A Lean-Based Simulation Approach to Setup Changeover Improvement on the Flexo 8 Machine Using Single-Minute Exchange of Dies (SMED) Method

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Abstract

Production efficiency is a crucial element in enhancing the competitiveness of manufacturing industries. One common challenge is the lengthy setup changeover time, which leads to downtime and reduced productivity. This study aims to propose an improvement to the setup changeover process on the Flexo 8 machine at PT APP Purinusa Eka Persada-Semarang by implementing the Single-Minute Exchange of Die (SMED) method combined with Arena simulation software. The research was conducted through direct observation, data collection of setup times during January–March 2024, and analysis using the SMED approach, which includes separation of internal and external activities, conversion of internal to external activities, and simplification of setup tasks. Subsequently, a simulation model was developed using Arena software to compare the conditions before and after SMED implementation. The simulation results indicate that the SMED method successfully reduced the average setup changeover time from 52.67 minutes to 35.13 minutes, representing a 33.3% reduction. These findings confirm that the SMED approach can simplify setup processes, reduce downtime, and improve resource efficiency. The study recommends integrating SMED with simulation as an effective strategy for optimizing production processes. However, this research is limited by the exclusion of external activities in the simulation and the reliance on the accuracy of observational data. Future studies may expand the analysis to examine the impact of SMED on cost and product quality.

Keywords: Arena Simulation, Production Efficiency, Lean Manufacturing, Setup Changeover Time, Single-Minute Exchange of Die (SMED).

I. INTRODUCTION

In today's era of globalization and increasingly fierce industrial competition, production efficiency has become a fundamental factor in ensuring the sustainability and competitive advantage of manufacturing companies [1]. Production efficiency encompasses not only the effective utilization of resources but also a company's ability to minimize production time and costs without compromising product quality [2]. One of the key issues that often impedes production efficiency is the prolonged setup changeover time [3]. Setup changeover time refers to the duration required to reconfigure machinery or equipment from producing one model to another, particularly in large-scale production settings [4]. Extended setup changeover times can result in increased machine downtime, leading to reduced production capacity and delays in product delivery to customers [5].

In manufacturing companies, activities that do not add value—or even generate waste—are frequently encountered [6]. This leads to the excessive use of resources, including energy, human resources, and time, ultimately causing inefficiencies throughout the production process [7]. There are eight commonly recognized types of waste: Defects, Waiting, Unnecessary Inventory, Inappropriate Processing, Unnecessary Motion, Transportation, and Overproduction [8]. Therefore, systematic and continuous efforts are required to identify and eliminate these forms of waste in order to enhance efficiency and productivity [9]. Prolonged setup changeover times are also classified as waste that must be eliminated [10]. One company that recognizes the importance of reducing setup changeover time is PT APP Purinusa Eka Persada-Semarang.

PT APP Purinusa Eka Persada-Semarang, a subsidiary of the Sinar Mas Group, manufactures paper packaging products such as carton sheets and carton boxes. The company utilizes several key machines in the production of these products, including the Corrugator for producing carton sheets and the Flexo machine for manufacturing carton boxes. The Flexo 8 machine plays a critical role in the company's carton box production process. Furthermore, the Flexo 8 is an inline Flexo machine with a production capacity of up to 350 boxes per minute. It can produce boxes with maximum dimensions of 600 mm × 1800 mm and supports up to four colors of ink. This machine consists of seven central units with distinct functions. The feeder unit transfers and arranges the carton sheets prior to printing. The printing unit then applies ink onto the sheets using printing plates, with the Flexo 8 equipped with four such units. Next, the slotter unit cuts the sheets into the required box dimensions. The gluing unit applies adhesive to the sheet edges, which are then folded and bonded by the folding unit. After folding, the boxes are stacked in the ejector unit, with a maximum stack height of 25 pieces. Finally, the packing unit binds the box stacks with straps. This production process on the Flexo 8 involves both setup time and production time. This study focuses specifically on the setup changeover time, which remains relatively long—ranging between 60 and 100 minutes—and thus reduces production efficiency. Consequently, a structured and systematic method is needed to reduce setup changeover time and improve overall production efficiency [11].

