A MULTITHREADING TABU SEARCH FOR SETUP TIME OPTIMIZATION FOR LIMITED MACHINE MAGAZINES IN THE CELL FORMATION PROBLEM

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ABSTRACT

This paper aims to present a solution for the Manufacturing Cell Formation Problem through the use of a multithreading Tabu Search that uses deterministic methods to effectively explore local optimum areas. Manufacturing Cell Formation problem involves the process of analysing parts and groups them according with their similarity. This paper presents a method focused in maximize the production efficiency, by minimizing the machine setup time in a limited magazine size through the reduction of tool changes by creating clusters of parts that share machining tools and present an initial scheduling based on tool changes reduction. In order to valid the proposed algorithm, the results obtained are compared against other Tabu Search solutions proposed in the literature. In order to validate the proposed method, the results obtained are compared against other solutions found in the literature and during this process, in some instances results better than the ones found in the literature are obtained.

KEYWORDS. Tabu Search; Machine Setup Time Optimization; Manufacturing Cell Formation

Main area: IND - OR in Industry

1. Introduction

The process of batching and automate manufacturing processes is an essential process for companies that want to make competitive products. The Batch manufacturing is estimated to be the most common form of production, constituting more than 50% of the total manufacturing activity in the US. In addition, there is a growing need to make batch manufacturing more efficient and productive (Groover, 2001).

In the batching process, Group Technology (GT) has an important role and offers relevant contribution helping to increase the efficiency of production operations and reducing the requirement of facilities (Xu et al., 2014). As part of GT, the Manufacturing Cell Formation problem aims to define an efficient struture to group machines(James et al., 2007).

The Manufacturing Cell Formation problem is NP-Hard (Spiliopoulos and Sofianopoulou, 2008). Thus, simple heuristics has the propensity to not present satisfactory results. Therefore, several methods making use of artificial intelligence techniques are proposed to solve the problem. Being the manufacturing cell formation a problem of combinatorial optimization, metaheuristic like Ant Colony (Li et al., 2011; Spiliopoulos and Sofianopoulou, 2008), Genetic Algorithms (Xiaodan et al., 2007), Tabu Search (Gómez et al., 2011) are commonly used to find a good solution. On this paper the metaheuristic Tabu Search is used to solve the problem.

Beyond that, another resource that currently receives increasing focus on academic papers is the parallel processing applied to these methods (Fiechter, 1994; He et al., 2005). In such cases, different processors can perform multiple calculations simultaneously.

Another method gaining increased attention is the hybridization of metaheuristics (Kaur and Murugappan, 2008). The success of the hybrid approach comes from the union factor of the strategic advantages of each method in a single metaheuristic; providing a better performance compared to the pure method (Tsai et al., 2009).

In this paper, a variation of the classical implementation of Tabu Search is proposed. Being part of this modification, concepts of hybridization and parallel programming are used to provide solutions near promising regions.

This paper is divided into 5 sections. Section 2 presents concepts of the Manufacturing Cell Formation problem as well as review from its literature. Section 3 presents details about the Tabu Search proposed to solve the problem, also further details about the multithreading concept used on this method are provided. Section 4 presents the methods used for general testing, as well as the metric used to compare the result against other solution found in the literature. Section 5 presents the conclusions.

2. Manufacturing Cell Formation Literature Review

The cellular formation for a manufacturing system is an application of the Group Technology (GT) – which is a tool to identify similar parts and group them together regarding similarities between them (Selim et al., 1998). The Cell Formation (CF) aims to reduce the setup and flow times – minimizing the inventory and manufacturing lead times (Wemmerlov and Hyer, 1989; Wu et al., 2010).

CF is a binary matrix machines versus parts which reorganizes rows and columns with the intention to group parts (part families) and machines (machine cell). The binary element in the Figure 1 represents the relationship between part and machine indicating:

- 1 – the part p uses the resource (or machine) m;
- 0 – the part p can't use the resource m;

Machine Number \ Part Number	1	2	3	4	5
1	0	1	0	1	1
2	1	0	1	0	0
3	0	1	0	1	0
4	1	0	1	0	0

Figure 1: Relationship between part and machine.

