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Designing a Model for Bi-criteria Objective Scheduling at Flexible Flow shop Production in Finishing Furniture Industries

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Abstract

The bi-criteria objective scheduling is essential in the Jepara furniture industry due to its competitiveness. Scheduling that not only considers the company's profits but also takes into account the customer's perspective can add significant value to the company. Based on that, this paper proposed a mathematical model for the furniture finishing industry. Then it transformed into a Microsoft Excel Solver model. Cost calculation is also considered to choose the best model. The system's characteristic is flexible flow shop production, not identical at the last stage, and sequence-dependent set up time. The objective of scheduling is to minimize total maximum completion time and total weighted tardiness. There are 3 scenarios in this paper, company focused, customer, and bi-criteria objective. After running the model, scenario 3 is the best choice for completing priority orders on time, while scenario 1 is ideal when seeking efficiency in production with delays being less of a concern.

***Keywords**:* Bi-criteria scheduling; Flexible flow shop; Furniture finishing industry; Microsoft Excel Solver; Total weighted tardiness; Sequence-dependent setup time.

1. Introduction

The furniture industry in Jepara Regency, Central Java, has thrived. Jepara, also known as The World Carving Center, is home to numerous furniture companies with international clientele. In 2018, the export value of Jepara's furniture and carving crafts exceeded US$190 million, contributing 34.87 percent to the Gross Regional Domestic Product (GRDP) of Jepara Regency (Erje, 2019). As a major industry, the competition in the furniture sector in Jepara is highly intense.

Several furniture industries in Jepara, both large and medium-sized, receive their semi-finished products from small and medium enterprises (SMEs) known as *pengrajin* or artisans (Melati et al., 2013). These artisans are essential for supplying custom-ordered products that companies are unable to produce in-house. The semi-finished products typically refer to furniture items that have not yet undergone the finishing process. Companies operating with such a system are required to continuously update their production scheduling to adapt to changing order demands and supply conditions.

One important area of focus is ensuring timely completion of orders, which is a significant concern for furniture companies in Jepara that specialize in finishing furniture. These companies regularly fulfill various orders each month, including priority orders that must be delivered on time. However, they encounter challenges in scheduling, resulting in delays in delivering these priority products. It is crucial to develop a scheduling system aimed at minimizing the delay of priority products (minimization of weighted tardiness). Additionally, the company needs to consider production costs. Focusing too much on minimizing tardiness can result in schedules that are not the most efficient in terms of total completion time (Pinedo, 2016). It will be a backlash to them as the competition is very competitive, price also can be a key factor to winning competition in Jepara's Furniture Market. While minimizing delays is important, it's also essential to avoid creating schedules that excessively delay non-priority products, leading to high labor and storage costs. Therefore, they need to schedule in a way that minimizes total weighted tardiness and also minimizes the maximum completion time.

2. Literature Review

Scheduling is an activity that involves the process of allocating available resources or machines to execute a set of tasks within a specified time frame (Baker and Trietsch, 2019). In recent years, there has been increasing research on multi-objective optimization (Yenisey and Yagmahan, 2014). Scheduling with two objectives, also known as bi-

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criteria objective, entails optimizing a linear combination of total weighted completion time and weighted tardiness (Shahvari and Logendran, 2016). Total weighted completion time aims to minimize production costs in terms of time, energy, and labor. On the other hand, total weighted tardiness focuses on minimizing delays to increase customer satisfaction.

In line with this, studies on flexible flow shop scheduling with bi-criteria objectives have gained attention, with 16 relevant articles published between 2016 and 2022. Research on multi-criteria scheduling has grown from the need to balance operational efficiency and customer-oriented performance (Pargar et al., 2018). From the company's perspective, objectives such as minimizing makespan or total completion time are commonly applied (Wang et al., 2018; Aqil & Allali, 2018; Khalfallah & Nabli, 2018; Golneshini & Fazlollahtabar, 2019; Yang & Liu, 2018). Conversely, customer satisfaction is often addressed by focusing on delay-related objectives such as maximum lateness (Golneshini and Fazlollahtabar, 2019), total tardiness (Khalfallah and Nabli, 2018), mean tardiness (Xue and Wang, 2023), and weighted tardiness (Shahvari and Logendran, 2018; Bozorgirad and Logendran, 2016). Some studies also incorporate other customer-centered metrics such as the Agreement Index (Yang and Liu, 2018) and customer priority levels (González-Neira et al., 2016).

