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Parallel Tabu Search for Multiobjective Flexible Job Shop

Ferdinan Rinaldo Tampubolon[1*], Rischa Devita[2], Sinta Marito Siagian[3] Samaria Chrisna HS[4] Switamy Angnitha Purba[5] Anna Angle Sitinjak[6]
[*1,4]*Teknik Elektronika, Politeknik Negeri Medan, Medan, Indonesia*
[2,3]*Teknik Listrik, Politeknik Negeri Medan, Medan, Indonesia*
[5]*Teknik Kimia, Politeknik Teknologi Kimia Industri,Medan, Medan, Indonesia*
[6]*Teknik Mesin, Politeknik Teknologi Kimia Industri,Medan, Indonesia*
Corresponding Author: Ferdinan Rinaldo Tampubolon

Abstract
Scheduling is an important part of the production process. Job Shop is a variant of machine scheduling where each job has operations that must be completed sequentially where there is only one machine that can process the operation. Meanwhile, Flexible Job Shop is a general form of Job Shop in which an operation can be processed by more than one machine. Thus, this research will focus on solving multiobjective flexible job shop with the objective function of minimizing completion time and carbon emission by considering the uncertainty in the processing time. Parallel tabu search method will be used to diversify the process of tabu search. In this research, the tabu search process will be divided into several threads, where each thread will undergo a mutation process with a different move, these will provide a variety of solution searches so that the best solution can be found quickly. The results of this study show that parallel tabu search produces more optimal solution with less time duration and iterations compared to the Tabu Search algorithm.

Keywords: *Tabu Search, Parallel, Flexible Job Shop, Emission*

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I. INTRODUCTION

Scheduling is an important part of the production process. A good schedule arrangement will make the production process run more optimally both in terms of time and cost [1]. Machine scheduling consists of several type depending on the process of making goods such as flow shop, job shop, open shop. Job Shop is one of machine scheduling where each job has operations that must be completed sequentially. Each of these operations can only be completed by exactly one machine. Meanwhile, Flexible Job Shop is a general form of Job Shop where an operation can be processed by more than one machine.. [2]. Flexible Job Shop is divided into two, namely Partial Flexible Job Shop where there are only a set of machines that can process an operation and Total Flexible Job Shop where each machine can process each operation [3]

The objective of Flexible Job Shop research varies although it is dominated by minimizing the total scheduling time, some other objective functions such as average job completion time, flow time, delays are generally related to operations.. [4]. Furthermore, the objective function research of Flexible Job Shops began to include environmental factors such as energy consumption, noise [5] and carbon emissions.[6]

Research related to flexible job shop is expanded by considering the uncertainty in the existing data, for example, uncertainty in processing time, so the concept of fuzzy numbers and grey numbers were used [7] , in fuzzy numbers there are a membership function, while in Grey numbers it only uses interval values, namely upper and lower bounds so it is more practical to use if our knowledge of job processing time is limited [8].

The FJSP solution consists of several methods both local and global search, for local search several solution methods have been used such as Simulated Annealing[9] and Tabu Search. [10]. Tabu Search method uses the concept of mutation with a memory to remember the move of the mutation that has been used before so it will not used again (tabu) during certain iteration processes. However, the concept of mutation in Tabu Search makes this algorithm is depended on the initial solution. If the initial solution is a not-so-good solution then it is likely that the search process in Tabu Search will be trapped at a local minimum.

To diversify the process of searching in Tabu Search, a parallel solution search is performed, the process of searching for solutions is divided into several threads, where each thread will undergo a mutation process with different moves, these things will provide a variety of solution searches so that the best solution can be found quickly, research related to parallel Tabu Search has been carried out by [11] in the case of flexible job shops and [12] for job shop cases.

However, these studies have not involved environmental considerations and uncertainty in job processing time. Thus, this research will focus on solving multiobjective flexible job shop with the objective function of minimizing completion time and carbon emissions with the existence of grey variables using Parallel Tabu Search.

1.1.1 Flexible Job Shop

Suppose there are n jobs $J = \{J_1, J_2, J_3 \dots J_n\}$ with m machine $W = \{W_1, W_2, W_3 \dots W_m\}$ where each job has p operation $O = \{O_{11}, O_{12}, O_{13} \dots J_{np}\}$ which can be processed by a set of machine with some rules as follows:

1. There is only one machine that can process an operation at a time period
2. Each operation in a job is processed sequentially
3. All machines can only process one job at a time.
4. Machines process an operation without any interruptions [13]

1.1.2 Parallel Tabu Search

Parallel Tabu Search is a development of Tabu Search where there are multiple agents (threads) searching for solutions. This is different from the classic Tabu Search which only uses one thread. The mutation performed in tabu search uses the following movement (move) as Figure 1:

2	1	3	1	2	2	3
	⇧			⇧		
2	2	3	1	1	2	3

Figure 1: Mutation

It is performed by randomly selecting two genes in the chromosome then exchanging the chromosomes to form a new chromosome as shown in Figure 1. The flowchart of Parallel Tabu Search is shown in Figure 2.

