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(Review Article)

Job shop scheduling with combinatorial priority rules in a furniture company

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Abstract

This paper analyzed a job shop scheduling problem with combinatorial priority rule from a case study of a furniture company, whose product – cupboard – has the highest volume and revenue while it is struggling with tardiness at about 10%. The goal of this scheduling is to minimize the mean flow time, mean tardiness time and the proportion of tardy jobs and compare its performance to one traditional priority rule – Longest Processing Time first. As results, the combinatorial priority rules in scheduling would bring a positive outcome with reducing mean flow time and around 3.45% for proportion of tardy jobs. Moreover, the most significant improvement is true for mean tardiness time, which is reduced by over 3 times compared to Longest Processing Time first alternative. This combinatorial priority rule is recommended to schedule in flexibly ways according to the customer's demand. It should be considered to use as the initial alternative for the improvement search algorithms to find out better solutions.

Keywords: Shop Floor Scheduling; Combined Priority Rules; Job Shop; Furniture Manufacturing

1. Introduction

Nowadays, industries are facing a new era of extraordinary challenges. End users are increasing asking for customized products, at the same as product life-cycles get shorter. In addition, the competition on the market becomes more cutthroat than ever due to the impact of COVID19 pandemic. Therefore, it is a must to achieve more flexible, agile and efficient production system [1]. Furniture manufactures have also been affected by this and must learn to cope with increasing product complexity, a reduction in time to market and costs, especially a decrease in production lead time.

As an answer to these and other challenges, scheduling is the popular as well as a useful technique for most production companies applying currently. This tool concerns the allocation of limited resources to tasks over time. It is a decision-making process that has as a goal optimization of one or more objectives. In recent, the performance of priority rules, which has mostly focused on the use of one rule at a time at all work stations during the entire period of operation, has attracted more attention. For every priority rule, they also have specific advantages and disadvantages as well, and such a consideration is appropriate when the emphasis is on understanding the performance characteristics of each rule individually and comparing them [2]. For instant, the "shortest processing time" rule does minimize the mean flow time but perform poorly in the tardiness measure. The rule that emphasizes job due dates, such as the "earliest due date", fails to provide superior results on due date related performance criteria. It is also the evident that no single rule is capable of performing equally well across all of the common performance measures, especially when two important factors, tardiness and flow time, are jointly considered. In order to overcome the limitation, the combinatorial rules, a type of rules formed by combining the element of two or more rules in one on a predetermined manner, has been introduced. Until now, there are some studied (Oral and Malouin 1973 [3], Eilon and Chowdhury 1976 [4], Baker and

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Kanet 1984 [5], Kannan and Ghosh 1993 [6] confirming that these combinatorial rules can tackle the difficulties of simple priority rules, and therefore, improve the overall performance of a shop.

The problem of scheduling furniture manufacturing is considered as a job shop scheduling. In particular, the research focused on scheduling one production company – FS Furniture Manufacturing Company – which has strategies for making to order production of a variety of products, which includes chairs, tables, closets, cupboards and so on. In this company, the key customers come from the EU market, so ensuring all products are high quality, required quantity and on-time delivery is very virtual. In 2019, it was reported that the cupboard was the item produced the most with 32.88%. Furthermore, it was also the source with the highest sales accounting for approximately 80% in annual revenue. However, other collected data shows that the tardiness of closet production was approximated 10% in total – a great warning number. Therefore, it is indicated that the cupboard item should be considered and taken action for improvement. In other words, this paper paid attention on scheduling the cupboard production part via combining priority rules with the aim of reducing mean flow time, mean tardiness time and the proportion of tardy jobs.

2. Literature review

The job shop scheduling problem (JSSP) is a well-known optimization problem in literature. The problem can be briefly summarized as follows. There are several jobs that must be completed on a number of machines. The jobs visit each machine in a predefined sequence. The goal is to schedule jobs on the machines while minimizing one or more performance measures, and keeping in mind that each machine can only process one job at a time and that preemption of jobs is not permitted. The classic job-shop problem has been shown to be an NP-hard combinatorial problem in Sotskov (1991) [7], the goal of which may be to minimize the Makespan or minimizing the tardiness penalty [8].

