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Setup Time Measurement on Flexo 4 Using The Single-Minute Exchange of Dies (SMED) Method in a Multi-Group Cardboard Production Setting

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Article Info	Abstract
Keywords: *Machine Setup* *Single-Minute Exchange of Dies (SMED)* *Flexo Machine*	Long and unstandardized setup times are a major source of inefficiency in the cardboard packaging production process, particularly on the Flexo 4 machine, which requires 1.5 to 2 hours for setup. This study aims to reduce setup time by implementing the SMED (Single-Minute Exchange of Dies) method. Three internal activities—ink retrieval, material preparation, and plate preparation—were converted into external activities, reducing setup time by up to 66.67%. Observations were made on three work groups during shift 1, with average setup times ranging from the longest to the shortest: Group C (33.9 minutes), Group A (32.3 minutes), and Group B (30.05 minutes). ANOVA results show no significant differences between the groups. The longest setup time occurred in Group C, with 7,500 pcs and 4 plates, taking 75 minutes. This was due to the Mounting Plate process and limited operator resources.

1. INTRODUCTION

In Indonesia and globally, the manufacturing sector is a key driver of economic growth. Over the past decade, it has consistently recorded annual growth rates between 2.2% and 6.1% (Harahap et al., 2023). Today's rapid industrial development demands the ability to implement effective and efficient operational processes (Lestari & WSU, 2017). To stay competitive amid complex markets and increasing global demand, manufacturers must optimize all aspects of production. One widely adopted systematic method to address these challenges is Lean Manufacturing, which seeks to eliminate waste and enhance efficiency (Andri & Sembiring, 2019; Dixit et al., 2015; Ahmad et al., 2021). It focuses on removing non-value-added activities and improving process flow, resulting in more efficient production processes and lower costs (Novirani et al., 2024). Waste in manufacturing includes defect, overproduction, waiting, non-utilized talent. Transportation, inventory, motion, and overprocessing (Maharani & Musfiroh, 2021; (Ahmad et al., 2021). Waste that occurs gradually causes various losses for the company, both those that are directly visible and those that have long-term impacts (Widodo et al., 2023). Lean manufacturing approach promotes streamlined and responsive workflows, driven by a strong commitment to continuous improvement. Productivity is one of the key performance indicators in the production process.

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Manufacturing companies are required to continuously improve productivity in order to reduce production costs, enhance product quality, and strengthen their competitiveness (Purnomo et al., 2021).

Among the common sources of inefficiency in production is prolonged and unstandardized machine set-up time. Set-up time refers to the duration required to prepare a machine when switching from one production cycle to another, including tasks such as tool changes, parameter adjustments, and cleaning. Poorly managed set-up time can reduce production line effectiveness, cause process bottlenecks, and result in lost production capacity. Therefore, reducing set-up time is a critical area within Lean Manufacturing strategies. To address such inefficiencies, the Single-Minute Exchange of Dies (SMED) method is introduced as a Lean technique to minimize set-up duration. Developed by Shigeo Shingo, SMED aims to convert internal set-up activities (requiring machine stoppage) into external ones (performed while the machine is running). The ultimate goal is to reduce set-up time to less than 10 minutes (Díaz-Reza et al., 2016; Yafi et al., 2024). SMED is a set of techniques that allows the setup process to be completed in less than 10 minutes. The term "single minute" does not mean that the setup process takes only 1 minute, but rather indicates that the time required is under 10 minutes or within a single digit minute range (Wibowo & Lukmandono, 2021). However, the success of SMED implementation highly depends on accurate and continuous measurement of set-up time performance.

This condition is observed in a manufacturing company operating in the packaging industry, producing various types of cardboard packaging in different sizes, designs, and colors. In its production process, the company utilizes several printing and cutting machines, including Flexo Machine 4, which belongs to the offline category. The Flexo machines are categorized into two types: Inline and Offline systems. The Inline category encompasses the entire production process from the initial stages through to the finishing phase, including coloring, cutting, folding the cardboard flaps, gluing, and bundling the finished products, typically into bundles of ten cardboard pieces. In contrast, the Offline category covers only the initial production steps, including coloring, cutting, and folding the cardboard flaps, without proceeding to the gluing and bundling stages.

