PRODUCTION TIME MINIMIZATION STRATEGIES IN A FLEXIBLE MANUFACTURING ENVIRONMENT
A Tabu Search approach

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Keywords: Tabu Search, Scheduling Problem, Flexible Manufacturing Systems.

Abstract: In this paper is proposed a computational model ("Modelo de Seleção de Partes e Escalonamento" – MSPE) to generate a scheduling of parts in a Flexible Manufacturing System environment, considering due dates, production turns and machine tools with magazine constraints. The problems considered are the Part Selection Problem and the Scheduling Problem. The scheduling objectives are the minimization of switching tools time, stop instants total time and the parts tardiness. The optimization police are defined according to Objective Function's weights values.

1 INTRODUCTION

In this paper are presented analysis of politics of production optimization through the management of the weights of an objective function. To make this analysis, a computational model was constructed considering the Part Selection Problem and the Scheduling Problem in a job shop of a Flexible Manufacturing System. The due dates and the magazine machine constraints are taken in account. The techniques chosen, for the construction of the model, are the Cluster Analysis and the Tabu Search.

2 PROBLEMS STUDIED AND TECHIQUES CHOSEN

The focus of this study is a Flexible Manufacturing System, where two classic problems are treated: the Part Selection Problem and the Scheduling Problem. As can be seen in bibliography (Groover, 2001; Dorf, 1994; Crama, 1997), a FMS can be composed of three basic components: (i) a set of CNC/DNC machines (Computer Numerical Control / Distributed Numerical Control) which possess a device for tool storage (magazine) with restricted capacity and a automatic system of tool exchange; (ii) an Automated Material Handling System (AMHS) that links the machines with the part storage an the warehouse, carrying parts and tools to the production line; (iii) a computational system that manages both the machine and the AMHS systems. Considering general-purpose machines, the entire system can be treated as one machine (Hwang, 1987). In this paper, the FMS considered is composed of one CNC/DNC machine, a AMHS and a computational control system.

In this environment, the first problem studied is the Part Selection Problem, which consists in group parts that possesses similar attributes in Part Families (PFs) (Groover, 2001; Kusiak, 1992) to take advantage of their similarities in design and production. In this study, the attribute chosen to generate PFs is the type of tool needed to process a set of parts. The parts of a same PF can be processed by the machine without stop for tool switching (setup). The complexity of this problem is NP-Complete (Hwang, 1987).

The second studied problem is the Scheduling Problem, where the classic goal is generate a schedule of parts which respects due dates constraints. Other constraints can be considered, such as magazine constraints, machine waste time constraints and production turns. The Scheduling Problem is difficult to solve and possesses computational complexity NP-Hard (Crama, 1996). Various authors use heuristic methods to deal with complexity (Kusiak, 1992).

To solve the Scheduling Problem, a Tabu Search approach was proposed (Glover, 1997). This technique has been applied in combinatorial

Gabriel Rodrigues A., Tórgo Gómez A. and Vicente Canto do Santos J. (2005).
PRODUCTION TIME MINIMIZATION STRATEGIES IN A FLEXIBLE MANUFACTURING ENVIRONMENT - A Tabu Search approach.
In *Proceedings of the Second International Conference on Informatics in Control, Automation and Robotics - Robotics and Automation*, pages 467-470
DOI: 10.5220/0001187704670470

optimisation problems, such as Travel Salesman Problem, Time Tabling Problem, Job Shop Scheduling Problem (Widmer, 1991).

3 PROPOSED MODEL

The MSPE model deals to generate a schedule that minimizes the following production times:
tardiness time: sum of differences between the predefined due date and the part completion date;
switching tools time: is the time to retrieve and insert tools in the magazine. The time to switching tools is proportional to the number of tools exchanged, here the time to exchange one tool is considered as one constant;
setup time: time to clean the workspace, maintenance of the machine, handling off the processed parts and restart the machine to the new operations.
The managing of the significance of these times it's made through the definition of values for the Objective Function's weights. The objective function was developed considering two dimensions: physical dimension (Part Families generation) and time dimension (scheduling).
Considering:
s a feasible solution;
N = total amount of parts;
L = number of setups in *s*;
U = number of switching tools in *s*;
i = index of a part;
j = index of a setup;
k = index of a switching tool;
Dvi = due date of part i;
Dsi = completion date of part i ;
Tr = time to restart the machine;
Te = time to exchange one tool.