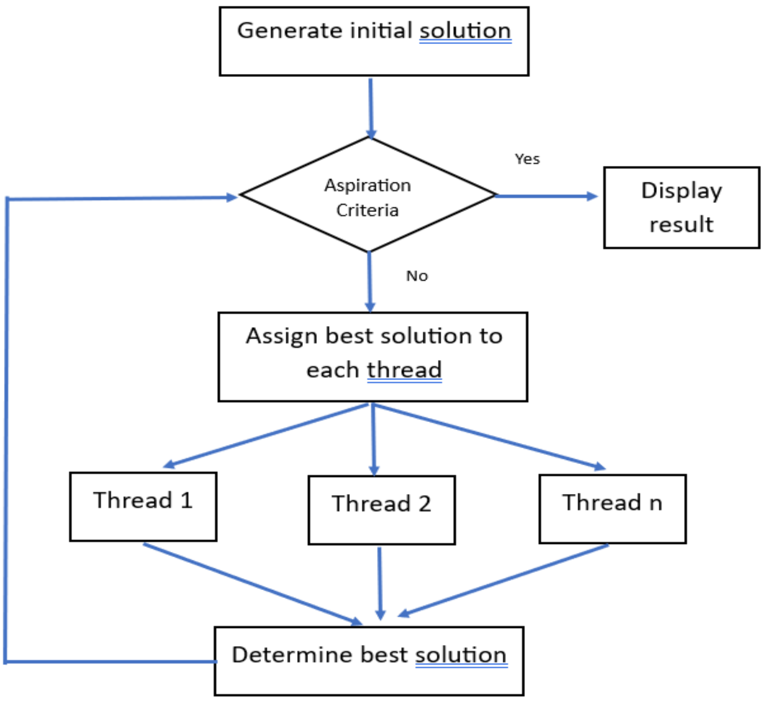

Figure 2:Parallel Tabu Search

Each thread in this algorithm will run a tabu search process, each thread has maximum iteration and tabu tenure just as classical Tabu Search. If each thread find a new best solution, than it will communicate with the other thread. If that solution is the best solution among the other thread, than the old best solution will be substituted. Than that new solution become a new best solution, and it will be used by each thread to perform a better solution.

II. RESULT AND DISCUSSION

The testing is conducted by generating a number of job and machine data as follows: there are 8 cases as follows: 4 x 4, 5 x 5, 10 x 6, 16 x 10, 20 x 10, 25 x 15, 30 x 10, 40 x 20, then generated uniformly distributed random numbers for each case as follows: the number of operations is an integer random number between 1 and 5, the processing time is a grey number A = [a,a+b] where a is an integer number from 5 to 30 and b is an integer number from 5 to 10, then the carbon emission is a grey number B = [c,d], where c is a decimal number from 0.01 to 0.03 and d is a decimal number from 0.1 to 0.3.
The parameters used in Tabu Search are as follows: Maximum Iteration: 20,000 and Tabu Tenure: 5-10
The parameters used in Parallel Tabu Search are as follows: Maximum Iteration: 50, Maximum Iteration if a better solution has not been obtained in each thread: 100, Number of Threads: 3-10, Tabu Tenure: 5-10

The Parallel Tabu Search algorithm is compared with Tabu Search with the objective function of minimizing the completion time and carbon emission as shown in Table 1.

Table 1:Result using Parallel Tabu Search

Cases	Parallel Tabu Search		Tabu Search	
	Makespan	**Emission**	**Makespan**	**Emission**
4 x 3	[64, 116]	[33.2, 54.5]	[88, 137]	[35.8,56.5]
5 x 5	[71, 107]	[47, 73.1]	[94, 134]	[57.5,85.9]
10 x 6	[92, 140]	[65.7, 106.2]	[125, 180]	[85.9,128.1]
16 x 10	[104, 159]	[113.2, 184]	[171,252]	[142.2, 210.9]
20 x 10	[193, 289]	[203, 295.2]	[235, 339]	[236.5, 337.7]
25 x 15	[161, 222]	[229.4, 333.5]	[215,313]	[248.5,360.2]
30 x 10	[205,298]	[335.4, 492.9]	[266,395]	[334.6, 491.4]
40 x 20	[178, 240]	[411, 612.1]	[204, 285]	[475.6, 671.8]

Case 1, with the size of 4 jobs and 3, the makespan provided using Parallel Tabu Search is $M_{11} = [64, 116]$ while using Tabu Search is $M_{12} = [88, 137]$, it can bee seen makespan which provided by parallel tabu search is more optimum than tabu search have. For the next objective function that is carbon emission, using Parallel Tabu Search $E_{11} = [33.2, 54.5]$ while using Tabu Search $E_{12} = [38.5, 56.5]$. Thus the solution provided by Parallel Tabu Search is dominant because it is smaller for both makespan and carbon emission

For other cases, the results obtained by Parallel Tabu Search dominate the solution produced by Tabu Search. Based on the number of iterations performed, Tabu Search performs 20,000 iterations while Parallel Tabu Search performs approximately 15,000 iterations (maximum iteration x maximum iteration for each tread x number of threads). The calculation duration for each algorithm is shown in Table 2.

Table 2:Durasi Algoritma (s)

Cases	Parallel Tabu Search	Tabu Search
4 x 3	1,76	8,48
5 x 5	1,50	9.07
10 x 6	4,54	12.02
16 x 10	4,17	16,67
20 x 10	3.89	21,87
25 x 15	4	24
30 x 10	8,27	28,17
40 x 20	7,7	33,9

Based on Table 2, it can be seen that the duration of the parallel tabu search algorithm is much smaller by a significant distance, for the first case, for example 4 x 3, the Parallel Tabu Search algorithm has a duration almost four times smaller than the Tabu Search algorithm.

III. CONCLUSION

Even with less number of iterations compared to the regular Tabu Search, the Parallel Tabu Search algorithm provides better results on the entire eight cases given. The results obtained with this algorithm are quite dominant with superior for both objective functions of the given problem. For the duration of the process, the Parallel Tabu Search algorithm also has a much faster completion time. This can be due to the use of more than one thread that can communicate with each other so that the search process is more varied and runs more optimally than using only one thread. However, the Parallel Tabu Search algorithm can be developed by involving crossover or combining with algorithms such as Genetic Algorithms to provide a more extensive search.

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