This distinction between Inline and Offline processes reflects different levels of operational integration and affects the overall efficiency and management of production workflows.This machine has a production capacity of 200 pcs/min and can handle products up to 1200 x 3000 mm in size with a maximum of four-color printing and equipped with a slotter knife. Based on field observations and interviews with shift leaders, operators, and supporting staff, it was found that one of the most significant wastes occurs in the set-up process of Flexo Machine 4, particularly in Shift 1 Groups A, B, and C. Ideally, the set-up process should be quick and efficient, but it currently takes between 60 and 120 minutes, depending on product type and size. This duration is considerably longer than the production process itself, leading to waiting time and decreased production flow efficiency ((Dharmayanti & Marliansyah, 2019)). To address this issue, this study aims to analyze the longest set-up times of Flexo Machine 4 using the SMED approach, as well as evaluate the performance of the set-up process based on Lean Manufacturing principles. By measuring and identifying the root causes of delays in set-up, the company can develop continuous improvement strategies that directly impact overall productivity.

2. METHODS

The object of this study is the machine setup process on Flexo 4 at a packaging company (formerly referred to as PT. APP Purinusa Ekapersada). Setup time observation data were collected during the period of January to March 2024 on every working day across three shifts. In-depth interviews were also conducted with the operators working on Flexo 4 to identify setup activities and problems within the work area. After data collection, the data were processed using the SMED (*Single-Minute Exchange of Dies*) method. The research stages carried out to analyze the setup time of Flexo 4 using the SMED method are illustrated in Figure 1.

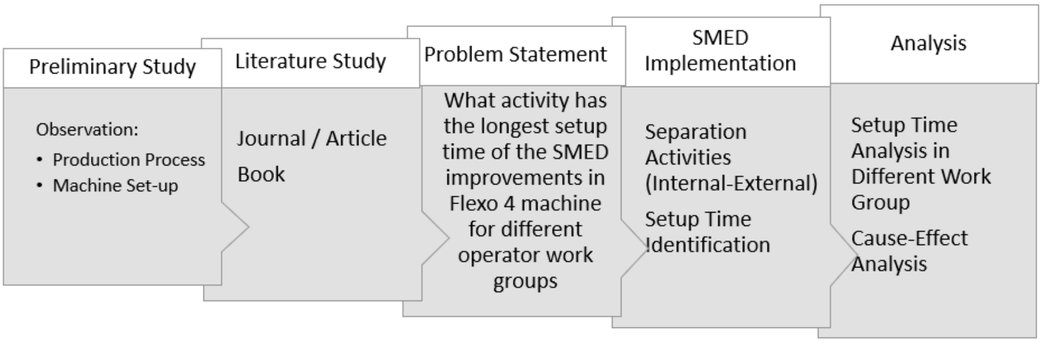

Fig. 1. Research' Phases

Machine setup refers to the process of changing the product on a machine from one type to another, involving the replacement of parts, molds, or other functions (Arief & Ikatrinasari, 2019). The setup activities commonly performed in industrial settings can be categorized into several types, as follows: (1) Preparation and Adjustment: This step includes preparing and adjusting the machine after a process, checking materials and equipment before the process begins, cleaning, and returning work tools to their original condition; (2) Installation and Removal of Components: In this phase, used components are installed and removed, followed by the organization and tidying of these components for the subsequent setup process; (3) Setting and Calibration: This stage involves inputting data and calibrating the machine and equipment during the process, including actions such as centering, dimensioning, and measuring temperature or pressure; and (4) Trial and Adjustment: This step takes place after the machine has been set and calibrated. It involves conducting trials to produce sample products, which are then classified as either acceptable (OK) or not acceptable (NG – not good).

Single-Minute Exchange of Dies (SMED) is one of the improvement methods in Lean Manufacturing aimed at reducing the time required for the setup process of changing production from one product type to another. The term "Single Minute" does not mean that the setup time is only one minute, but rather indicates that the time needed is less than 10 minutes, or in other words, within a single digit minute range. SMED is a strategy to accelerate the product changeover process. There are two types of setup: internal setup and external setup. Internal setup refers to activities that are performed when the machine is stopped or idle, while external setup involves tasks that can be done while the machine is still operating, either before or after the machine functions (Widodo et al., 2023).