Various methods have been developed to reduce setup changeover time, one of which is the Single-Minute Exchange of Die (SMED) method [2]. SMED is a proven approach for minimizing changeover time during product transitions [12]. Developed by Shigeo Shingo in Japan during the 1950s [13], SMED has since been widely adopted across numerous industrial sectors worldwide [14]. The core principle of SMED is the classification of setup activities into internal and external categories [15]. The method then seeks to convert internal activities into external ones and simplify all setup tasks to reduce the total time required [16]. The SMED method has been shown to reduce setup changeover time by as much as 66.67% [17]. By applying SMED principles, companies can optimize setup times, increase productivity, and lower production costs [18].

This study aims to reduce setup changeover time by implementing the SMED method in the carton box production process on the Flexo 8 machine, supported by simulation modeling. The use of Arena simulation software allows for analysis and optimization of the setup changeover process [19]. Arena will be used to simulate both the current setup changeover conditions and the proposed improvements using SMED. Through simulation, the company can evaluate the impact of the improvements on the efficiency and effectiveness of the production process [20]. As a result, the company can predict the effects of the proposed changes on the Flexo 8 machine before actual implementation.

II. METHOD

This study focuses on the setup changeover process of the Flexo 8 machine at PT APP Purinusa Eka Persada-Semarang, a company specializing in the production of paper packaging products. Setup time data were collected through direct observation over a period from January to March 2024, during the first work shift on weekdays. The collected data were then analyzed using the Single-Minute Exchange of Die (SMED) method. The stages of this research in analyzing the setup changeover time using the SMED method are illustrated in Figure 1.