Then, apply the algorithm proposed by Kusiak and Chow (1987) to find any relationship between parts and machines – rearranging the cells and resulting in two cellular formation for manufacturing systems and two part families, as described in the Figure 2.

		FP-1		FP-2		
		1	3	2	4	5
CM-1	2	1	1			
	4	1	1			
CM-2	1			1	1	1
	3			1	1	

Figure 2: Cells created by Kusiak Algorithm.

3. Proposed Tabu Search

Firstly proposed in 1986, Tabu Search is a method that can be used to solve different problems on combinatorial optimization environment (Glover, 1986). According with Glover (1986), Tabu Search may be viewed as a metaheuristic superimposed on another heuristic. This method uses a list in order to forbid movements ("tabu movement") that drives to solution areas already explored.

Basu (2012) brings a brief and updated literature review about the Tabu Search being used as a problem resolution tool related to combinatorial area. On this paper, the main methods used to perform movements from one solution to another(in order to generate the neighbourhood), Tabu List size and type, search intensification and diversification, aspiration criteria as well as a couple of other relevant details are pointed along the article.

The diffent methods overviewed by this article are evaluated qualitatively (through the quality of the solution) as well as quantitatively (by checking the number of times this method is used in the studied articles). The methods employed in the proposed Multithreading Tabu search take in account of the methods pointed as the most efficient and appropriate to the resolution of combinatorial problems.

The solution quality is evaluated by using a metric named "effective clustering" (Kumar and Chandrasekharan, 1990). This metric is represented by the equation(1).

$$\tau = \frac{e - e_0}{e + e_v} \qquad (1)$$

In the given equation, *e* represents the number of 1's in the given matrix, e_v represents the number of voids (number o 0's inside the clusters in the main diagonal) e_0 is the number of exception (the number of 1's outside the main diagonal).

3.1. Initial Solution

As initial solution, the Kusiak Algorithm is used. This algorithm is an iterative process that selects rows and columns in a matrix in order to simultaneously create Family Parts and Machine Clusters. Kusiak and Chow (1987) have initially proposed an algorithm that identifies the similarity between manufacturing processes and creates separable groups. This method uses a binary part-machine incidence matrix A = $[a_{ij}]$ and decomposes A into sub matrices A_1, A_2, ..., A_n. Each sub matrix can be defined as a machine cell.

However, once this paper aims to control and reduce the number of tool changes in a limited magazine, it is necessary taking in account of the machine magazine limit. For this reason, the algorithm used on this paper to generate the initial solution is a method proposed by Gómez (1996), because this method considers the similarity of tools used in the manufacturing process, as well as the machine magazine limit.

Despite this kind of method hardly returns the optimal solution, it is frequently used because it points to an optimum solution. Usually an exact algorithm points to a local optimum solution instead of a global one. However, this algorithm can in some particular cases point to the optimal solution as well as it can point to a near-optimal solution that can be considered an acceptable result (Black, 2005).

3.2. Search Intensification

Proposed by Croes (1958) as a method to solve the travelling salesman problem, the 2-opt is widely used to modify a current solution and generate a new neighborhood until the stop criteria requirements are met (Lim, Yong, Ramli and Khalid, 2011). Also, it is used as a local search method in many other combinatorial problems (Kothari and Ghosh, 2013; Hasegawa, Ikeguchi and Aihara, 1997).

The 2-opt movement occurs through the removal of two non-adjacent parts or machines from a cluster. After the removal of these components, those parts or machines have their position exchanged thus preventing the need of perform an evaluation of a subgroup again. In addition to, 2-opt movement is also used to exchange the families orders, thus changing the current scheduling. This proccess helps in reducing the number of tool change between Family parts, consequently reducing the setup time.

The intensification occurs due the non-substantial change of only two parts or machines, thus creating a solution near of the current solution. Considering it is a simple movement, consequently it has a low computational complexity – $\theta(n^2)$ for 2-opt algorithm (Croes, 1958). For this reason, this method can be commonly find in Tabu Search implementations. In this paper, the 2-opt movement is used to generate 20 neighbours and potential candidate solutions.

Another mehod used in the implementation and on search intensification is a column insertion method. In this method, as initial step an part or machine is randomly selected and then, this component is removed from its cluster. In a next step, the algorithm should find the best cluster to insert this part or machine back (Semet and Taillard, 1993).