Many precise and heuristic solution procedures have been developed over the years due to their practical importance. These procedures can find optimal or near-optimal solutions, but the computational cost increases dramatically as the problem size grows. To overcome these computational costs, priority rules (in the static case) or dispatching rules (in the dynamic case) have frequently been used in practice. These rules inspect the waiting jobs and select the job with the highest priority to be processed next. Although these rules cannot outperform the previously mentioned exact and heuristic solution procedures, they are frequently used due to their ease of implementation and low time complexity [9].

Priority rules, in fact, are often used as sub-methods in more advanced (meta-) heuristic solution approaches [10]. Furthermore, simple and easy-to-understand priority rules are often a matter of degree in real scheduling environments due to practical reasons (size of the problem, complexity of the scheduling environment, lack of scheduling software) [11]. Finally, because of the dynamic nature of the jobs that arrive at the company, simple priority rules that act as dispatching rules can easily determine which jobs get priority during the manufacturing process.

Simple priority rules like "shortest processing time" (SPT), "earliest due date" (EDD), and "First come first served" (FCFS) do not perform best across all performance measures since priorities are determined using a single job attribute [4]. It has been shown that combined versions of priority rules from the literature perform better on all objective functions than single priority rules separately [12]. This choice was inspired by the findings of Barman (1997) [13], and Holthaus (2010) [14], who observed that no single priority rule has been found to perform well on all flow time- and tardiness-related objectives and that the combination of priority rules can overcome this limitation.

3. Problem statement

3.1. Job shop scheduling problem

A basic JSSP can be formally specified as follows in a manner similar to Blazewicz (2000) [15] with subtle differences in notation: A set of jobs $J = \{J_1, \dots J_j, \dots, J_N\}$ on a set of machines $M = \{M_1, \dots M_i, \dots M_M\}$. Each job is an ordered subset of a set of operations $O_i = \{O_1, \dots O_q, \dots, O_Q\}$ for which precedence constraints are defined. Technological precedence constraints directly emerge from the ordered sets of O_i, meaning that for each pair of operation $(q, q+1)$, operation $q+1$ cannot start before operation q has been completed. Operations O_{ij} of a job have to be performed in the predefined order by specified machines $M(O_{ij}) = M_i$ within p_{ij} time units, allowing no more than one operation to be processed on a machine at a time. In this study, $P_{q+1,j}$ denotes the total processing time of all jobs in the queue of the next operation $(q\ +\ 1)$ of job j and C_{qj} is the completion time of the qth operation of job j.

3.2. Longest Processing Time

The longest processing time rule arranges the jobs in the order of decreasing processing times. When a machine becomes available, the largest job available at the time begins processing. This algorithm is a heuristic used for determining the shortest makespan of a schedule. It prioritizes the longest jobs first so that no single large job "sticks out" at the end of the schedule and significantly delays the completion time of the last job.

2PT + WINQ + NPT rule

Let τ be the current time at which the dispatching decision is to be made. Suppose job j is loaded on machine i for its operation q, and $p_{q,j}$ denotes the processing time of the q th operation of job j, which corresponds to a certain p_{ij} - value according to the machine i on which operation q is to be processed. Work in next queue (WINQ) selects the job going next to the queue containing the least total work [16]. Let $WINQ_{q+1}$ denote the sum of imminent process times of all jobs waiting at the queue of the next operation of job j. If job j is to be loaded after all jobs waiting in the queue of the next operation, then the completion time of job j is given by $(\tau + p_{ij} + WINQ_{q+1} + p_{j,q+1})$.

It is evident that in order to minimize the total flowtime of jobs, we need to load the job with the minimum sum of expected completion times for the present and the next operations.

Using these principles, we formulate the priority index of job j as follows:

$$Z_j = 2 \times p_{q,j} + P_{q+1,j} + p_{q+1,j} \text{.........(1)}$$

The job with the least Z_j is chosen for loading.

3.3. Performance measurements

There are 3 objective functions used in this study to evaluate and compare with current state's priority rule. They include both time-based performance measure and tardiness-based performance measures and are summarized as following. These measurements were demonstrated to be more robust than the makespan and maximum tardiness objectives in Sels. (2011) [12].

The first criterion pertains to time based measures, the others are due date related. Mean flow time is important for minimizing work in process and lead time without impacting production capacity.

