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Optimization of Flexible Job Shop Scheduling Using Heuristic Algorithms to Minimize Tardiness and Overtime Cost

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ABSTRACT
Metal manufacturing SMEs under Make-to-Order systems, such as CV. XYZ in Surabaya, often face a critical problem: excessive tardiness and overtime costs caused by an unstructured scheduling approach in a Flexible Job Shop environment. This study addresses this problem by developing and comparing two heuristic scheduling algorithms, the Active Schedule Algorithm with the Most Work Remaining (MWKR) rule and the Non-Delay Algorithm with the Shortest Processing Time (SPT) rule, aiming to minimize makespan, tardiness, and overtime cost. Historical order data from December 2025 to February 2026, covering 13 jobs across 7 workstations, were collected and validated through stopwatch time studies. Performance was evaluated using makespan, tardiness, and overtime cost, benchmarked against the company's existing scheduling condition. Active Schedule-MWKR achieved a makespan of 26,022 minutes, a 27.42% reduction from the 35,880-minute baseline, completely eliminating tardiness and overtime. Non-Delay-SPT yielded only marginal improvement (11.26%), retaining 6.80 days of tardiness and IDR 999,600 in overtime costs. Compared to actual company conditions, Active Schedule-MWKR delivered IDR 2,415,000 in cost savings with full overtime elimination. These findings establish Active Schedule-MWKR as the recommended scheduling policy for Flexible Job Shop environments with heterogeneous job types, offering a practical and replicable framework for Indonesian manufacturing SMEs.

INTRODUCTION

The metal manufacturing sector in Indonesia, particularly small and medium enterprises (SMEs), operates under intense competitive pressure that demands rapid and on-time delivery responses. In a Make-to-Order (MTO) production system, production activities begin only after customer orders are received, creating significant pressure on meeting predefined due dates [1]. CV. XYZ is an SME in Surabaya, producing Spur Gears and Housing Bearings through a Flexible Job Shop production flow, characterized by flexible routing on two identical lathe machines. A critical problem faced by the company is its heavy dependence on overtime work to meet customer due dates, driven by an unstructured scheduling approach.

Production scheduling is a critical decision-making process that determines the assignment of jobs to machines and sequence of operations over time [2]. In job shop environments, the scheduling problem becomes NP-hard, making exact methods computationally infeasible [3]. Heuristic algorithms provide practical and efficient alternatives. The Active Schedule Algorithm guarantees no machine is kept idle if work is available, ensuring optimal solutions are always members of the active schedule set [4]. The Non-Delay Algorithm eliminates idle time by immediately assigning available operations to free machines [5]. The Most Work Remaining (MWKR) rule prioritizes jobs with the largest remaining processing time to prevent bottleneck accumulation [6], while Shortest Processing Time (SPT) minimizes mean flow time [7]. Previous studies have demonstrated the effectiveness of these approaches. Harto et al. (2016) showed Non-Delay with SPT reduced makespan by 3 working days in a furniture job shop [8]. Kulsum et al. (2020) confirmed Active Schedule achieved a makespan reduction from 4,246 to 4,088 minutes against Existing Conditions in a MTO machining company [9]. Applied Non-Delay on multi-machine job shop at an SME, achieving 4.55% makespan efficiency [10]. Kaweegutbundit (2016) demonstrated Active Schedule effectively reduced work-in-process queues in stamping operations [11]. Proposed a Hybrid Active-Non Delay algorithm that significantly improved scheduling performance in a paint manufacturing company [12].

However, limited research has simultaneously addressed tardiness and overtime cost minimization in Flexible Job Shop environments within Indonesian SME contexts, particularly in metal component manufacturing. This study fills this gap by comparing Existing Conditions against Active Schedule-MWKR and Non-Delay-SPT, evaluating performance across three criteria: makespan, tardiness, and overtime cost savings. The research contributions of this study is threefold. First, it provides empirical validation of Active Schedule-MWKR and Non-Delay-SPT algorithms in a real-world Flexible Job Shop environment with heterogeneous job types, extending beyond prior simulation-based evaluations. Second, it incorporates overtime cost as an explicit performance criterion alongside makespan and tardiness, reflecting the practical financial impact that scheduling decisions have on SME profitability. Third, the study develops a replicable scheduling framework applicable to similarly-structured SMEs in the Indonesian metal manufacturing sector, contributing to the broader agenda of productivity improvement in the national industrial engineering domain. The findings are expected to serve as a practical reference for production planners and industrial engineering practitioners operating in resource-constrained manufacturing environments.