Suppose that the Families FP-1, FP-2 and FP-3 (Figure 3) are clusters that represent the current solution for a machine that supports 4 tools and the part 4 that belongs to the Cluster FP-3 is removed. Considering the, algorithm should find the best family to insert this part back aiming to minimize the associated objective function as well as its restrictions. On this particular example, since the part "4" shares resources with FP-1, then the part "4" must be moved to this cluster reducing the FP-3(Figure 4). In a second iteration the part 7 could be moved to FP-2 cutting the FP-3 off.

		FP-1			FP-2			FP-3	
Machine Number		1	5	3	6	2	8	7	4
CM-1	1	1		1					
	2	1	1						
CM-2	3					1			
	4				1	1	1		
CM-3	5				1		1	1	
	6			1					1

Figure 3: incidence matrix $[a_{ij}]$ before insertion movement.

		FP-1				FP-2		FP-3	
Machine Number		1	5	3	4	6	2	8	7
CM-1	1	1		1					
	2	1	1						
	6			1	1				
CM-2	3						1		
	4					1	1	1	
CM-3	5					1		1	1

Figure 4: incidence matrix $[a_{ij}]$ after insertion movement.

When comparing both proposed intensification methods, it is possible to notice that both methods are very similar. More than that, it is possible to affirm that the insert column method is an improved 2-opt once in both cases a randon part or machine is selected. However, on insert column algorithm, when returning this part to a cluster an objective function must be respected giving always the best solution. Due the second method require more computational resources than the 2-opt method, it is used to generate only 5 neighbours and potential candidate solutions.

3.3. Search Diversification

Different from the movements proposed in order to intensify the search (movements that usually are simpler), in situations where it is necessary to diversify the search and then to reach a solution far from the current solution then diversification movements are used. The diversification movements should perturb the neighbourhood increasing its candidate solution range consequently reaching solutions areas not explored before.

In the proposed model, the diversification of movements occur only after a pre-defined number of iterations without improving the current value of the actual solution or the value of the objective function. By default, this value is set as half of the value proposed as stopping criteria (The stopping criteria is defined as a finite number of iteration without improvement the value of objective function).

Once the iteration counter reaches half of the stopping criteria, automatically diversification movements are made perturbing the current neighbourhood. In this paper the chosen stopping criteria is 500 rounds without improvement, consequently the diversification movements only creates candidate solutions after 250 iterations. Two different methods are proposed in order to generate candidate solutions.

As previously cited in this paper, the Tabu Search is a method that improves the results through several iterations using a list of movements that should not be repeated and it has resources to avoid becoming stuck in local optima area. However, the performance and the time to obtain an optimal or near-optimal solution are strongly affected by the proposed initial solution (Liu et al., 2009).

Bearing in mind that the diversification algorithm is only used after several rounds without improvements, we can assume that it is potentially stuck in a local optimal. If so, the result hardly will be improved. For this reason, the implemented Tabu Search proposes the usage of the same deterministic method previously used to generate the initial solution again, generating a unique candidate solution that points at a new optimal or suboptimal region, region which can possibly be the global optimal solution (Black, 2005).

It is known that the deterministic algorithm used to find an initial solution has a higher complexity - $\theta(2mn)$ (Kusiak, 1987) - than the standard algorithm used during the search intensification like 2-opt ($\theta(n^2)$). Nevertheless, with the advancement from studies related to the parallel processing area in addition to technological advancement of the computer hardware, it becomes possible to use algorithms with higher complexity instead of saving processing time in combinatorial problems. Thus, it is proposed the use of the modified Kusiak Algorithm in parallel to the Tabu Search algorithm to create a candidate solution. The Figure 5 shows the architeture used to run the initial solution method in parallel to the intensification and diversification movements. Once it is a multithread processing method, an iteration should not be finished until both processes are completely done, otherwise there is a risk of losing the synchronization between both.