3.3.1. Flow-time based performance measures:

Mean flow time: $\bar{F} = \frac{1}{n}\sum_{j=1}^{n} F_j$, with $F_j = C_j - r_j$............(2)

3.3.2. Tardiness-based performance measures:

Proportion of tardy jobs: $\%T = \frac{\sum_{j=1}^{n}\delta(T_j)}{n}$, with $\delta(T_j) = 1$ if $C_j > d_j$, 0 ....(3) other-wise

Mean tardiness: $\bar{T} = \frac{1}{n}\sum_{j=1}^{n} T_j$, with $T_j = \max(0, C_j - d_j)$,.................(4)

3.4. Experimental Setup

This study was conducted at Furniture Manufacturing Company FS, a job shop and make-to-order factory. A cupboard was previously identified as the research subject (**Error! Reference source not found.**). This product has six main components that represent six jobs: side frame, back, shelf, on top, bottom, and door. Each job has a number of operations (Figure).

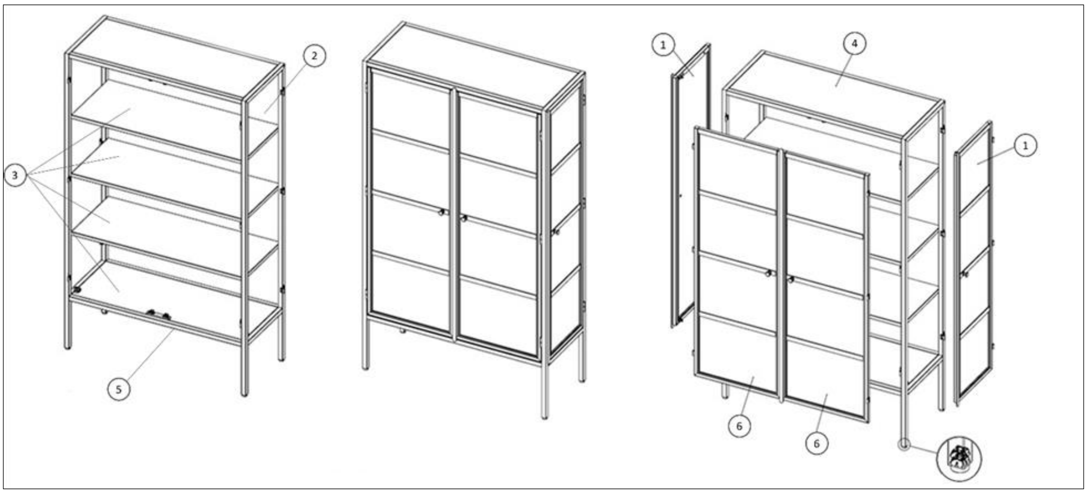

Figure 1 Cupboard furniture product

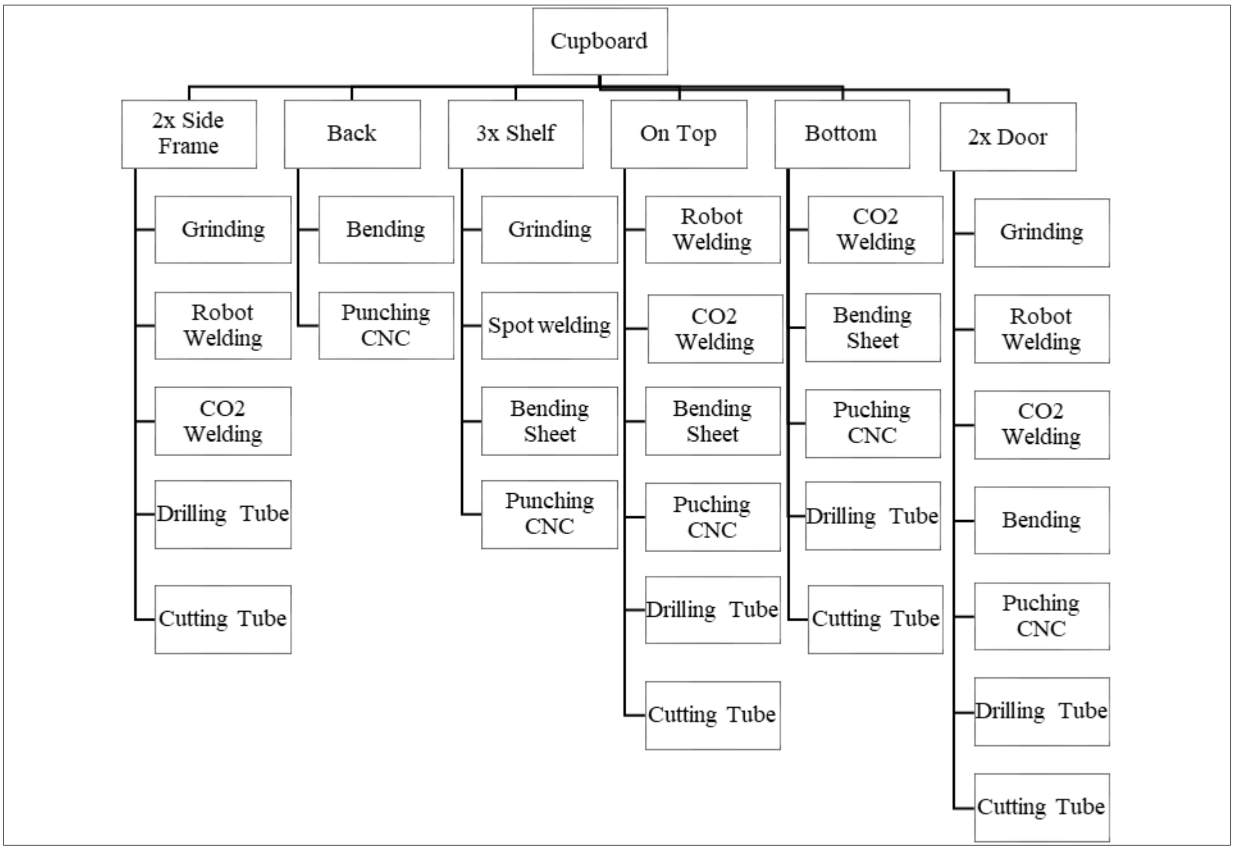

Figure 2 Cupboard manufacturing design

The cupboard is made with the help of 8 different machines. The manufacturing process was then examined and broken down into operations. The processing time of each operation was measured using a stopwatch and a sample size of 10. Process and scatter the data to determine the new sample size. If necessary, an additional sample collection was carried out. Table 1 shows the processing time of each operation on related machine.