The concept of multi-criteria objective in scheduling problems signifies that there is more than one objective involved. Consequently, the model for this type of problem encompasses not just one, but two objectives. Pargar (2018) discusses the minimization of both maximum completion time and tardiness and defines the objective function as min α Cmax + β∑Tj, where α and β are weight coefficients with α > 0 and α + β = 1. On the other hand, Shahvari and Logendran (2016), with the goal of minimizing weighted completion time and weighted tardiness, define the objective function as:

$$min\ Z = \propto . \sum_{i=1}^{g} \sum_{s=1}^{n_i} \sum_{j=1}^{n_i} w_{ij} X_{isj}^{st_{ij(mij)}} + \beta \sum_{i=1}^{g} \sum_{j=1}^{n_i} w_{ij} TD_{ij} \quad (1)$$

In this formulation, i = 1, 2, ..., g, j = 1, 2, ..., ni, and s = 1, 2, ..., gi are indicators of groups, jobs, and batches respectively. Here, Xisj represents the completion time of job j in batch s of group i. Meanwhile, Tij denotes the tardiness of job j in group i and is defined as max(0, Xisj – dij), where dij stands for the due date of job j in group i.

In the model also included a setup time indicator which depends on the job previously performed and is commonly referred to as Sequence Dependent Setup Time (SDST). In recent years, SDST has become the dominant type of setup time considered in scheduling models (Neufeld et al., 2016). Several studies addressing bi-criteria objectives that incorporate SDST have been conducted by Bozorfirad & Logendran (2016), Vaisi et al. (2016), Aqil & Allali (2018), and Yu et al. (2020).

The model by Shahvari and Logendran (2016) used for batching scheduling where job assignments are more complex compared to the group scheduling model in this study. Therefore, adjustments to the model are necessary. Variables and indices used for batch scheduling that are not required should be eliminated. In addition, the model does not include constraints for non-identical parallel machines. However, in the case study being examined, there is a stage that involves machines/operators that are non-identical parallel.

The finishing process at the company starts with sanding, followed by a "sanding coat," the first Topcoat, a second round of sanding, and finally, the second Topcoat. This process is set up as a flexible flow shop. Tyagi et al. (2017) stated that a flexible flow shop is a generalization of the classic and simple flow shop, characterized by a processing environment that includes parallel machines at one or more stages. It means that each step involves multiple operators, and products can be handled by any operator in the following step. The company handles various types of finishing, requiring setup each time a different finishing type is processed. Therefore, scheduling considers the order of tasks and the time needed for setup.

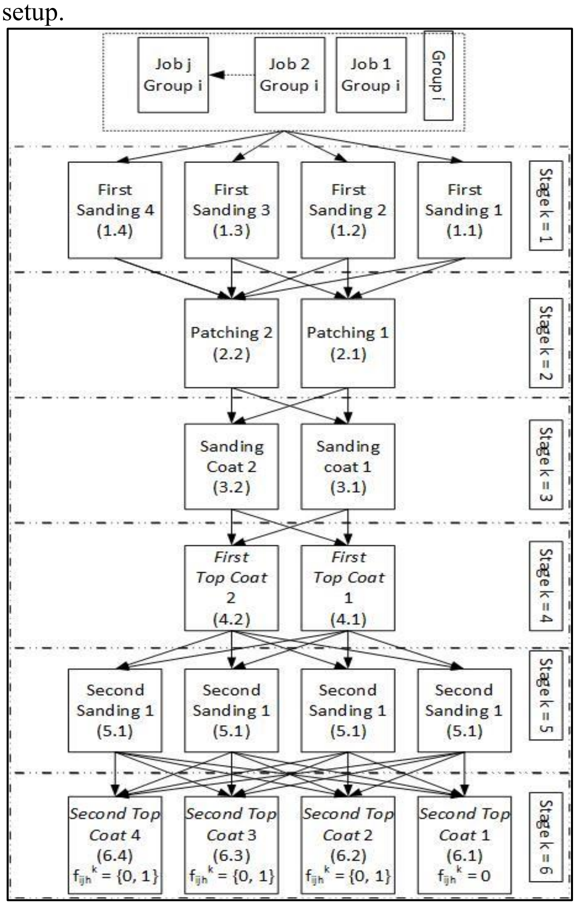

Figure 1. Company's Production System.