MATERIALS AND METHODS

Research Object and Data

This study was conducted at CV. XYZ, a metal manufacturing SME in Surabaya. Historical order data from December 2025 to February 2026 were used, comprising 13 jobs of two product types: Spur Gear (9 jobs) and Housing Bearing (4 jobs), processed across 7 workstations.

Standard Time Measurement

Standard processing times were established using the stopwatch time study method [13]. A total of 60 observations were conducted per work element. Data validation involved the Data Sufficiency Test (Equation 1) and Uniformity Test using Shewhart control charts at 95% confidence (Equations 2–3). Standard time was calculated by multiplying cycle time by the Westinghouse performance rating factor and applying an allowance factor.

$$N' = \frac{[\frac{k}{s}\sqrt{N\sum x^2-(\sum x)^2}]}{\sum x} \ldots(1)$$

$$BKA = \bar{X} + k\sigma \ldots(2)$$

$$BKB = \bar{X} - k\sigma \ldots(3)$$

Production Capacity

The company operates 7 productive hours/day (08:00–16:00 WIB) with 6 working days/week. Total regular capacity over the study period was 28,980 minutes (69 days × 420 min/day).

Existing Conditions

The existing operational condition of the company serves as the performance baseline in this study. This baseline model is reconstructed by evaluating actual historical demand data collected during the observation period from December 2025 to February 2026. The dataset encompasses 13 distinct customer orders consisting of Spur Gear and Housing Bearing products. To simulate the actual production floor behavior, the scheduling sequence is structured chronologically based on the order arrival dates, mirroring the company's unoptimized daily operations. The performance of this existing system is subsequently assessed by calculating three primary indicators: the total completion time (makespan), the potential tardiness relative to predefined customer due dates, and the total overtime hours required to achieve zero tardiness.

Proposed Algorithms

(1) Active Schedule with MWKR. The Active Schedule Algorithm constructs schedules where no machine can start earlier without delaying another job [4]. At each decision step, a conflict set is identified and MWKR resolves it by selecting the job with the largest remaining total processing time [7] (Equation 4):

$$MWKR(j) \ = \sum(i \ \backslash in\ R\_j)\ p\_(i,j) \ldots(4)$$

(2) Non-Delay with SPT. The Non-Delay Algorithm ensures no machine is idle when work is available [8]. The Non-Delay heuristic algorithm is an active scheduling method wherein no machine is permitted to remain idle while the production process is ongoing[14] . SPT selects the operation with the smallest processing time at each step [6] (Equation 5):

$$SPT \ = \backslash min \left\{ p_{i,j} \backslash mid \ \text{all available operations} \right\} \ldots(5)$$

Performance Evaluation Criteria

Three criteria were evaluated to compare the performance of each scheduling method: makespan, tardiness, and total operational cost including overtime. Each criterion is formally defined below.

(1) Makespan (Cmax)

Makespan is the total elapsed time from the start of the first operation to the completion of the last operation across all jobs and all machines [5]. It represents the overall duration of the production schedule. Minimizing makespan is the primary objective as it directly reflects machine utilization efficiency and capacity consumption. Makespan is formally defined as (Equation 6):

$$Cmax \ = \ max \left\{ Ci \mid i \ = \ 1,2,\ldots,n \right\} \ldots(6)$$

where Ci is the completion time of job i, and n is the total number of jobs. A makespan value that exceeds the available regular capacity K = 28,980 minutes directly indicates the presence of overtime. Makespan values at or below K indicate that all jobs can be completed within regular working hours.

(2) Tardiness

Tardiness measures the number of working days by which the total schedule exceeds the available regular production capacity [15]. It is calculated as the excess makespan beyond K = 28,980 minutes, converted into working days based on a daily working duration of 420 minutes (7 productive hours per day). Tardiness is computed as (Equation 7):

$$T = \max \{ 0, (Cmax - K) / H \} \ldots(7)$$

where T is total tardiness in working days, Cmax is the makespan (minutes), K = 28,980 minutes is the total regular capacity over the study period (69 working days × 420 min/day), and H = 420 minutes is the daily productive hours. A tardiness value of zero indicates that the schedule is completed within regular working time with no delivery delay.