The implementation of SMED involves several stages, with the initial identification phase having both direct and indirect impacts on the subsequent stages. Effective planning and a thorough understanding of the production process are essential before initiating SMED implementation (Díaz-Reza et al., 2016). The method focuses on transforming internal activities into external ones and streamlining the setup processes (Sugarindra et al., 2019). SMED has been successfully utilized in various industries, including automotive parts manufacturing and forging, leading to substantial reductions in changeover times (Sugarindra et al., 2019; Talekar et al., 2019). However, despite its effectiveness, some companies face challenges in implementing SMED, often due to a lack of familiarity with the stages or their interconnections. In general, SMED provides a fast and efficient approach to enhancing manufacturing productivity by minimizing non-productive time associated with setup changes (Talekar et al., 2019). Stages of SMED:

1. Separating Internal and External Setup: This process involves identifying and separating internal setup activities (those that can only be done while the machine is stopped) from external setup activities (those that can be done while the machine is operating).
2. Converting Internal to External Setup: This activity aims to convert internal setup tasks into external ones, so that more tasks can be completed while the machine is running.
3. Streamlining All Aspects of the Setup Operation: This stage focuses on simplifying and optimizing all activities related to the setup proces

Research has shown that implementing SMED can decrease setup times by as much as 90% with relatively moderate investments. For instance, the application of SMED in a shoe mold manufacturing company resulted in a 60% reduction in setup time and a 3% increase in productive capacity (Ribeiro et al., 2019). Similarly, a textile manufacturing company in Malaysia reported a 25.62% decrease in changeover time following SMED adoptionThe implementation of SMED provides multiple benefits, such as reduced material exchange times, a lower incidence of errors during exchanges, enhanced product quality, and greater production flexibility (Ribeiro et al., 2019). Furthermore, SMED supports waste elimination, quality improvement, and the achievement of low-cost, flexible operations. Collectively, these findings underscore SMED’s effectiveness in boosting manufacturing efficiency across a range of industries.

3. RESULT AND DISCUSSION

Observations of the production process were conducted in the Flexo 4 machine area, which is used for cardboard manufacturing. The machine operates in an offline configuration, where the production process involves coloring, cutting, and folding the cardboard flaps, without proceeding to final assembly. Flexo 4 has a production capacity of 200 pieces per minute, with a maximum product size of 1200 x 3000 mm, capable of printing up to four colors, and is equipped with a slotter blade. The Flexo 4 machine operates across three work shifts each day, with a five-day workweek. The working hours are as follows: Shift 1 from 07:30 AM to 04:30 PM; Shift 2 from 04:30 PM to 11:30 PM; and Shift 3 from 11:30 PM to 07:30 AM.

The machine setup process on Flexo 4 is structured into several distinct stages prior to SMED implementation, namely Ink Retrieval, Material Preparation, Plates Preparation, Input parameter and machine starting, Plate 1-2 Loading-Unloading, Plate 3-4 Loading-Unloading, Creasing Setup & Slotter Measurement, Ink Cleaning, Ink Filling, Counter Reset, Layout and Print Setup, Color and Print Inspection, Cleaning Previous Plate, Ink Returning. Internal setup activities are performed when machines are stopped, while external activities can be done while machines are operating (Suhardi & Satwikaningrum, 2015). Among these fourteen setup activities, eleven are classified as internal setup operations (Fig 2). In this condition, the machine setup time requires 1,5 hours to 2 hours before starting the production process. The long setup time can impact the overall production completion time.

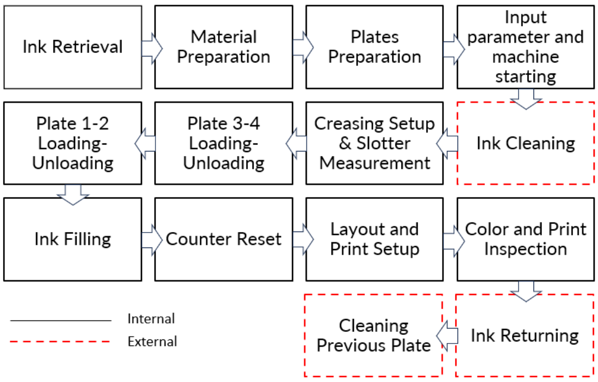

Fig. 2. Existing Setup Activities on Flexo 4 Machine

SMED Implementation: Convert Internal and External Setup

The Single Minute Exchange of Die (SMED) methodology focuses on distinguishing between internal and external setup activities, aiming to convert internal activities to external ones and minimize internal activities overall (Ulutas, 2011). Converting internal to external activities, setup times can be dramatically reduced, leading to improved productivity and capacity (Ani & Shafei, 2013). In the implementation of SMED, the setup activities on the Flexo machine were modified, with ink retrieval, material preparation, and plates preparation being shifted from internal activities to external activities (Table 1).