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In the finishing process, all operators can work on natural finishing, but certain color finishes are limited to specific operators. Taking these conditions into account, scheduling must consider the sequence-dependent setup time, the flexible flow shop layout, with not identical parallel machine and a dual objective. The model used is a production scheduling model for flexible flow shop scheduling, aimed at minimizing the total processing time while also incorporating the weighted tardiness objective criterion.

3. Research Method

The research started in August 2023 at UD Harapan Kita, a medium-sized company located in Kecapi Village, Tahunan District, Jepara Regency, Central Java, Indonesia. The company specializes in furniture finishing and serves both international and local customers. The orders received by the company are usually ongoing, with each buyer's order spanning multiple shipments in one performance order throughout the year.

3.1 Production System

The production process begins with quality inspection of the furniture products delivered by the craftsmen. Once the products pass quality control, they are left to dry for a week to ensure complete dryness. After drying, the furniture is moved to the production floor. The production system of the company can be seen in Figure 1.

The dried and quality-checked furniture then undergoes the sanding process to smooth the surfaces. Next, defects or holes in the wood are patched during filling, followed by sanding filler to close the pores and prevent liquid absorption. The first topcoat is then applied, followed by another sanding before the second topcoat. The final color, typically Natural, is applied during the second topcoat, though Honey, Dark Brown, and Black are also available. While all operators can apply Natural, other colors are handled by second topcoat 1.

3.2. Weighted Scores

The priority of furniture shipping is determined by the customer. There are three types of priorities: Customer Order, Need Stock Order, and Regular Order, with different weight scores assigned to each. The weight scores are Customer Order (Scores: 1), Need Stock Order (Scores: 0.5), and Regular Order (Scores 0.1).

3.3. Processing Time

The finishing processes are based on company data and are displayed in Table 1. The setup times mentioned are specifically for the second Topcoat process and vary depending on the product color. For other processes, setting up times are consistent and are completed before starting the work. Setup time is 30 minutes before changing the finishing color types for the second topcoat process.

4. Result

In the context of a bi-criteria objective function, the objective is to minimize both makespan and tardiness. These criteria are impacted by a variety of factors, including the attributes of the company and the customer. Makespan is calculated as the difference between the maximum completion time and the release time, while total weighted tardiness is determined by the job's completion time in relation to the due date, multiplied by the job's weight coefficient. The completion time is influenced by several elements, such as run time, availability time, setup time, assigned job, and the type of finishing applied. Run time signifies the processing duration of each job, while availability time is contingent on the completion time of the previous job. Additionally, setup time is determined by the machine, jobs, and the type of finishing involved.

4.1. Mathematic Model

$$min\, Z = \propto . C_{max} + \beta \sum_{i=1}^{g} \sum_{j=1}^{n_i} w_{ij} . TD_{ij} \tag{2}$$

$$TD_{ij} = max(0, C_i^k - d_{ij}) \tag{3}$$

$$C_{max} = max. C_i^k - r_{ij} \tag{4}$$

Subject to:

$$C_i^k \geq C_p^k + S_{pih}^k + t_{ijh}^k + M. f_{pih}^k \,; M : Big\ Number \tag{5}$$

$$p \in I^k (p = i - 1); j \in J_p^k \,; h \in v_{ij}^k; k = 1, 2, \dots, m$$

$$C_i^k \geq \sum_{h \in v_{ij}^k} \left(a_k^h + s_{p\,ih}^k + t_{ijh}^k + M. f_{pih}^k\right) Z_{ish}^k; \tag{6}$$

$$C_i^k - C_i^{k-1} \geq \sum_{h \in v_{ij}^k} \left(a_k^h + s_{pih}^k + t_{ijh}^k + M. f_{pih}^k\right) Z_{ish}^k \tag{7}$$

$$\sum_{h \in v_{ij}^k} Z_{ih}^k \leq 1 \tag{8}$$

$$\sum_{i=1}^{g_i^k} \sum_{h \in v_{ij}^k} Z_{ih}^k = g_i^k \tag{9}$$

$$C_i^k, TD_{ij}, C_i^k \geq 0 \tag{10}$$

$$Z_{ih}^k \in \{0,1\}; i, p \in I^k \,; h \in v_{ij}^k \tag{11}$$

$$f_{pih}^k \in \{0,1\}; i, p \in I^k \,; h \in v_{ij}^k \tag{12}$$

Table 1. Finishing Processing Time.