The factory is currently scheduling jobs using the LPT priority rule, but the delivery time has not yet been met. This study employs an advanced priority rule proposed by Holthaus (2010) [14] to reduce mean flowtime, the proportion of tardy jobs, and mean tardiness.

Table 1 Operation processing time (in minute)

Job (j)		Precedence	Machine (i)							
			1	2	3	4	5	6	7	8
Side frame	1	1,2,6,7,8	10	5				20	30	10
Back	2	3,4			10	10				
Shelf	3	3,4,5,8			20	30	30			40
On top	4	1,2,3,4,6,7	20	10	10	20		30	20	
Bottom	5	1,2,3,4,6	20	20	20	20		20		
Door	6	1,2,3,4,6,7,8	20	10	10	20		30	20	20

Note: Machine (1): Cutting tube; Machine (2): Drilling tube; Machine (3): Punching CNC; Machine (4): Bending sheet; Machine (5): Spot welding; Machine (6): CO2 welding; Machine (7): Robot welding; Machine (8): Robot welding.

4. Experimental Result

4.1. Implementing priority rule in JSSP

Currently, the company in this case study applies LPT priority rule to solve the job shop scheduling problem. The objective index will be calculated: $Z_j = p_{qj}$ The job has the biggest objective Z_j (P_{ij}) will be scheduled. Using the job precedence given in Table 1, we conducted a disjunctive graph in **Error! Reference source not found.**3.

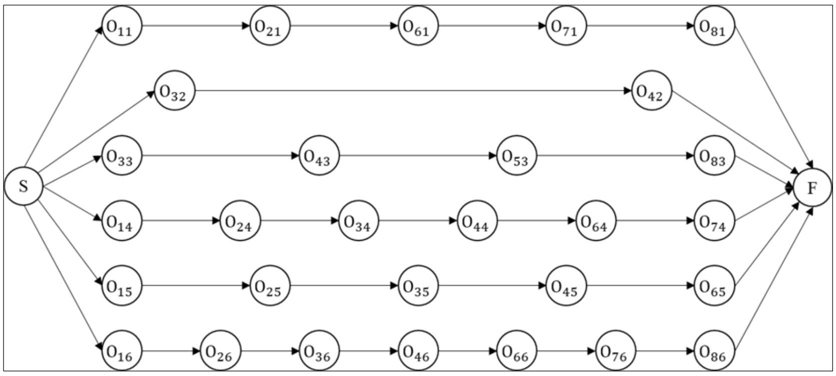

Figure 3 Disjunctive graph representation for the case study

The following are the calculation steps of the LPT rule for each τ. The priority of scheduling jobs at τ = 0 will be show in Table 2. The green cell represents for the jobs are ready for schedule on machine, the blue cell represents for the job is in process and the orange cell represents for the job that has been completed.

