CONCLUSIONS

The experiments presented in this paper has the objective of investigate the influence of TS paramenters in a computational model developed to deal with Job Shop Scheduling Problem with tooling and due date constraints. This model allows to manage three decision variables of an objective function: tardiness, tool replacement and tool removal. Previous experiments shows a conflict between minimizing tool replacement and tool removal *versus* tardiness. Those expriments shows the positive influence of the increasing of the tabu list size and *nbmax number* in minimization of tardiness.

Experiments were made, where these TS parameters were variated. In the initial experiments, tabu list size was variated, and the increasing of this parameter results in better At time. It noticed that some values assigned to tabu list size minimizes At more than other values. In the second type of experiments, *nbmax* was increased, considering the best value of tabu list size. The reduction of At value obtained was the same of the initial experiments. The tabu list size parameter is the main factor in the diversification of the search, determining the variation of At component.

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