Table 1. Changes in Setup Activities as an Implementation of SMED

Activities	Internal	External	Code
Ink Retrieval	-	√	E.1
Material Preparation	-	√	E.2
Plates Preparation	-	√	E.3
Input parameter and machine starting	√	-	I.1
Plate 1-2 Loading-Unloading	√	-	I.2
Plate 3-4 Loading-Unloading	√	-	I.3
Creasing Setup & Slotter Measurement	√	-	I.4
Ink Cleaning		√	E.4
Ink Filling	√	-	I.5
Counter Reset	√	-	I.6
Layout and Print Setup	√	-	I.7
Color and Print Inspection	√	-	I.8
Cleaning Previous Plate		√	E.5
Ink Returning		√	E.6

Setup Time Measurement of Flexo 4 Across Different Work Groups

Following the conversion of internal activities to external activities, setup time measurements were conducted after the implementation of SMED. Observations and measurements were carried out on three work groups A, B, and C, with each group undergoing 20 work observations. The setup time was measured directly using a stopwatch time study method. The results of the observations for each work group are presented in Tables 2 to 4. The setup time measurement aims to determine the time required by operators to perform the setup of the Flexo 4 machine and to evaluate the effectiveness of the changes made to the setup activities. Each work group consists of two to three operators.

Table 2. Setup Time Measurement of Group A

Obs. No.	Order Qty (pcs)	Color Qty (pcs)	Plate Qty (pcs)	Internal (min)									External (min)						
				I.1	I.2	I.3	I.4	I.5	I.6	I.7	I.8	$\sum_{int}$	E.1	E.2	E.3	E.4	E.5	E.6	$\sum_{ext}$
1	2600	4	4	1	4	6	1	2	1	3	1	19	1	1	4	6	3	1	18
2	1500	3	3	1	6	9	1	2	1	5	1	26	1	1	7	4	4	1	21
3	1000	3	3	1	3	4	1	1	1	3	1	15	1	1	5	3	4	1	18
4	4000	2	2	1	9		1	1	1	3	1	17	1	2	5	2	3	1	16
5	1000	1	1	1	7		1	1	1	3	2	16	1	2	5	1	5	1	19
6	1000	2	2	1	9		1	1	1	4	1	18	1	1	3	1	3	1	12
7	500	2	2	1	8		1	1	1	3	1	16	1	2	8	2	3	1	19
8	3000	1	1	1	4		1	1	1	2	1	11	1	1	6	1	4	1	17
9	5000	1	1	1	9		1	2	1	4	2	20	1	2	7	1	3	1	17
10	7500	2	2	1	15		1	3	1	5	3	29	1	2	11	2	4	1	24
11	4000	3	3	1	28	27	1	2	1	12	1	73	1	1	15	3	5	1	30
12	2100	4	4	1	15	15	1	2	1	10	1	46	1	1	15	5	3	1	28
13	10.000	4	4	1	25	28	1	2	1	13	1	72	1	2	13	4	3	1	26
14	1000	3	3	1	20	23	1	2	1	11	1	60	1	1	20	3	4	1	33
15	1000	2	2	1	10		1	1	1	3	1	18	1	1	5	1	3	1	14
16	1000	3	3	1	5	5	1	1	1	5	1	20	1	2	6	3	4	1	20
17	2500	2	2	1	19		1	2	1	9	3	36	1	1	8	2	3	1	18
18	5000	1	1	1	47		1	1	1	10	10	71	1	1	13	1	5	1	26
19	2000	2	2	1	13		1	2	1	4	2	24	1	2	11	2	3	1	22
20	2000	4	4	1	11	13	1	2	1	9	1	39	1	1	16	3	3	1	27