Table 2 The priority of scheduling jobs at τ = 0

No	Job (j)	Machine (i)	1	2	3	4	5	6	7	8
1	Side frame	1,2,6,7,8	10	5				20	30	10
2	Back	3,4			10	10				
3	Shelf	3,4,5,8			20	30	30			40
4	On top	1,2,3,4,6,7	20	10	10	20		30	20	
5	Bottom	1,2,3,4,6	20	20	20	20		20		
6	Door	1,2,3,4,6,7,8	20	10	10	20		30	20	20

At τ = 0, based on the sequence of each job, only the machine 1 and machine 3 are ready for schedule. Follow the LPT rule, O_{33} and O_{14} are chosen to be scheduled. The figure below shows the schedule status at τ = 0 (Figure 4).

At τ = 20, O_{33} and O_{14} has been completed, machine 1, 2, 3 and 4 are ready for scheduling. Follow the LPT rule, O_{15}, O_{24} , O_{32} and O_{43} are chosen. The figure below shows the schedule status at τ = 20 (

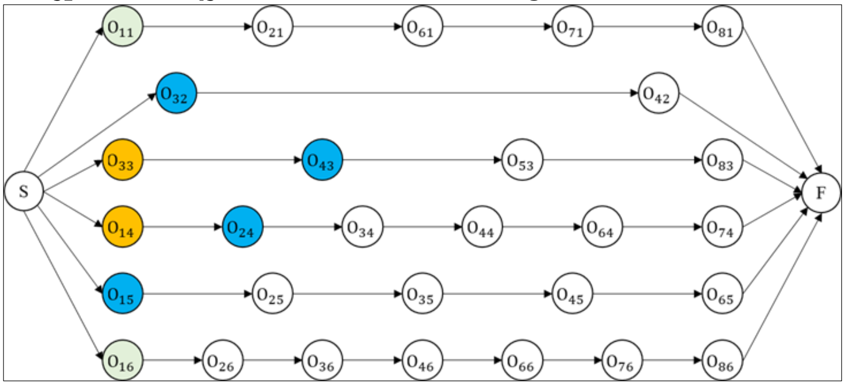

Figure 5 Scheduled job at τ = 20

5).

Continue calculating and scheduling for all remaining jobs with the same logic until there's no job left in the system. Table3 summarized the priority of the scheduling jobs for each machine using LPT and was put in **Error! Reference source not found.**6 for visualization.