(3) Total Overtime Cost

Total overtime cost captures the financial impact of the scheduling decision of overtime labor costs [16]. The regular rate is IDR 15,000/hours (OR). The overtime rate is IDR 21,000/hours (OL), reflecting the standard overtime premium applicable to the company. The total overtime cost is calculated conditionally based on whether the makespan exceeds the regular capacity threshold (Equation 8):

$$\text{If } Cmax > K: \ TBO = (Cmax - K) \times OL$$
$$\text{If } Cmax \leq K: \ TBO = Cmax \times OR \ \ldots(8)$$

where OL = IDR 21,000/hours is the overtime labor rate, K = 28,980 minutes is the total regular capacity, and Cmax is the resulting makespan from each scheduling method. The cost efficiency of a proposed method relative to the existing conditions baseline is calculated as (Equation 9):

$$\text{Cost Efficiency (\%)} = ((TBO_{existing} - TBO_{proposed}) / TBO_{existing}) \times 100\% \ \ldots(9)$$

Research Flow

This research is motivated by a recurring overtime problem at CV. XYZ, a Small and Medium Industry (SME) in Surabaya operating under a Make-to-Order system. The company's existing condition, which is evaluated based on actual historical demand data, lacks a structured scheduling framework. This unstructured operational process consistently pushes production schedules beyond regular capacity, forcing the company to heavily rely on overtime hours to meet customer due dates and consequently driving up additional operational costs.

To address this issue, two heuristic scheduling algorithms are proposed and compared: the Active Schedule Algorithm combined with the Most Work Remaining (MWKR) priority rule, and the Non-Delay Algorithm combined with the Shortest Processing Time (SPT) rule. Historical order data spanning from December 2025 to February 2026, covering 13 jobs across 7 workstations, are collected and validated through stopwatch time studies, ensuring data reliability via sufficiency and uniformity testing.

The evaluation of the existing condition produces a baseline makespan of 35,880 minutes, resulting in a potential tardiness of 16 days in the absence of overtime. To achieve zero tardiness, the company requires 115 overtime hours, incurring an additional operational cost of IDR 2,415,000. The proposed Active Schedule-MWKR algorithm successfully resolves this by reducing the makespan to 26,022 minutes, effectively eliminating both tardiness and the need for overtime. By contrast, the Non-Delay-SPT algorithm offers a lower degree of improvement, yielding a makespan of 31,838 minutes, which leaves 6.8 days of tardiness and requires 47.6 hours of overtime costing IDR 999,600.

The study concludes that the Active Schedule-MWKR algorithm is the superior scheduling method for CV. XYZ. It delivers a 27.42% makespan efficiency improvement, yields a 100% savings on overtime costs amounting to IDR 2,415,000, and frees up machine idle time that increases potential output capacity from 114 to 152 units. This method is highly recommended as the company's standard scheduling policy going forward to improve on-time delivery and operational efficiency.

Figure 1. Research Flow

RESULTS AND DISCUSSIONS

Results

Company Profile and Production System

CV. XYZ operates 7 workstations as identified in Table 1. The Flexible Job Shop classification arises from the presence of two identical lathe machines (M2a and M2b) allowing flexible job routing. Table 2 summarizes the two product types, their routing sequences, and average processing times per job based on 13 historical orders. The Spur Gear has a longer routing sequence (7 operations including two passes at M1 for gear grinding) and significantly higher average processing time (788 min/job) compared to Housing Bearing (511 min/job), reflecting its greater manufacturing complexity. This heterogeneity in job complexity is a key factor influencing scheduling algorithm performance.

Table 1. Workstation Identification

Code	Workstation	Qty
M1	Grinding Machine	1
M2	Lathe Machine	2
M3	Milling Machine (Frais)	1
M4	Milling Machine	1
M5	Gear Hobbing Machine	1
M6	Heat Treatment Machine	1
M7	Final Inspection	1

Table 2. Product Routing and Processing Time Summary

Product	Jobs	Routing Sequence	Avg. Time/Job (min)
Housing Bearing	4	M1→M2→M3→M7	511
Spur Gear	9	M1→M2→M4→M5→M6→M1→M7	788

Standard Time Results

All 60 observations per work element passed both data sufficiency and uniformity tests at the 95% confidence level. Standard times were multiplied by order quantities to obtain total processing times (pi,j) per job, serving as the primary input for all scheduling calculations. Table 3 presents a summary of the resulting standard times per operation type. For Spur Gear, the most time-intensive operations were the second pass at M4 (Milling Machine, averaging 2,140 min/job) and M2 (Lathe Machine, averaging 3,836 min/job), while the Hobbing Machine at M5 averaged 2,069 min/job. For Housing Bearing, the lathe machines at M2 consumed the largest portion of processing time, averaging 3,627 min/job, followed by the frais operations at M3 averaging 1,492 min/job. These results confirm the significant time asymmetry between the two product types and highlight why scheduling decisions that fail to account for workload magnitude can cause severe bottleneck accumulation at critical workstations, particularly at M2.