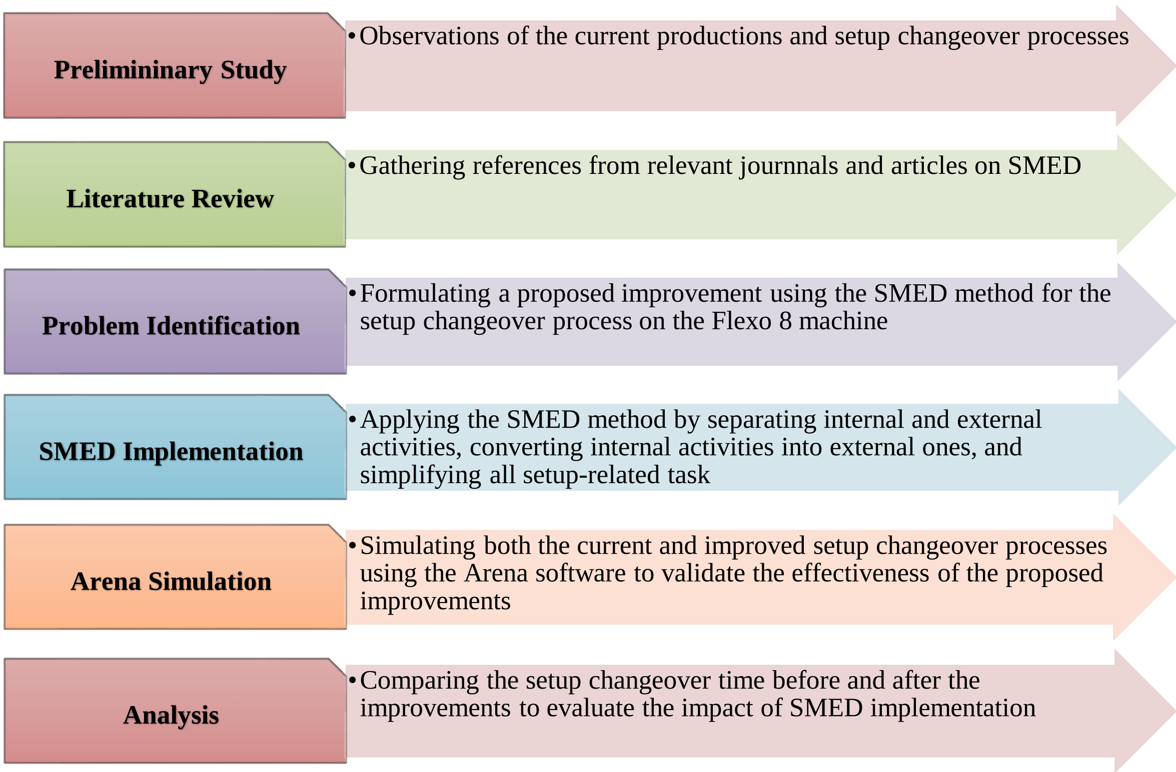

Figure 1 Methodological Framework for Setup Time Reduction Using SMED and Arena Simulation

Lean is a business philosophy that prioritizes the reduction of resource usage, including time, across various organizational activities [21]. Its main objective is to identify and eliminate non-value-added activities in design, production, operations, and supply chain management directly related to customer satisfaction [22]. Lean implementation can take various forms, one of which focuses on time efficiency improvements [23]. The SMED method is one of the key tools in Lean Manufacturing that aims to minimize setup time [24].

SMED is a structured and systematic approach that emphasizes reducing equipment and machine setup changeover time during product changeovers [2]. Setup changeover time is defined as the duration from the end of the last product's production run to the start of the next product's production [25]. Product model transitions often take several hours, forcing companies to use large lot sizes to avoid frequent changeovers [26]. In Lean Manufacturing, changeover time is considered a form of waste as it adds no value to the product and interrupts the production flow [27]. The SMED method addresses this by classifying setup activities into two categories: internal and external [28]. Internal activities are those that can only be performed when the machine is stopped, whereas external activities can be executed while the machine is running [29]. Implementing SMED provides benefits such as reduced setup time, shorter production lead times, lower production costs, and minimized bottlenecks [18].

The application of the SMED (Single-Minute Exchange of Die) method involves a series of structured stages designed to optimize setup changeover processes and minimize machine downtime [12], [13]. The preliminary step requires a thorough observation of all setup activities, including measuring the time taken for each task, conducting interviews or discussions with machine operators to understand practical challenges, and documenting the entire setup process through photos or videos for detailed analysis. Following this, Step 1 focuses on distinguishing between internal activities, which can only be performed when the machine is stopped, and external activities, which can be carried out while the machine is still in operation. In Step 2, efforts are made to convert as many internal activities as possible into external ones, allowing certain tasks to be completed simultaneously with machine operation, thereby reducing overall downtime. Finally, Step 3 emphasizes the improvement and simplification of both internal and external activities, identifying redundancies, streamlining procedures, and implementing practical solutions to enhance efficiency. By systematically following these stages, the SMED method not only reduces setup time but also improves operational productivity, ensures smoother workflow transitions, and supports better resource utilization in manufacturing processes.

After applying SMED, the proposed improvements to the setup changeover process must be quantitatively assessed. The resulting time improvements are then compared with the pre-improvement setup times [2], [24]. A simulation model is used to validate the effectiveness of the improvements before field implementation [30]. Arena is a simulation software based on Discrete Event Simulation (DES) that is used to model and analyze real-world systems—such as production, service, or logistics processes—through a visual and dynamic framework [31]. Conducting simulations in Arena before implementing changes in the actual environment offers significant benefits, including identifying potential issues, testing various scenarios, and making better-informed decisions without the risk or cost of real-world trial and error [32].