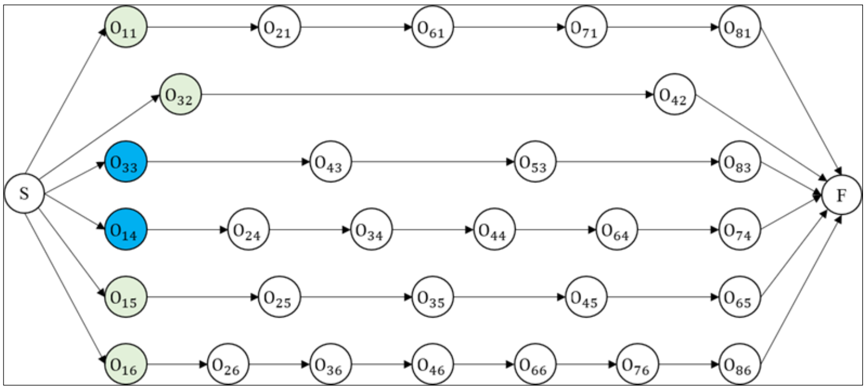

Figure 4 Scheduled job at τ = 0

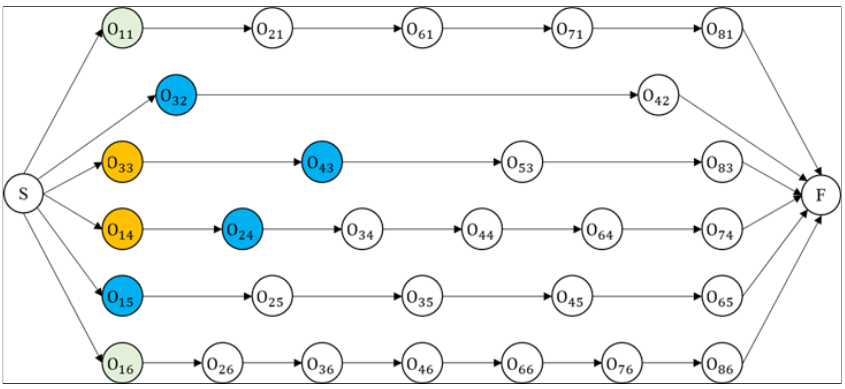

Figure 5 Scheduled job at τ = 20

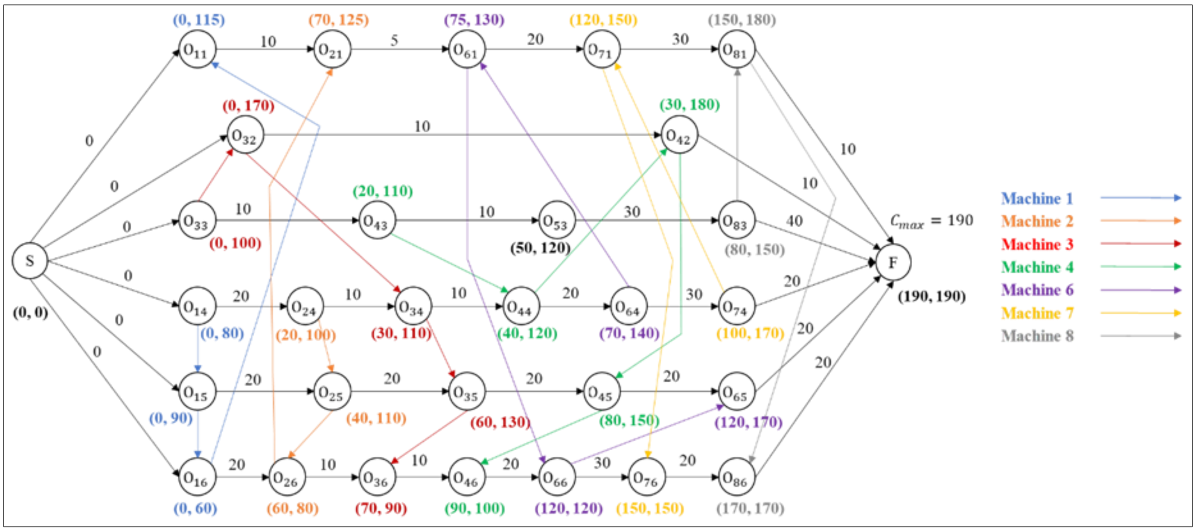

Figure 6 Scheduled job for all machines

Table 3 The priority of scheduling jobs for each machine using LPT

	Machine (i)							
Time (τ)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0	J4		J3					
20	J5	J4	J2	J3				
30			J4					
40	J6	J5						
50				J4	J3			
60	J1	J6	J5					
70		J1		J2		J4		
75								
80			J6	J5				J3
90								
100				J6		J1	J4	
120						J6	J1	
150						J5	J6	J1
160								
170								J6
	J4, J5, J6, J1	J4, J5, J6, J1	J3, J2, J4, J5, J6	J3, J4, J2, J5, J6	J3	J4, J1, J6, J5	J4, J1, J6	J3, J1, J6

4.2. Implementing 2PT + WINQ + NPT rule in JSSP

In order to explain the abbreviations used in previous sections, a disjunctive graph of the study's problem with 8 machines and 6 jobs given in **Error! Reference source not found.**3. In this problem, each job j ($j = \{1, 2, 3, 4, 5, 6\}$) has a number of difference operations to be performed on one of the machines i ($i = \{1, 2, 3, 4, 5, 6, 7, 8\}$), which is denoted as O_{ij}. The index q is used to refer to the q th operation of a job. For example, operation O_{22} is the first operation of job 2 on machine 2, indicated by $j = 2, i = 2$ and $q = 1$.

The priority index (Z_j) was calculated for each operation O_{ij} at time τ. Assume this corresponds to the current operation q that will be performed on machine i.

At τ = 0, the jobs are ready to proceed at machine 1 and machine 3. Next, Z_j is calculated for machine 1 and the priority was arranged as 1, 5, 4, 6 showed in Table 4.