Minimize:
$$f(p,t) = P_1 * At(p,t) + P_2(p,t) * Sp(p,t) + P_3 * St(p,t)$$

Where

$At(p,t) = \sum_{i=1}^{N} (Dv_i - Ds_i)$ such $(Dv_i - Ds_i) \geq 0$, $i \in \{1,...,N\}$;

$Sp(p,t) = \sum_{j=1}^{L} Sp_j * Tr$ such $Sp_j \geq 0$, $Tr \geq 0$, $j \in \{1,...L\}$;

$St(p,t) = \sum_{k=1}^{U} St_k * Te$ such $St_k \geq 0$, $Te \geq 0$, $k \in \{1,...,U\}$;

and

$P_1 \geq 0$, $P_2 \geq 0$ e $P_3 \geq 0$.

4 EXPERIMENTS

The model's implementation was made in C++ language, using GCC compiler in a GNU-Linux operational system. A Pentium III 833Mhz 128MB RAM was used to perform the experiments batches.
The experiments were made according three optimization politics: (i) minimization of switching tools time, (ii) minimization of setup time, and (iii) minimization of tardiness time. In all experiments t were considered: a set of 10 parts and 9 tools to process them; the maximum capacity of the magazine is 4 tools; the time spend for each tool switch is 4 minutes; the time for restart the machine operation is defined as 5 minutes; the production period (turn) is defined as 480 minutes; the tabu list stores 5 forbidden moves; and *nbmax* number is defined as 100 iterations. It was made 100 experiments with the MSPE to define the initial value of the Objective Function *f* weights. In these experiments the values of the each weight are randomly varied in a 0 - 100 uniform distribution interval. The behavior of the results generated was observed and any optimization policies were used. It was noticed that the results generated favors the minimization of tardiness. This is due to the fact that the weight of the tardiness (*At*) are significantly high compared to the 2 others weights (*St* and *Sp*). The results obtained in these experiments are the following:

Table 1: Initial solution obtained in the experiments to define the initial values of weights of *f*

	Average	
makespan	499,69 min	4,83 min
At	425,68 min	109,85 min
Sp	24,65 min	1,28 min
St	43,04 min	3,56 min

The best result was encountered in a average of 3,47 iterations (σ 3,39). In a manner to obtain a solution in which any decision variable of *f* were privileged (non-tendentious solution), the average of the weights of *St* an *Sp* (P_2 and P_3) were divide by the average of the weight of *At* (P_1). The proportion reached is:
$P_1 = P_2 * 17{,}27$ and $P_1 = P_3 * 9.89$
Once defined a proportion among the weights of *f* that constitutes a non-partial solution, the MSPE Module 4 is run with the weights $P_1 = 1$, $P_2 = 17{,}27$ and $P_3 = 9{,}89$. The result is showed in Table 2.

Table 2: solution obtained with non-tendentious solution's weights

makespan	501 min.
At	397 min.
Sp	25min. (5 setups)
St	44 min. (11 tool switches)

In the experiments described in the following items, the different optimization policies are analyzed through the managing of the values of the weights of Objective Function *f.* For these experiments the values obtained in the non-tendentious solution are used as initial point.

4.1 Switching tools time minimization

The objective of this experiment is minimize the time of switching tools (*St*) favoring P_3 weight. The weights P_1 and P_2 were made constants with the values of the non-tendentious solution. The weight P3 was varied, starting with non-tendentious solution (9.89) and increased of 5 units until reach value close to 1000. The table below summarizes the experiment results.

Table 3: Switching tools time minimization

P_3	*At*	*Sp*	*St*
9,89	397	25	44
20	624	20	36
40	709	20	32
45	709	20	32
50	891	20	28
1000	891	20	28

The increment of P_3 makes the variable *St* more significant and the others (*At* ad *St*) have them influence reduced. The increasing of the At value denotes a existent conflict between minimize tardiness time and minimize tool switch time. It was made experiments were *At* was not considered (P_1 = 0) and P_2 fixed in 17,27. In these experiments, for values of P3 higher than 9,89 the tool switches time and the setup time is lower (28 and 20 minutes, respectively), and *At* increases to 1029 minutes.