Table 3. Setup Time Measurement of Group B

Obs. No.	Order Qty (pcs)	Color Qty (pcs)	Plate Qty (pcs)	Internal (min)									External (min)						
				I.1	I.2	I.3	I.4	I.5	I.6	I.7	I.8	$\sum_{int}$	E.1	E.2	E.3	E.4	E.5	E.6	$\sum_{ext}$
1	4500	2	2	1	5		1	3	1	2	4	19	3	1	1	3	2	3	13
2	3000	2	2	1	10		1	1	1	8	1	23	4	1	2	7	3	3	20
3	5000	4	4	1	7	9	1	1	1	3	1	24	4	1	1	3	4	5	18
4	1000	2	2	1	5		2	1	1	6	4	20	3	1	2	4	1	3	14
5	1000	3	3	1	8	6	1	1	1	4	2	24	5	1	1	5	3	5	20
6	520	1	1	1	6		1	2	1	7	2	20	3	1	2	3	1	3	13
7	1000	1	1	1	7		1	2	1	8	3	23	3	1	2	6	1	3	16
8	300	1	1	1	8		2	1	1	1	1	15	4	1	2	3	1	3	14
9	5000	4	4	1	13	16	1	1	1	5	1	39	3	1	2	8	3	5	22
10	2600	2	2	1	12		1	1	1	7	1	24	4	1	1	6	1	4	17
11	500	2	2	1	14		1	2	1	10	1	30	5	1	1	5	2	4	18
12	500	1	1	1	8		1	2	1	9	1	23	3	1	1	2	1	3	11
13	1550	3	3	1	12	8	1	2	1	14	1	31	3	1	2	7	3	5	21
14	1000	1	1	1	18		1	2	1	5	2	30	4	1	2	5	1	3	16
15	5000	2	2	1	11		1	1	1	36	1	54	3	1	1	3	3	3	14
16	3000	2	2	1	19		1	1	1	12	1	36	4	1	2	4	2	4	17
17	5000	2	2	1	38		1	1	1	30	1	73	3	1	1	3	3	3	14
18	1000	3	3	1	14	10	1	1	1	11	1	40	5	1	1	7	3	5	22
19	500	1	1	1	6		1	1	1	4	1	15	3	1	2	2	1	2	11
20	2500	2	2	1	19		1	2	1	13	1	38	3	1	1	5	2	3	15

Table 4. Setup Time Measurement of Group C

Obs. No.	Order Qty (pcs)	Color Qty (pcs)	Plate Qty (pcs)	Internal (min)									External (min)						
				I.1	I.2	I.3	I.4	I.5	I.6	I.7	I.8	$\sum_{int}$	E.1	E.2	E.3	E.4	E.5	E.6	$\sum_{ext}$
1	1000	3	3	3	5	5	1	2	1	16	3	36	3	1	2	3	3	3	15
2	3025	1	1	1	11		1	2	1	11	3	30	4	1	1	7	4	4	21
3	1000	2	2	1	18		1	1	1	3	1	26	4	1	2	5	3	4	19
4	800	2	2	1	20		1	2	1	7	5	37	3	1	2	4	4	3	17
5	1000	1	1	1	10		1	1	1	8	2	24	5	1	2	6	3	5	22
6	600	1	1	1	7		1	2	1	7	2	21	3	1	1	3	4	3	15
7	500	3	3	1	8	8	1	2	1	8	3	32	3	1	2	8	3	3	20
8	200	1	1	1	10		1	2	1	1	1	17	4	1	1	3	4	4	17
9	200	3	3	1	7	4	1	1	1	5	1	21	3	1	2	10	4	3	23
10	1000	1	1	1	12		1	2	1	10	2	29	4	1	1	11	3	4	24
11	1000	1	1	1	9		1	2	1	8	1	23	5	1	1	15	4	5	31
12	5000	1	1	1	37		1	2	1	11	2	55	3	1	1	8	4	3	20
13	5000	3	3	1	21	10	1	2	1	14	2	52	3	1	2	7	4	3	20
14	4500	2	2	1	19		1	1	1	5	2	30	4	1	2	15	3	4	29
15	6000	2	2	1	11		1	1	1	7	1	23	3	1	1	6	4	3	18
16	7500	4	4	1	27	24	1	1	1	19	1	75	4	1	2	10	3	4	24
17	3000	2	2	1	25		1	2	1	9	2	41	3	1	2	4	4	3	17
18	5000	2	2	1	21		1	1	1	13	1	39	5	1	1	9	3	5	24
19	5000	1	1	1	11		1	2	1	9	1	26	3	1	1	17	4	3	29
20	7500	3	3	1	19	8	1	2	1	8	1	41	3	1	2	16	4	3	29