III. RESULTS AND DISCUSSION

Observations were conducted on the production process using the Flexo 8 machine, which is responsible for producing carton boxes. The Flexo 8 has a production capacity of up to 350 pieces per minute, supports a maximum product size of 600 mm × 1800 mm, is capable of four-color printing, and is equipped with a slotter unit. This machine operates in an inline configuration, handling processes such as printing, cutting, gluing, folding, and packaging. It runs three shifts per day, five days per week, with the following schedule: Shift 1 from 07:30 to 16:30, Shift 2 from 16:30 to 23:30, and Shift 3 from 23:30 to 07:30.

A. Initial Condition of the Setup Changeover Process

The data collected in this study consisted of detailed records of the activities and durations associated with the setup changeover process conducted during production using the Flexo 8 machine. In this context, setup changeover time is defined as the period between the completion of the last product from the previous order and the successful production of the first product in the subsequent batch [25]. Accurate measurement of this interval is critical, as it directly reflects the efficiency of machine utilization and the responsiveness of the production system to model or order changes. To ensure reliability, observations and time measurements were carried out during 20 separate setup changeover events, all conducted during the first shift of the workday to maintain consistency in operator conditions and environmental factors. The observation technique employed was a stopwatch time study, which allowed for precise tracking of each task involved in the setup sequence. This method involved four Flexo 8 machine operators who performed their usual routines without interference, ensuring the data reflected realistic production behavior. The detailed breakdown of activities and the recorded durations from each observation session are summarized and presented in Table 1.

Table 1 Summary of Setup Changeover Activities and Duration Before SMED Implementation

	Setup Changeover Activity																Total time	Average
Observation (minutes)	Material preparation	Plate preparation	Returning ink from previous order	Fetching ink	Input machine parameters & open unit	Removing & installing printing plates 1 & 2	Removing & installing printing plates 3 & 4	Washing plates from previous order	Cleaning ink	Filling ink	Loading system	Setting OS-DS, folding, press gap	Feeding material	Setting print layout	Color adjustment	Plate polishing		
Obs-1	-	-	3	5	3	8	5	2	3	3	2	6	2	8	1	5	51	
Obs-2	-	-	1	8	1	7	6	5	10	2	1	3	3	5	1	5	52	
Obs-3	-	-	3	3	3	5	5	2	5	2	1	1	1	13	2	4	45	
Obs-4	-	-	9	10	1	8	6	1	1	3	1	1	1	17	3	5	61	
Obs-5	-	-	3	3	3	11	11	2	3	2	2	1	2	19	1	5	57	
Obs-6	-	-	2	3	1	6	3	1	1	3	1	1	4	21	1	7	52	
Obs-7	-	-	4	2	4	12	11	2	3	5	3	1	1	11	1	4	53	
Obs-8	-	-	3	3	3	14	9	2	6	3	1	2	4	15	1	5	62	
Obs-9	-	-	4	4	3	9	7	2	2	3	1	2	4	14	1	4	53	
Obs-10	-	-	3	2	6	2	7	3	1	2	2	3	1	15	2	3	50	55,5
Obs-11	-	-	3	9	2	3	6	2	3	4	1	4	1	26	2	7	70	
Obs-12	-	-	3	4	5	9	8	2	3	2	1	1	1	22	1	10	64	
Obs-13	-	-	4	2	7	7	6	2	2	5	2	1	1	19	1	2	55	
Obs-14	-	-	2	2	2	5	7	2	5	3	1	2	2	24	4	5	61	
Obs-15	-	-	3	5	1	2	3	3	2	6	1	3	6	20	2	7	62	
Obs-16	-	-	5	3	1	6	6	3	4	2	1	1	1	14	1	5	47	
Obs-17	-	-	2	2	1	12	7	2	2	3	1	1	2	16	9	5	58	
Obs-18	-	-	4	2	2	6	8	3	3	2	1	2	2	10	1	3	43	
Obs-19	-	-	3	5	1	9	4	2	3	4	1	1	3	13	6	4	55	
Obs-20	-	-	3	4	1	8	10	2	5	2	1	1	3	17	3	7	59	

It is important to note that the activities "Removing and installing printing plates 1 & 2" and "Removing and installing printing plates 3 & 4" were conducted in parallel. Therefore, to avoid duplication, only the longer of the two durations was included when calculating the total setup time. Based on the observational data, the average setup changeover time for the Flexo 8 machine was 55.5 minutes. This average indicates that the setup changeover process is relatively long. As shown in Figure 2, a cause-and-effect fishbone diagram was used to investigate the root causes.