Table 4 The priority at cutting tube machine

Job	**1**	**4**	**5**	**6**
Zj	85	130	120	150
Priority	1	3	2	4

The jobs were ordered first, so the next time a decision is made is based on the most recent completion time at each previous machine. When τ = 20, machine 2 and 4 becomes available for the next review. Z_j was calculated again to determine the machining order. Applying the same logic to the next machines yields the following dispatching order showed in Table 5.

Table 5 Dispatching order using 2PT + WINQ + NPT rule

	Machine (i)							
Time (τ)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0	J1		J2					
10	J5	J1	J3	J2				
15						J1		
20								
30	J4	J5		J3				
35							J1	
50	J6	J4	J5					
60					J3			
65								J1
70		J6	J4	J5				
75								
80			J6					
90				J4		J5		J3
110				J6		J4		
130								
140						J6	J4	
160								
170							J6	
190								J6
210								

	J1, J5, J4, J6	J1, J5, J4, J6	J2, J3, J5, J4, J6	J2, J3, J5, J4, J6	J3	J1, J5, J4, J6	J1, J4, J6	J1, J3, J6

5. Results

The result for this case study shows that proposed combined 3 single priority rules rule has smaller mean flow time, proportion of tardy jobs and mean tardiness than LPT rule with given parameter (Table6).

All 3 objectives are reduced: mean flow time, proportion of tardy jobs and mean tardiness.

The mean flow time in a job shop scheduling problem provides a measure of the average time that a job spends within a machine. It is indicative of the increasingly important manufacturing lead time. It has been reduced from 28.28 min to 23.62 min. Meaning that the total time reduces within the shop is approximately 5 min.

The proportion of tardy jobs provides a measure of the percent those jobs that are completed late. Thus, minimizing number of tardy jobs criterion is equivalent to maximizing number of early jobs criterion. This performance measure reduce significantly from 13.79% to 3.45% (with 75% improvement).

Mean tardiness, occasionally known as conditional mean tardiness, is computed from only those jobs that are completed late, and it represents their mean lateness. The reduction is considerably high with over 77% decrease. This measure represents an average level of customer satisfaction in terms of delivery performance (1), which directly emerges to our case study's objective.

Table 6 Compare the results of combined priority rule and LPT rule

Objective	LPT	2PT + WINQ + NPT	% improvement
Mean flow time	28.28	23.62	16.46%
Proportion of tardy jobs	13.79%	3.45%	75.00%
Mean tardiness	3.10	0.69	77.78%

6. Discussion

According to the final result of the combined priority rule, it can be seen that the combine of single priority rules creates a new rule that solve the shop job scheduling problem in the better way measured by objectives such as: mean flow time is 23.62 improves 16.46%, proportion of tardy jobs is 3.45% improves 75% and mean tardiness is 0.69 improves 77.78% comparing to LPT rule application in current state.

After calculating the objectives index, beside the improvement the performance measures, the makespan increase 10% (from 190 mins when apply LPT rule to 210 mins when apply 2PT + WINQ + NPT rule). That's mean the proposed method can improve the lead time but machine utilization has not been optimized. It is recommended to try other combined priority rule which can support to minimize makespan as well as other performance measures.

For the further development, this rule should as well be applied for scheduling other products at the company. Based on the single priority rules, combine these rules randomly and compare with the rule that combined in the previous so that can continuous improvement the better rule use for the job shop scheduling problem. The implementing in programming for dynamic model in the flexible job shop scheduling problem should be considered.

In addition, the practical setup time for each station will increase the computational dimension. As a result, development of heuristics and metaheuristics become more essential.

7. Conclusion

This research has discussed an extensive comparison of different priority rules to solve the job shop scheduling problem under five objective functions that can be classified into two main categories. One flow time-related objectives the mean flow time, and two tardiness-related objectives, the proportion of tardy jobs and the mean tardiness, have been used to measure the performance of the proposed method compare to the exists.

The 2PT + WINQ + NPT rule produces a job sequence for each machine is better than LPT rule measured by 3 objectives: The mean flow time, the proportion of tardy jobs and the mean tardiness. The combined rule improves the mean flow time 16.46%, the proportion of tardy jobs 75% And the mean tardiness 77.78% than the existing (LPT). There are still so many chances to apply a new combine single priority rules to get more better result when the parameter is changed.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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