Code	Processing Time (minutes)					
	k=1	k=2	k=3	k=4	k=5	k=6
K-1	45	23	22	25	40	46
K-2	33	16	16	18	29	34
K-3	47	28	23	26	42	48
K-4	18	16	10	11	17	24
B-1	124	42	66	77	86	112
B-2	48	13	27	30	32	42
B-3	161	54	82	96	108	140
B-4	68	29	33	42	47	66
B-11	33	8	19	21	23	28
M-1	42	20	22	38	28	56
M-2	67	32	34	60	45	88
M-3	47	23	24	42	32	62

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Code	Processing Time (minutes)					
	k=1	k=2	k=3	k=4	k=5	k=6
M-4	98	47	46	85	64	64

The objective function of this scheduling model is represented by Formula 2, with the objective of minimizing the sum of completion time and weighted tardiness. The coefficients α and β are used in the calculation, with the requirement that α + β = 1. Formula 3 and 4 are utilized to calculate tardiness and maximum completion time. Tardiness is determined by taking the greater value between 0 and the job's completion time minus its due date. The maximum completion time is calculated as the job's completion time minus the release time.

Formulas 5 to 11 define the constraints of the scheduling mathematical model. Formula 5 determines the sequence of each job and incorporates the research gap. In this formula, f_{pih}^{k} represents a constraint for the type of finishing that an operator can perform, with a value of 0 indicating the operator has the capability to perform the finishing, and a value of 1 indicating that it is not their specialization. Meanwhile, M is a large number used to ensure that a job is not assigned to the wrong operator.

Formula 6 ensures that a job cannot be processed if the machine is not available. Formula 7 ensures that the processing of each job cannot start if the job has not been released. Formula 8 aims to ensure that all jobs are processed. Formula 9 ensures that the values of completion time and tardiness are non-negative. Formula 10 to ensure all jobs will be assigned. Finally, Formulas 11 and 12 ensure that Z_{ih}^{k} and $f_{pih}^{k}$are binary variables.

4.2. Solver Model

In the calculations of the designed mathematical model, the Solver tool from Microsoft Office Excel 2013 was used. This tool was chosen due to its ease of use, especially for companies accustomed to using Microsoft Office Excel to complete their tasks. To design the model in this tool, the following components need to be developed are processing time sheet, job list sheet, grouped job list sheet, set up time sheet, scheduling sheet and solver configuration.

In processing time sheet contains a database of the processing times required for each process. Table 1 showing furniture code and processing times for each stage, starting from the first sanding, filling, sanding coat, the first topcoat, the second sanding, and the second topcoat. In the processing time sheet, the user can input the times for the first sanding, filling, sanding, the first topcoat, the second sanding, and the second topcoat. The user can also input the codes, which can be referenced when filling in the job list.

The job list sheet contains a list of jobs that need to be scheduled. The jobs are sorted and grouped shown in Table 3 that includes job code, group, due date, job weight, processing time at each stage, completion time, tardiness, weighted tardiness, and type of finishing. On this sheet, the user needs to input the job code, furniture code, due date for each job, the weight of each job (ranging from 0.1 to 1), and the type of finishing used.

The grouped job list sheet includes the working times for jobs after they have been grouped. It contains details such as group, due date, processing time, completion time, tardiness, weighted tardiness, and type of finishing. The group list in this sheet is almost the same as the job list. In these sheets jobs are automatically combined into one group. This group list is what will be scheduled.

Meanwhile in the setup time sheet, the following information outlines the setup time values for each job when the preceding process was job k-1. It comprises a matrix depicting the transition from jobs in group i to the jobs in the preceding group i on the same machine. If the finishing type differs between the group and the previously completed group, the value is 30; if it is same, the value is 0.

The scheduled sheet contains the job assignments for the scheduling, which will impact the calculation of the objective function. The sheet includes machine availability, processing time, completion time per group, due date, group list, and machine list for each stage. Calculations using the Solver are performed on this sheet. The values from the job assignment matrix are input by Excel Solver to find the minimum value of Function Z. The job order remains the same from stage 1 to stage 6. Stages 1 through 5 have a similar layout, while stage 6, the second topcoat process, has a slightly different layout.