Table 5. Summary of Statistic Setup Time Measurement

Statistic	Setup Time (min)		
	A	B	C
Sum	646	601	678
Average	32,3	30,05	33,9
Max	73	73	75
Min	11	15	17
Variance	435,27	196,47	196,83

Table 6. Result of ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	149,6333333	2	74,81666667	0,270886333	0,763679504	3,158842719
Within Groups	15742,95	57	276,1921053			
Total	15892,58333	59				

Group A recorded an average setup time of 32 minutes, with the shortest setup time being 11 minutes and the longest 73 minutes. The longest setup time of 73 minutes occurred in the 11th observation, involving three plates, with a total internal activity duration of 73 minutes and external activities taking 30 minutes. The cause of this delay was that during the setup process, the materials or cartons to be processed were still mixed with other orders, and only half of the required cartons had been located. As a result, the operators and outsourced workers had to search for the materials around the storage area, causing the setup process to be interrupted. Additionally, another obstacle encountered during the setup process was the limited space available to accommodate the processed products, as the transport vehicles were still in the process of delivering goods, and the volume of products being manufactured exceeded the available storage capacity.

Group B recorded an average setup time of 30 minutes, with the shortest setup time being 15 minutes and the longest 73 minutes. The longest setup time of 73 minutes occurred in the 17th observation, involving two plates, with a total internal activity duration of 73 minutes and external activities taking 14 minutes. The cause of the prolonged setup was the occurrence of a plate mounting process in the middle of the machine setup. Plate mounting refers to the activity of modifying the structure or arrangement of the plates by adding or removing components. This situation arose due to the incompatibility of the plates with the machine, as one plate was used for the same order but across different machines. Therefore, when the plate was installed on the Flexo 4 machine, it was possible that the structure of the plate had already been altered due to its prior use on a different machine.

Group C recorded an average setup time of 34 minutes, with the shortest setup time being 17 minutes and the longest 75 minutes. The longest setup time of 75 minutes occurred in the 16th observation, involving four plates, with a total internal activity duration of 75 minutes and external activities taking 17 minutes. The cause of the extended setup time was similar to that in Group B, namely the occurrence of a plate mounting process during the machine setup, requiring modifications to the structure or arrangement of the plates to fit the Flexo 4 machine. Additionally, one outsourced worker was absent on that day, resulting in a shortage of manpower during the setup process. Consequently, the operator and the remaining outsourced worker had to handle the setup with fewer resources, leading to a heavier workload compared to previous days. This situation caused the setup process to take longer, as it was carried out by only two workers. The following is a graph showing the average setup times for the three groups, A, B, and C.

The variance values for the three work groups—Group A (435.27), Group B (196.47), and Group C (196.83)—indicate differences in the consistency of setup times within each group. Variance measures the degree of dispersion around the mean; higher variance suggests greater variability in the data, while lower variance implies more consistency. In this case, Group A has a notably higher variance (435.27) compared to Group B (196.47) and Group C (196.83). This result suggests that setup times within Group A are more widely spread out and less consistent, with some observations significantly higher or lower than the group's average. On the other hand, Group B and Group C exhibit relatively similar and lower variances, indicating that setup times within these groups are more consistent and closer to their respective means. The larger variability in Group A may reflect differences in operator skill levels, inconsistencies in material availability, procedural deviations, or equipment-related factors that caused setup times to fluctuate more heavily compared to Groups B and C. Therefore, special attention might be needed to standardize practices or address the sources of inconsistency within Group A to achieve a more uniform setup performance.

A one-way ANOVA test was conducted to evaluate whether there were statistically significant differences in the average setup times among the three work groups (A, B, and C). The analysis results show an F-value of 0.2709 with a p-value of 0.7637. Meanwhile, the critical F-value at the 5% significance level is 3.1588. Since the calculated F-value (0.2709) is less than the critical F-value (3.1588), and the p-value (0.7637) is greater than 0.05, it can be concluded that the null hypothesis is not rejected. This means that there is no statistically significant difference in the average setup times among the three work groups. Therefore, based on this analysis, there is insufficient evidence to suggest any difference in setup performance between the groups. Furthermore, the sum of squares (SS) for within-group variation (Within Groups) is 15,742.95, which is much larger than the between-group variation (Between Groups) of 149.63, indicating that most of the variability in the data is due to individual differences within groups rather than differences between groups.