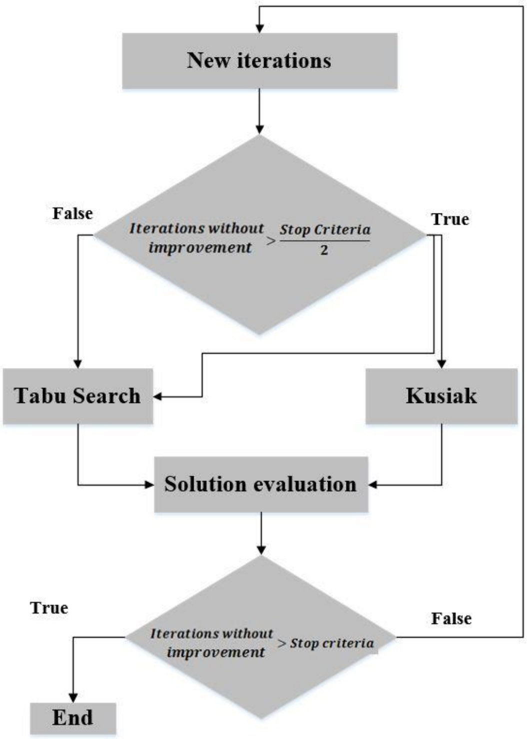

Figure 5: multithreading Tabu Search architecture

The implemented alternative Kusiak Algorithm can be defined as a deterministic algorithm, being non deterministic only when selecting the initial part represented by a row in the matrix. For this reason, depending on the initial part selected, the same resulting matrix can be obtained more than once. It occurs every time the initial part previously selected is selected again. For this reason, the implementation of the second Tabu List is proposed in order to prevent that the same initial part is selected several times. This secondary Tabu List is responsible for storing a set of initial parts that were already used. This special list size is proportional to the problem size and has a size equivalent to 10% of the problem size.

3.4. Tabu List

When generating a collection of solutions, it can be observed that the new neighbourhood can present only worse solutions in comparison with the best solution found. The Tabu Search has resources that can prevent the method to visit these worse solutions again, as well as it has resources avoid becoming stuck in a local optimal region (Sorlin and Christine, 2005). A solution is added to the Tabu List every time it was already visited.

The Tabu Search is a method with memory structures. This memory structure is used in order to store a finite collection of movements made during its processing. Therefore, a list is necessary to store these movements, being that list known as the Tabu List (Glover, 1986). Bearing in mind that whether it is an finite size list, each movement added to the Tabu List must remain in this list for a limited and pre-defined time. This limitation occurs through the definition of the Tabu List Size (Basu, 2012).

The size of the Tabu List allows the user to intensify or diversify the search. The Tabu List memory types can be divided into three different categories Short-term, Intermediate-term or Long-term.

The Tabu List size can also be static, dynamic or random (Tang and Hooks, 2005). According to Basu (2012) survey, lists with static size are the most common and its size usually varies from 0 a 4 like as proposed in (Crainic et al., 1993). On the other hand, there are articles that also present static lists, however with a larger list allowing more than 30 values (Lau, Sim and Teo, 2003). In this paper as well as presented by Ting, Li and Lee (2003) and Greistorfer (2003), the Tabu List size is proportional to the number of parts and machines being analyzed, the chosen proportion on this implementation is 25% of the problem size.

4. Experiments and Results

In order to test the Tabu Search implementation, a set of 11 problems extracted from the literature is used. This set of problems was previously tested by James et al. (2007) and Gómez et al. (2011). The best solutions found in both papers are compared against the solutions obtained on this paper. The list of test instances was extracted from James et al. (2007).

Once the proposed Tabu Search uses multithreading processing – a multi core processor must be used to evaluate the processing time gain, therefore the tests were made in a computer with an Intel Core i5-3210M processor with 2.5GHz and 6GB of RAM memory.

Each problem was submitted to 75 executions considering a machine magazine limited to 4 tools. In the Table 1 it is shown the obtained: worse and best efficiency results, average efficiency result and its standard deviation. Like in James et al. (2007) the problems are organized by ID and problem source. In addiction to , the problem size and the maximum number of tools used in a individual part are also present on Table 1.

An relevant point observed during the tests is the low processing time. In most cases, the processing time has not exceed 2 seconds. The lowest processing time is observed on problem 1 – average processing time of 1 second and 200 milisenconds – and the biggest processing time is observed on problem 8 taking 2 seconds and 79 miliseconds. When comparing this processing time to the average time to obtain a solution in James et al. (2007) it is possible to observe that the processing time does not increase significantly even using the proposed method.