It's important to set up the Solver in Microsoft Excel to carry out optimization calculations. The parameters should be entered based on the defined mathematical model. The Solver calculation takes place on stage 1 sheet. The objective is specified as cell $D$6, which contains the objective function for the scheduling task. The "To:" checkbox is set to "Min" to minimize the value of the objective function. The job assignment matrix is then input under "By Changing Variable Cells" for adjustment.

4.3. Model Verification

Verification of the model involves validating whether the Microsoft Excel Solver aligns with the designed mathematical model. The initial step in the verification process is to ensure the correct functioning of the model. Upon running the model with dummy data, it was established that the model operates as intended, yielding the desired values for the objective function. Subsequently, the next step entails comparing the designed mathematical model with its implementation in Microsoft Excel Solver. This comparison is presented in Table 2, detailing the variances between the mathematical model and its implementation in Solver.

Table 2 demonstrates that all mathematical models have been incorporated into the designed Microsoft excel solver. From the two verifications conducted, it can be concluded that the model has been verified.

Table 2 Solver model verification.

Formula	Solver Implementation	Location	Verification
(1)	=B1*F1+B2*F2 =SUM(P9:P51)	Sheets (Daftar Job).Cells (F3) Sheets (Daftar Job).Cells (F2)	✓
(2)	=MAX(N9-E9;0)	Sheets (Daftar Job).Cells (O9)	✓
(3)	=MAX('t6'!$D$14:$D$27)-B3	Sheets (Daftar Job).Cells (F1)	✓
(4)	=MAX('t6'!$D$14:$D$27)-'Daftar Job'!B3	Sheets(Daftar Job).Cells(F1)	✓
(5)	=MAX(F7;F8)+F11 +SUM(F9:F10) =SUMPRODUCT(F14:F27; 'Daftar Grup'!$J$2:$J$15)	Sheets (t6).Cells(F12) Sheets (t6).Cells(F11)	✓
(6)	$K$6>=$G$6	Solver	✓
(7)	$D$8:$D$17<=1	Solver	✓
(8)	$D$4:$D$6>=0	Solver	✓
(9)	$D$4:$D$6>=0	Solver	✓
(10)	$G$8:$P$17=binary	Solver	✓
(11)	=IFERROR(IF(G3="N";0;IF(G3=" ";0;100000000));0)	Sheets(t6).Cells (G10)	✓

5. Discussion

In this paper, scheduling was performed for finishing group 1 for the production of the first week of February 2024. Three scenarios were implemented to compare the outcomes of the scheduling process.

Jobs will be grouped according to the company's requirements. This grouping is based on jobs that cannot be separated to ensure uniformity of color and to avoid the risk of products being separated from their corresponding set. Table 3 displays the jobs that have been grouped.

The list of groups in Table 3 is then input into the Microsoft Excel Solver model. Job data needs to be detailed using the notation J_{11} to J_{92}. Additionally, the weight attribute (wij) must also be included. As per the company's priority levels, the weight attribute (wij) assigned to Customer Orders (CO) is 1, to Need Stock Orders is 0.5, and to Regular Orders is 0.1.

Table 3 Grouped work order 2-9 September 2023

Group	Code	Qty	Col.	Cust.	Priority	Due Date
1	K-1	6	N	P7	CO	5 Sept 23
1	M-2	1	N	P7	CO	5 Sept 23
2	K-1	8	N	P2	RO	6 Sept 23
2	M-3	1	N	P2	RO	6 Sept 23
3	K-1	8	N	P2	NSO	6 Sept 23
3	M-4	1	N	P2	NSO	6 Sept 23
4	B-3	3	DB	CL	RO	25 Sept 23
5	B-3	2	N	CL	RO	25 Sept 23
6	B-1	1	N	NC	RO	6 Sept 23
6	B-2	1	N	NC	RO	6 Sept 23
7	K-2	4	N	CL	RO	9 Sept 23
7	M-1	1	N	CL	RO	9 Sept 23
8	K-4	4	N	P2	NSO	6 Sept 23
9	B-2	2	N	P7	NSO	5 Sept 23
9	B-4	2	N	p7	NSO	5 Sept 23