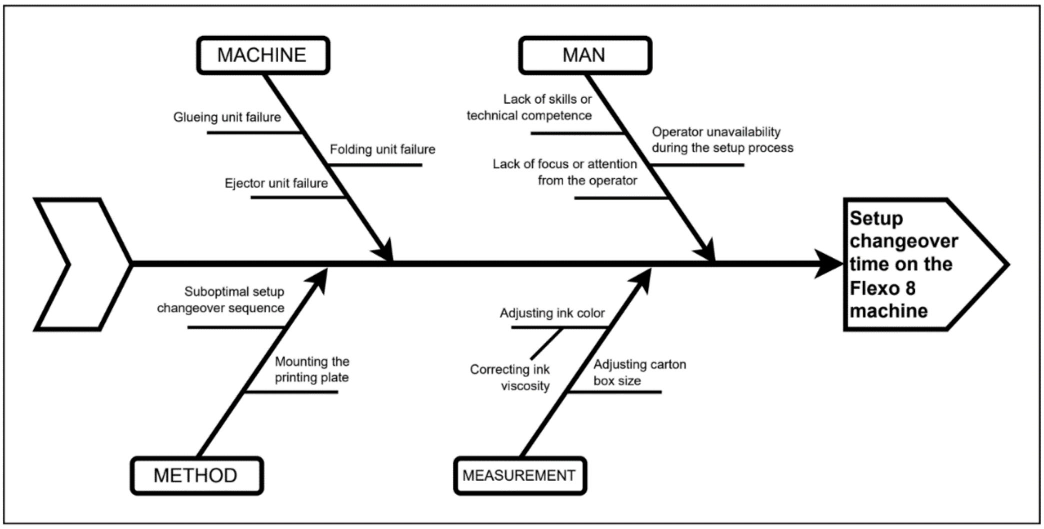

Figure 2 Fishbone Diagram of Factors Causing Flexo 8 Setup Time Increase

Based on the fishbone diagram, several factors were identified as the main contributors to prolonged setup changeover time on the Flexo 8 machine, one of which is the mounting of the printing plates. Under the Man category, issues included inadequate operator technical skills, lack of concentration during setup, and absence of operators during critical stages. These factors led to delays and inconsistencies, especially when experienced operators were unavailable. As a solution, technical training for operators is necessary to ensure smooth operations regardless of individual availability. From the Machine aspect, malfunctions were identified in three key units: gluing, folding, and ejector units. These breakdowns contributed to increased downtime and disrupted the setup process. Periodic maintenance is recommended to address these mechanical issues.

From the Method perspective, the setup procedure was not yet optimized and lacked standardized workflows, particularly during the mounting of printing plates—which consumed a significant amount of time. Thus, the application of the SMED principles and standardization of work steps are deemed necessary to accelerate the process. In the Measurement category, frequent issues were found in parameter settings, such as ink color adjustments and carton box dimension setup, which were often inaccurate. The absence of standard parameters led to high variability in setup times. Therefore, standardizing the setup changeover procedure is essential to achieve greater consistency and efficiency. This analysis forms the basis for the improvement proposals in this study, which aims to streamline the setup changeover process on the Flexo 8 machine.