Table 3. Standard Time per Operations

Machine Name	AVG Spur Gear (min/job)	AVG Housing Bearing (min/job)
Grinding Machine	148	107
Lathe Machine	3836	3627
Milling Machine (Frais)	0	1492
Milling Machine	2140	-
Gear Hobbing Machine	2069	-
Heat Treatment Machine	838	-
Final Inspection	42	-
Grinding Machine	12	12

Existing Conditions

The evaluation of the existing production condition, reviewed based on actual historical demand data for 13 jobs, yielded a total makespan of 35,880 minutes. This processing time significantly exceeds the 28,980-minute regular capacity, directly translating to a heavy reliance on mandatory overtime to meet customer delivery deadlines. Specifically, to achieve zero tardiness, the company requires 115 hours of overtime. Table 3 summarizes these baseline results.

The unstructured historical scheduling practice, by ignoring customer due dates and the complexity of remaining workloads, creates an unbalanced workload distribution across the production period. Processing orders purely based on historical data without considering the heterogeneous routing of products—such as the complex processes required for Spur Gears—causes bottleneck accumulations at critical workstations. This aligns with Sels et al. (2012) [13], who argued that unstructured or arrival-based practices are consistently outperformed by workload-aware rules in multi-machine job shop environments.

Table 4. Performance Criteria – Existing Conditions

Criteria	Value	Unit
Makespan	35,880	Minutes
Tardiness	16	Days
Overtime Duration	115	Hours
Total Overtime Cost	Rp2,415,000	–

Proposed Method 1: Active Schedule – MWKR

The Active Schedule-MWKR algorithm was applied iteratively to all 13 jobs. At each decision step, the conflict set was identified and MWKR selected the operation from the job with the highest total remaining processing time, prioritizing complex jobs early. Table 4 presents the results.

Active Schedule-MWKR achieved a makespan of 26,022 minutes, well within the 28,980-minute regular capacity, completely eliminating tardiness and overtime. The algorithm's iterative conflict resolution process, driven by the MWKR priority rule, ensured that the nine Spur Gear jobs—each with seven-operation routing sequences and processing times exceeding 788 minutes—were consistently frontloaded at M1 and M2, preventing the bottleneck accumulation observed under existing conditions. The resulting schedule maintained near-continuous machine utilization across all seven workstations, with idle time occurring only at M5 (Gear Hobbing) during the early scheduling phase before Spur Gear jobs progressed from upstream operations. This pattern of dense machine utilization is consistent with Kulsum et al. (2020) [9], who demonstrated Active Schedule produces denser machine utilization compared to Existing Conditions in MTO environments. The MWKR rule's effectiveness confirms Thenarasu et al. (2022) [6], who demonstrated through simulation that workload-aware dispatching rules such as MWKR consistently outperform arrival-based and short-processing-time rules in multi-machine flexible job shop environments, consistent with the 7-workstation configuration at CV. XYZ. The total overtime cost under Active Schedule-MWKR was IDR 0, calculated at the regular rate of IDR 250/minute with no overtime premium incurred. Saving 100% overtime cost.

Table 5. Performance Criteria – Active Schedule (MWKR)

Criteria	Value	Unit
Makespan	26,022	Minutes
Tardiness	0	Days
Overtime Duration	0	Minutes
Total Overtime Cost	IDR 0	–

Proposed Method 2: Non-Delay – SPT

The Non-Delay-SPT algorithm yielded a makespan of 31,838.78 minutes, only marginally lower than existing conditons. Table 5 presents the results. The marginal 11.26% makespan reduction (4,041 minutes) was insufficient to bring total production time within the 28,980-minute regular capacity, leaving a tardiness of 6.80 days and an overtime requirement of 2,859 minutes. The root cause of this underperformance lies in the structural conflict between the Non-Delay framework and the SPT priority rule when applied to the heterogeneous job mix at CV. XYZ. The Spur Gear jobs, with average processing times of 788 min/job, were systematically deprioritized throughout the scheduling horizon as SPT continuously selected shorter Housing Bearing operations and early-stage Spur Gear sub-operations. By the time the long mid- and late-stage Spur Gear operations became available at M4, M5, and M6, significant scheduling slack had been consumed and queue pressure had built up at these specialized workstations. This result is consistent with Harto et al. (2016) [8] and Wasito et al. (2024) [17], who noted SPT must be combined with due-date-aware rules to effectively control tardiness in heterogeneous job shop environments.