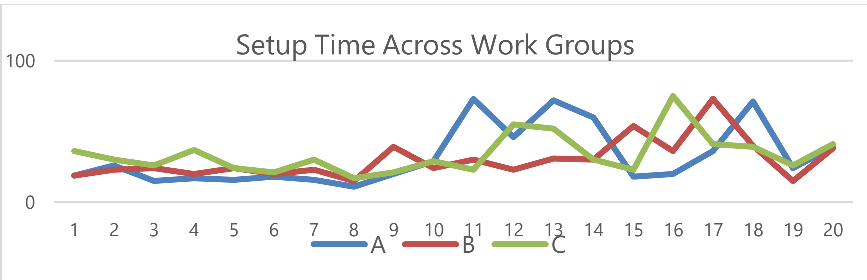

Fig. 3. Setup Time Across Work Groups

Figure 3 illustrates the average setup times for Group A (blue), Group B (orange), and Group C (gray) over 20 observation periods. All three groups experienced varying fluctuations, with significant spikes and drops at certain points. Group A was the most stable at the beginning but showed a sharp increase in the middle of the period. Group B demonstrated good consistency early on but saw a decline in performance from the middle to the end of the period. Group C recorded the highest and most variable setup times, especially during the middle periods, indicating potential inefficiencies or technical issues. Periods 10–17 were critical for all groups, as significant spikes occurred across nearly all of them.

Based on the results of the measurement, the implementation of the new standard work using SMED was able to reduce setup time by 66.67%. This is consistent with other studies that report significant reductions in setup times, ranging from 16.68% to 66.67% (Shinde et al., 2014; Gavali et al., 2016; Marcella & Widjajati, 2024). Previously, the processes of ink retrieval, material preparation, and plates preparation were carried out during machine downtime, but now these activities are performed while the machine is running on the previous order. SMED implementation involves identifying and optimizing internal and external activities, simplifying work preparation steps, and eliminating waste in the production process (Marcella & Widjajati, 2024). Set-up time measurement not only helps identify inefficiencies but also serves as a benchmark for the success of Lean tools implementation such as 5S, Visual Management, and Standard Work (Shinde et al., 2014). Systematic measurement of set-up time enables companies to develop more efficient standard operating procedures (SOPs) and set measurable performance improvement targets. SMED approach can significantly reduce setup times in manufacturing processes, such as injection molding and CNC machining (Nee et al., 2012); Ani & Shafei, 2013). Implementation of SMED has shown significant time savings with minimal investment, as demonstrated in a Styrofoam manufacturing process (Ulutas, 2011), and increased monthly income in a furniture company (Suhardi & Satwikaningrum, 2015). The benefits of SMED extend beyond time reduction, including increased productivity, reduced downtime, and improved operational efficiency (Rahul et al., 2012).

Analysis of the Causes of The Longest Setup Time

After compiling the setup data for the three groups (A, B, and C), the next stage is to analyze the causes of the longest setup times. The analysis of the causes of the longest setup time aims to identify the underlying factors that contribute to extended setup durations during production processes. A detailed examination of operational activities, equipment readiness, material availability, workforce efficiency, and procedural adherence is conducted to determine bottlenecks or inefficiencies. Understanding these causes is critical for formulating targeted improvement strategies, enhancing operational effectiveness, and supporting continuous improvement initiatives within the manufacturing environment. By addressing the root causes, organizations can significantly reduce non-productive time, optimize resource utilization, and improve overall production performance.

Each group experienced the longest setup times, with distinct contributing factors. However, Group C recorded the longest setup time, with an average of 33,9 minutes. The primary causes identified include the occurrence of the Mounting Plate process during the machine setup and the absence of one outsourced worker. Consequently, prior to implementing any improvements, the initial step involved identifying the underlying issues using a fishbone diagram, which is presented in the following figure (Figure 4).