The set for g_1 in Table 3 is $\{j_{11}, j_{12}, j_{13}, j_{14}, j_{15}, j_{16}, j_{17}\}$, g_2 is $\{j_{21}, j_{22}, j_{23}, j_{24}, j_{25}, j_{26}, j_{27}, j_{28}, j_{29}\}$, g_3 is $\{j_{31}, j_{32}, j_{33}, j_{34}, j_{35}, j_{36}, j_{37}, j_{38}, j_{39}\}$, g_4 is $\{j_{41}, j_{42}\}$, g_5 is $\{j_{51}, j_{52}, j_{53}\}$, g_6 is $\{j_{61}, j_{62}\}$, g_7 is $\{j_{71}, j_{72}, j_{73}, j_{74}, j_{75}\}$, g_8 is $\{j_{81}, j_{82}, j_{83}, j_{84}\}$ and g_9 consist of $\{j_{91}, j_{92}, j_{93}, j_{94}, j_{95}\}$. The number of stages (m) is 6. Release time (r_{ij}) is 0 and the availibility time assumed to be 0. The weight atribute $(\propto, \beta)$ are entered based on the specific scenario being executed.

5.1. Scenario one: Company Focused Objective

Objective: Minimizing the maximum completion time; focus: This scenario prioritizes the company's internal efficiency by ensuring that the maximum time taken to complete any job is minimized. This helps in optimizing resource usage and improving production turnaround time.

In this scenario, as shown in Figure 2, value of $\propto$ is 0,9 and β is 0,1. The results from running the Solver show that the maximum completion time obtained is 2354 minutes to complete all jobs. Meanwhile, the total weighted tardiness is 4230 minutes. The value of the Z function is 2541,6. The resulting job order is g_8, g_6, g_9, g_7, g_4, g_2, g_3, g_5 and g_1.

5.2. Scenario two: Customer Focused Objective

Objective: Minimizing the total weighted tardiness; focus: This scenario is designed to enhance customer satisfaction by minimizing delays in job completion relative to their due dates. It aims to ensure that the jobs are completed on time or ahead of schedule, thereby maintaining good customer relationships and reducing penalties for late deliveries.

In this second scenario, as shown in Figure 3, it's prioritized minimization of total weighted tardiness. The weight attribute used is $\propto = 0{,}1$ dan nilai $\beta = 0{,}9$. The results of this scenario show that the total weighted tardiness is 124 minutes, while the maximum completion time is 2670 minutes. Therefore, the value of the objective function Z is 378.6. The job assignment order obtained from Microsoft Excel Solver in scenario 2 is g_9, g_1, g_3, g_7, g_2, g_4, g_8, g_5 and g_6.

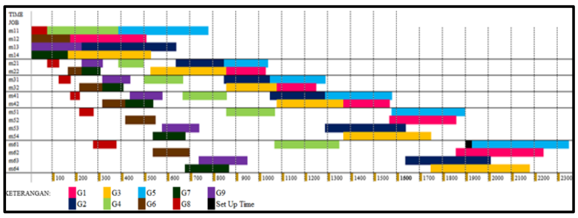

Figure 2. Scenario 1 Gantt Chart

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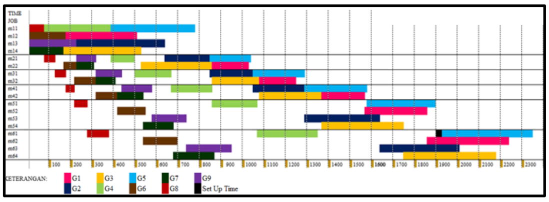

Figure 3. Scenario 2 Gantt Chart

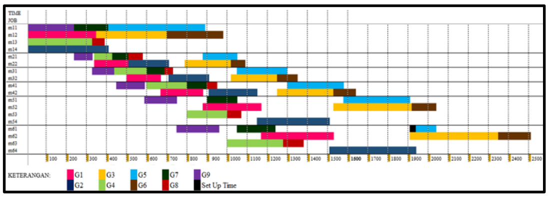

Figure 4. Scenario 3 Gantt Chart

5.3. Scenario three: Bi-Criteria Objective

Objective: Balance both company and customer needs with equal weight; focus: This scenario combines both the company and customer objectives by equally weighting the minimization of maximum completion time and total weighted tardiness. It aims to find a balanced approach that meets the company's efficiency needs while also ensuring customer deadlines are respected. In this scenario, the value of $\propto = 0{,}5$ and $\beta = 0{,}5$.