Table 6. Performance Criteria – Non-Delay (SPT)

Criteria	Value	Unit
Makespan	31,838.78	Minutes
Tardiness	6.80	Days
Overtime Duration	2,859	Minutes
Total Overtime Cost	IDR 999,600	–

Comparative Analysis

Table 6 provides a comprehensive comparison of all three scheduling methods. Figure 1 visualizes the makespan differences against the 28,980-minute regular capacity threshold. Active Schedule-MWKR demonstrates clear superiority across all performance dimensions. Its 27,47% makespan improvement (saving 9,858 minutes) eliminates overtime entirely and achieves a cost saving of IDR 2,415,000 (100% cost efficiency). This is consistent with Baker and Trietsch (2019) [4] and aligns with Harto et al. (2016) [8], who demonstrated Hybrid Active-Non Delay scheduling successfully reduced overtime in a similarly complex manufacturing environment.

The inferior performance of Non-Delay-SPT is attributable to job complexity heterogeneity. The significant difference in average processing times between Spur Gear (788 min/job) and Housing Bearing (511 min/job) amplifies the SPT rule's tendency to continuously defer complex jobs, creating schedule overruns the Non-Delay framework cannot compensate for. Wahyudi et al. (2021) [10] reported a similar pattern in multi-machine job shop configurations with heterogeneous job complexity.

Table 7. Comparative Analysis of All Scheduling Methods

Method	Rule	Makespan (min)	Tardiness (days)	Efficiency	Cost (IDR)
Existing Conditions	-	35,880	16	–	2.415,000
Active Schedule*	MWKR	26,022	0	27.42%	0
Non-Delay	SPT	31,839	6.80	11.26%	999,600

**Best method*

Data for Figure 2:

Method	Makespan (min)
Existing Conditions	35,880
Active Schedule–MWKR *	26,022
Non-Delay–SPT	31,839

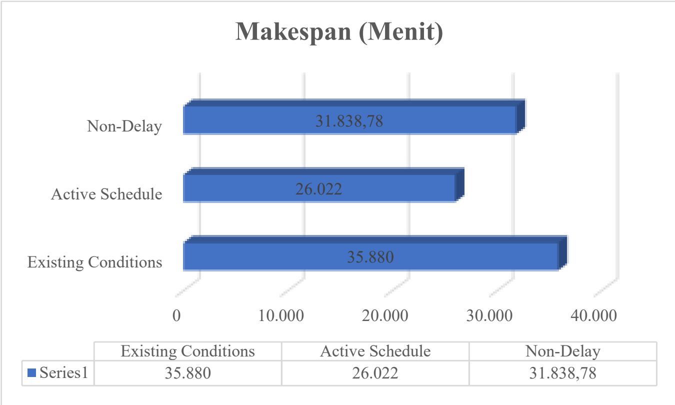

Figure 2. Comparison of Makespan Across Three Scheduling Methods Against Regular Capacity Threshold (28,980 minutes)

Discussions

The results of this study confirm that scheduling algorithm selection has a profound impact on operational performance in Flexible Job Shop environments. The Active Schedule-MWKR algorithm's ability to reduce the makespan by 27.42%—from the historical baseline of 35,880 minutes down to 26,022 minutes—represents a practically significant outcome for SMEs operating under tight capacity constraints. By completely eliminating the initial 16 days of tardiness and 115 hours of overtime, this method aligns with the theoretical foundation established by Baker and Trietsch (2019) [4], who argued that active schedules form a dominant set containing optimal solutions that maximize efficiency. In the context of CV. XYZ, this operational improvement translates directly into a 100% financial saving on extra labor, saving IDR 2,415,000 per observation period. Furthermore, the idle time recovered through this efficiency allows the company to increase its potential output capacity from 114 units to 152 units within the same regular working timeframe.