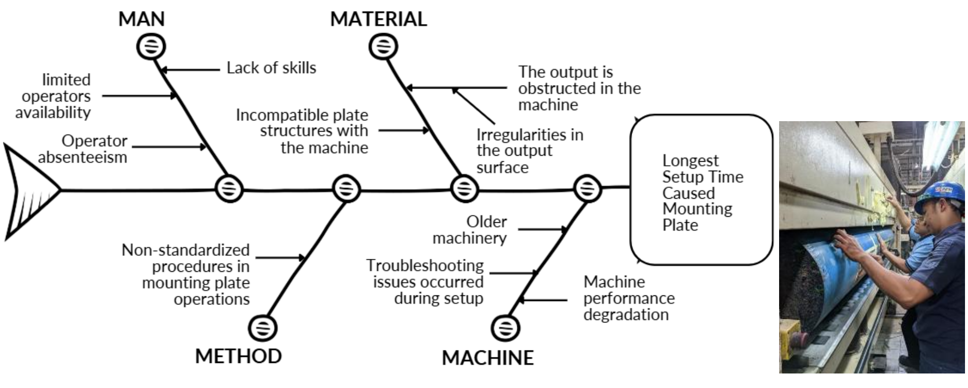

Fig. 4. Fishbone Diagram

Based on the Fishbone diagram above, several factors have been identified as contributing to the occurrence of Mounting Plate issues, including factors related to Material, Man, Machine, and Method. In terms of material, the output frequently becomes stuck in the machine due to an uneven surface. Furthermore, the plate structure used for the previous order differs, requiring adjustments before being used for the subsequent order. Suggested improvements include: (1) conducting a more thorough inspection of the cardboard material during the material feeding process; and (2) designing adjustable plates. Furthermore, from the human aspect, the lack of understanding, knowledge, and skills among the workforce regarding the mounting plate activity hinders the process, often observed in outsourcing or internship operators. In addition, when issues arise, operators frequently wait for repairs from the mechanics, who are in limited supply, resulting in increased repair waiting times. The limited number of operators also means that when an operator is absent, the process takes longer as fewer operators are available to perform the tasks. It is recommended that the company provide training to operators on the mounting plate process to enable them to resolve issues without waiting for mechanics. To address absenteeism, the company could consider utilizing substitute outsourcing workers or implementing shift swaps.

In terms of the machine aspect, issues typically arise due to the lack of regular inspection and maintenance, leading to machine troubles or breakdowns. Furthermore, the Flexo machine is relatively old and lacks advanced features, resulting in suboptimal performance compared to other machines. Additionally, monitoring of machine performance is infrequent. Necessary improvements include: 1) Establishing a schedule for regular inspections and maintenance; 2) Replacing outdated components or modifying the machine with additional features to enhance productivity; and 3) Implementing a monitoring system to track machine performance, analyze performance data, and provide recommendations for machine improvements or maintenance. From the method perspective, there is currently no standardized procedure for handling the mounting plate. The company needs to conduct an evaluation and establish methods for addressing mounting plate issues, as well as set standardized procedures for mounting plate handling.

4. CONCLUSION

Based on the data collection and processing conducted, the following conclusions can be made: (1) the internal activities that were changed to external are ink retrieval, material preparation, and plate preparation; (2) Based on the machine setup time calculations on three groups in the Flexo 4 machine using the SMED (Single-Minute Exchange Dies) method, the average setup times from longest to shortest are Group C (33.9 minutes), Group A (32.3 minutes), and Group B (30.05 minutes); (3) ANOVA results show no significant differences between the groups; (4) The longest setup time is Group C, which is 75 minutes, with an average setup time of 33.9 minutes, consisting of 75 minutes of internal activity and 17 minutes of external activity; (5) The cause of the long setup time is the mounting plate process during the setup. Based on the analysis of the setup time calculations, mounting plate is the activity that causes the long setup time on the Flexo 4 machine. Therefore, several improvement suggestions can be made to the company, taking into account the aspects of man, material, machine, and method, including: (1) Providing training for workers on the mounting plate process; (2) More thorough inspection of cardboard material during the feeding process; (3) Creating plates for each machine, even for the same order; (4) Conducting supervision, inspection, and regular maintenance to ensure the machine operates well; (5) Replacing old components or adding new features that can enhance machine productivity and performance. These recommendations are intended to save overall setup time, minimize waste such as excessive waiting time, and ensure that the work performed becomes more efficient and comfortable with a manageable workload.

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