4.2 Setup time minimization

The objective in this experiment is minimize the setup time (*Sp*). It is considering that the value of *Sp* weight P_2 is increased and the values of P_1 and P_3 are constants, having the value of the non-tendentious solution. The initial value of P_2 was 17,27, being increasing of 5 units *per* run.

The results of the 20 experiments that were made are summarized in the table below.

Table 4: Setup time minimization

P_2	*At*	*Sp*	*St*
17,27	397	25	44
20	397	25	44
500	624	20	36
1000	624	20	36

In the initial solution, the parts were grouped in 5 PFs, so the minimum number of batches is the same number of PFs. Between the processing of these batches its necessary tool switching (4 setups in this situation). In this case, considering the Objective Function, the setup time would be equal to 20 minutes. In the experiments performed, with P_2 › 25, the schedules generated by MSPE had the minimum setup time.

Although the setup time resulting of the increment of P_2 had be the same that the setup time encountered in the P_3 experiments, the switching tools time reached with P_2 is higher. It was identified in P_3 experiments the existence of a relation between the minimization of *St* and *Sp*. So, the minimization of *St* implies in a minimization of *Sp*, but in the other hand, the minimization of *Sp* does not lead *St* to its minimum value.

4.3 Tardiness time minimization

In this experiment the behavior of the solutions generated by MSPE are analyzed, considering the initial solution presented in the table 1, where tardiness time is privileged. Once the initial solution privileges the tardiness time reduction (962 to 397 minutes in the initial solution), the increasing of P_1 doesn't influence the behavior of the results in this experiment (*At*=397, *Sp* = 25 and *St*=44).

4.4 Tabu list and *nbmax* variation

The size of the tabu list and the tabu search parameter *nbmax* were varied in these experiments, in order to verify the influence of these in the results of f. Four categories of experiments were made:

using values of weights of the non-tendentious solution (P_1=1, P_2=17.27 and P_3=9.89);

using weights that privilege *St* (P_1=1, P_2=17.27 and P_3=100);

using weights that privilege *Sp* (P_1=1, P_2=100 and P_3=9.89); and

using weights that privilege *At* (P_1=100, P_2=17.27 and P_3=9.89);

The tabu list size was increased in 50 units while *nbmax* was increased in 100 units per run. The results obtained are summarized in the next tables.

Table 5: Tabu list size and nbmax variation for weights of the non-tendentious solution

nbmax	tabulist	*At*	*Sp*	*St*
200	100	397	25	44
…	…	…	…	…
1000	500	397	25	44

Table 6: Tabu list size and nbmax variation for solution that privileges St

nbmax	tabulist	*At*	*Sp*	*St*
200	100	891	20	28
…	…	…	…	…
1000	500	891	20	28

Table 7: Tabu list size and nbmax variation for solution that privileges Sp

nbmax	tabulist	*At*	*Sp*	*St*
200	100	624	20	36
…	…	…	…	…
1000	500	624	20	36

Table 8: Tabu list size and nbmax variation for solution that privileges At

nbmax	tabulist	*At*	*Sp*	*St*
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

5 CONCLUSIONS

In this paper was proposed a computational model, the MSPE, that considers Part Selection Problem and Scheduling Problem in a job shop. This model allows that starting with a set of parts and tools could be obtained a scheduling that reflects optimization strategies through the managing of the weights of an objective function. Experiments were performed, in which, the values of the weights of the objective function were varied according to 3 strategies of minimization: (i) tool switches time, (ii) setup time and (iii) tardiness time. To perform the analysis it was defined an initial solution for the Objective Function weights, with the intent of all variables had the same contribution for the result of *f*. Considering the high significance of the tardiness time variable, the initial solution privileged this variable. In the minimization of the switching tools time it was identified a conflict between this objective and the tardiness time minimization. As in the *St* experiments, the *Sp* minimization conflicts with *At* minimization. The increasing of weight value of *Sp* reduces the influence of *At*, but do not lead *St* to its minimum value. This is due to the fact that for the same setup time exists two or more different tool switches times. The minimization of the tardiness time can be verified with the increasing of the tabu list size and the *nbmax*. As in the other experiments, the times of setup and switching tools became higher as *At* is increased. In this experiments, the increasing of tabu list size and *nbmax* has positive impact in the tardiness time minimization. A tabu list with higher size acts as diversification factor, forcing the tabu search to visit a higher number of feasible solutions in the neighborhoods generated.

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