This low processing time - even using the Kusiak Algorithm to diversificate the search - shows that with the new hardware improvements, methods with a higher complexity can be used in metaheuristics without performance loss.

The method proved itself powerful when grouping jobs where the number to tools used do not exceed the magazine limit. On this particular case the method is imposing a magazine limit of 4 tools. Consequently, if a machine has to process more than 4 parts – it tends to create a bottleneck because this part has to be processed in more than one step. This situation is observed on problem 9, this problem has several parts that requires 5 tools on its production. For that reason, it is expected to have a result above the found on the literature where this restriction is not impose.

Table 1: Minimum, maximum and average efficiency.

ID	Problem Source	Problem Size	Max number of tool used	Min	Max	Average	σ
1	King and Nakornchai (1982)	7x5	3	82,35	82,35	82,35	0
2	Waghodekar and Sahu (1984)	7x5	4	70	80	74,08	2,44
3	Seifoddini (1989)	18x5	3	79,59	79,59	79,59	0
4	Kusiak and Cho (1992)	8x6	4	80	80	80	0
5	Kusiak and Chow (1987)	11x7	3	58,62	60,71	58,97	0,75
6	Boctor (1991)	11x7	3	70,37	73,08	71,18	1,31
7	Seifoddini and Wolfe (1986)	12x8	5	76	76	76	0
8	Chandrasekharan and Rajagopalan (1986a)	20x8	5	66,67	67,44	66,89	0,36
9	Chandrasekharan and Rajagopalan (1986b)	20x8	6	18,18	26,77	22,47	4,52
10	Mosier and Taube (1985)	10x10	4	70,59	76	71,87	2,26
11	Chan and Milner (1982)	15x10	4	92	92	92	0

In other hand, in problems where 4 or fewer tools are used during the process, like in problems 1, 2, 3, 4 and 5, the results are better or the same when compared to the literature. Table 2 shows the results in the literature in comparison to the obtained on this paper. Proposed Tabu Search represents the results found on this paper. Results better than the ones found in the literature are in bold.

Table 2: Comparison between literature results and proposed Tabu Search results.

ID	Best Solution in source Problem	James et al. (2007)	Gómez et al. (2011)	Proposed Tabu Search
1	73,68	82,35	82,35	82,35
2	68	69,57	69,57	**74,08**
3	79,59	79,59	79,59	79,59
4	76,92	76,92	76,92	**80,00**
5	53,13	60,87	60,87	58,97
6	70,37	70,83	70,83	**71,18**
7	68,3	69,44	69,44	**76,00**
8	85,25	85,25	85,25	66,89
9	58,72	58,72	56,70	22,47
10	72,79	75	70,35	**71,87**
11	92	92	92	92

Though the Table 2 it is possible to observe that the solutions found to the problems 2, 4, 6, 7 and 10 are better than the solutions presented by the literature. On problems 1, 3 and 11 the same result was found. On problems 5, 8 and 9 the results found in the literature are better than the ones found by the proposed Tabu Search.

5. Conclusions

This paper aims to present a solution for the Manufacturing Cell Formation Problem through the use of a multithreading Tabu Search, that uses deterministic methods to effectively explore local optimum areas. On this paper, the magazine is considered with limited capacity. The magazine capacity considered is four tools.

The method obtained better solutions when compared against other solutions found in the literature when using 4 or fewer tools on the manufacturing proccess, proving to be a powerfull method to create manufacturing cells for limited number of tools or resources.

However, due the magazine limit restriction added to the problem the better results are limited only to parts that use 4 or fewer tools on its processing. Thus, an independent method to deal with this restriction could be implemented in order to improve the result efficiency. Consequently reducing the number of tool changes and setup time. Future works will present other studies on the problem addressed in this article.

Also, the method proved itself powerful to obtain solutions in real time without reducing the solution quality. Thus being possible to use this method in situations where a real-time solution for a cell formation problem is necessary - like in stochastic scheduling problems.

Future works will present other studies on the problem addressed in this article. Also, the limited magazine should change from a fixed number of tools - on this paper 4 - to the maximum number of tool being used in a given problem, thus testing the grouping efficiency without creating a bottleneck.

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