The superiority of the MWKR priority rule in this study is consistent with Thenarasu et al. (2022) [6], who demonstrated through simulation-based evaluations that workload-remaining rules deliver superior makespan performance in multi-machine configurations compared to simpler rules such as SPT. With CV. XYZ operating seven workstations, the MWKR rule effectively frontloads the most complex jobs—specifically Spur Gears, which require extensive routing—ensuring that bottleneck workstations receive priority assignments early in the scheduling horizon. This proactive approach prevents the compounding delays that characterized the company's unstructured historical practices, where complex jobs encountered congested queues at critical workstations The empirical evidence from Kulsum et al. (2020) [9] similarly demonstrated that active scheduling principles yield denser and more balanced machine utilization, a pattern clearly replicated in this study's results.

The underperformance of the Non-Delay-SPT algorithm requires deeper analytical consideration. While the Non-Delay framework theoretically minimizes machine idle time by always assigning available operations, the SPT priority rule introduces a structural bias that is incompatible with the job complexity profile of CV. XYZ. SPT's greedy preference for short-duration tasks systematically deprioritizes high-complexity jobs, creating a pattern of prolonged queue accumulation at late-stage operations. Consequently, the Non-Delay-SPT algorithm only managed to reduce makespan marginally to 31,838 minutes, leaving 6.8 days of tardiness and still requiring 47.6 hours of overtime. This phenomenon is well-documented in the literature: Wasito (2024) [17] concluded that SPT must be augmented with due-date-sensitive criteria such as Earliest Due Date (EDD) to effectively manage tardiness in heterogeneous manufacturing environments. Similarly, Wirawan et al. (2025) [12] demonstrated through extensive computational experiments that arrival-order and short-processing-time rules are consistently dominated by workload-aware alternatives when jobs differ substantially in complexity and duration. The findings of this study provide additional empirical support for these conclusions within the specific context of Indonesian SME metal manufacturing.

From a practical implementation standpoint, the Active Schedule-MWKR approach presents a realistic and accessible solution for SMEs like CV. XYZ. Unlike metaheuristic methods such as Genetic Algorithms or Simulated Annealing, which require substantial computational infrastructure and specialized expertise, the MWKR-based active schedule can be executed manually through a systematic step-by-step priority decision process or implemented using basic spreadsheet tools. This accessibility is critical in the Indonesian SME context, where digital infrastructure and technical capacity are often limited [1]. The study by Kulsum et al. (2020) [9] similarly advocated for active scheduling approaches in stamping operations precisely because of their practical implementability without requiring advanced computational resources.

Nonetheless, several limitations of this study warrant acknowledgment. First, the scheduling model assumes deterministic processing times derived from historical stopwatch measurements, whereas actual production is subject to variability arising from operator skill differences, machine condition fluctuations, and material quality variations. Second, the study does not account for dynamic disruptions such as machine breakdowns, urgent order insertions, or operator absenteeism, all of which are common occurrences in SME manufacturing environments. Third, the dataset is limited to 13 jobs spanning a three-month period, which may not fully capture seasonal demand variations or order complexity shifts. Future research should address these limitations by incorporating stochastic processing time distributions, developing dynamic rescheduling policies responsive to real-time disruptions, and testing the algorithms over longer data horizons. Additionally, exploring hybrid approaches—such as the Active-Non Delay combination proposed by Wirawan et al. (2025) [12]—could yield further performance improvements in scenarios where job complexity profiles are more balanced between product types.

CONCLUSION

This study compared three production scheduling methods at CV. XYZ, a Flexible Job Shop SME in Surabaya: the existing conditions, Active Schedule with MWKR, and Non-Delay with SPT, based on 13 historical jobs across 7 workstations involving two product types (Spur Gear and Housing Bearing).

The existing conditions resulted in a makespan of 35,880 minutes, tardiness of 16 days, overtime of 6,900 minutes, and total cost of IDR 2,415,000. Active Schedule-MWKR is the most effective method, reducing makespan to 26,022 minutes (27,42% improvement), completely eliminating tardiness and overtime, and saving IDR 2,415,000 (100% cost efficiency). Non-Delay-SPT offered only marginal improvement (11,26%) and failed to resolve tardiness and overtime.

It is recommended that CV. XYZ implement Active Schedule-MWKR as its standard production scheduling policy. Future research should incorporate dynamic factors such as machine breakdown, maintenance schedules, and operator availability, and explore metaheuristic approaches such as Genetic Algorithms or Simulated Annealing for more complex scheduling scenarios.

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