As shown in Figure 4, the results from running the Microsoft Excel Solver for scenario 3 show that the maximum completion time obtained is 2503 minutes, and the total weighted tardiness is 1201.1 minutes. Therefore, the value of the objective function obtained is 1852.05. The job assignment order obtained is g9, g1, g4, g2, g7, g3, g8, g5 and g6.

5.4. Cost Calculation

This cost calculation is determined by assessing the advantages in three scenarios from an economic perspective. It encompasses direct labor costs for task completion, expenses for storing undelivered products, and penalties incurred due to delays for Customer Order's priority.

The total number of workers in Finishing Group 1 consists of 8 sanding workers, 2 wood filling workers, 2 sanding filling workers, and 6 topcoat workers, bringing the total workforce to 18 people. Each worker is paid a daily labor rate of Rp 100,000, which results in a total direct labor cost of Rp 1,800,000 per day for the entire group. To convert this daily cost into a cost per minute, the total amount is divided by the total number of working minutes in a day, which is calculated as 7 working hours × 60 minutes, or 420 minutes. This gives a cost per minute of approximately Rp 4,285.714. This cost per minute is then used as a multiplier against the maximum order completion time to estimate the total labor cost per order.

Table 4 Total Cost Each Scenario

Scenario	Labour Cost	Holding Cost	Penalty Cost	Total Cost
1	10.088.571,43	7.269,60	510.000,	10.605.841,03
2	11.442.857,14	4.301,10	-	11.447.158,24
3	10.727.142,86	9.503,4	-	10.736.646,26

Table 5 Scheduling result

Scenario	Maximum Completion Time (minute)	Total Weighted Tardiness (minute)	Total Cost (Rp)
Scenario 1	2354	4230	10.605.841,03
Scenario 2	2670	124	11.447.158,24
Scenario 3	2503	1201,1	10.736.646,26

There are three types of priorities: Customer Order, Need to Stock Order, and Regular Order. In the case of the first priority, the company is fined according to the agreement with the customer when a delay occurs. The amount of the fine depends on the value of the delayed products. For customer NC and P2, there is a fine of 2.5% for each delayed item in the first week. If the items remain delayed in the next shipment, an additional fine of 10% is imposed. For customer P7, a 10% fine is imposed if the goods are late in the first shipment, with no additional fine for subsequent delayed shipments. Customer CL does not impose any late fines. Meanwhile, for the second and third priorities, the loss is calculated by the storage cost of the goods until the next shipment, plus the maintenance costs required. Meanwhile, the company's storage cost is Rp 52,083 per m3 per year or Rp 4,340 per m3 per month. Apart from storage costs, there are also maintenance expenses that must be covered before the goods are returned to the customer. The company has a policy that requires a reevaluation of the condition of goods if they are stored for more than 3 months. The company has estimated the cost of this inspection to be Rp 55,000. Based on that calculation, the total cost of each scenario is shown in Table 4.

5.5. Result Comparison

The best scenario is determined by comparing the results of scheduling from three scenarios. The result from three scenarios is shown in Table 5. The data in Table 5 shows that Scenario 1 has the shortest maximum completion time, taking 2354 minutes. Meanwhile, Scenario 2 has the lowest total weighted tardiness at 124 minutes. Additionally, Scenario 3 outperforms Scenario 2 in terms of maximum completion time and outperforms Scenario 1 in terms of total weighted tardiness. Meanwhile, in terms of expenses, scenario 2 has the highest costs, while scenario 1 has the lowest costs. Scenario 3 has slightly higher costs compared to scenario 1.

6. Conclusion

The results show that scenario 1 is the most efficient option. It has the minimum maximum completion time, and the lowest cost compared to

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scenarios 2 and 3. However, it also results in the highest total weighted tardiness and incurs penalties for delayed priority orders. Although the financial impact is not significant, continual delays could harm the company's reputation. On the other hand, scenario 3 has the second-lowest total cost, differing by Rp 130,805.23 from scenario 1, which is relatively small compared to potential reputation damage. Thus, scenario 3 is the best choice for completing priority orders on time, while scenario 1 is ideal when seeking efficiency in production with delay being less of a concern.

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