B. Separation of Internal and External Activities in Setup Changeover

After thoroughly identifying and documenting all activities involved in the setup changeover process, the next crucial step was to carefully analyze each task and categorize it based on whether it could be performed while the machine was stopped or while it was still in operation. This classification allowed the activities to be separated into internal activities, which must be completed when the machine is offline, and external activities, which can be carried out simultaneously with machine operation. The results of this detailed separation and classification are summarized and presented in Table 2, providing a clear overview of the workflow and highlighting opportunities for optimizing the setup process.

Table 2 Classification of Setup Activities into Internal and External Categories

Setup Changeover Activity	External Activity	Internal Activity
Material preparation	✓	
Plate preparation	✓	
Returning ink from previous order		✓
Fetching ink		✓
Input machine parameters & open unit		✓
Removing & installing printing plates 1 & 2		✓
Removing & installing printing plates 3 & 4		✓
Washing plates from previous order		✓

Setup Changeover Activity	External Activity	Internal Activity
Cleaning ink		✓
Filling ink		✓
Loading system		✓
Setting OS-DS, folding, press gap		✓
Feeding material		✓
Setting print layout		✓
Color adjustment		✓
Plate polishing		✓

Based on this careful classification of setup activities, it was determined that only “Material preparation” and “Plate preparation” fall into the category of external activities, meaning these tasks can be performed while the machine is still in operation, without causing downtime. In contrast, all other activities are considered internal, indicating that they can only be carried out when the machine is stopped, which directly contributes to production downtime. This distinction between internal and external activities is critical for identifying opportunities to streamline the setup process, as converting internal tasks to external ones can significantly reduce overall changeover time and improve operational efficiency. By clearly separating these activities, the workflow becomes more transparent, and targeted interventions can be implemented to optimize productivity and minimize interruptions in the production schedule.

C. Converting Internal Activities into External Activities

Once all setup activities had been thoroughly classified into internal and external categories, the subsequent step involved identifying which internal activities could feasibly be converted into external activities. This conversion process focused on tasks that, with careful planning and adjustments, could realistically be performed while the Flexo 8 machine remained in operation, without interrupting the production process. The primary objective of this approach was to minimize the total setup downtime by allowing certain preparatory or auxiliary tasks to be completed concurrently with machine operation. By strategically shifting activities from internal to external, the workflow becomes more efficient, machine idle time is reduced, and overall productivity is enhanced. This step is a critical component of the SMED methodology, as it enables the production system to maintain continuity while optimizing the setup process, ultimately supporting faster changeovers and more consistent operational output.

Table 3 Conversion of Internal Activities to External Activities Based on SMED Principles

Setup Changeover Activity	External Activity	Internal Activity
Material preparation	✓	
Plate preparation	✓	
Returning ink from previous order	✓	
Fetching ink	✓	
Input machine parameters & open unit		✓
Removing & installing printing plates 1 & 2		✓
Removing & installing printing plates 3 & 4		✓
Washing plates from previous order	✓	
Cleaning ink		✓
Filling ink		✓
Loading system		✓
Setting OS-DS, folding, press gap		✓
Feeding material		✓
Setting print layout		✓
Color adjustment		✓
Plate polishing		✓

Three specific activities were successfully converted from internal to external, namely "Returning ink from the previous order," "Fetching ink," and "Washing plates from the previous order." By reclassifying these tasks as external, they can now be performed either before the setup process begins or after it is completed, without requiring the Flexo 8 machine to be stopped. This adjustment not only reduces the total machine downtime but also allows operators to better plan and sequence their work, ensuring that essential preparatory tasks do not interfere with ongoing production. The conversion of these activities exemplifies the practical application of the SMED methodology, demonstrating how careful analysis and process restructuring can enhance operational efficiency, streamline workflow, and contribute to faster, more effective setup changeovers.

D. Process Improvement and Simplification Using the Single-Minute Exchange of Die (SMED) Method

Following the successful conversion of selected internal activities into external ones, the proposed improvements and optimizations to the setup changeover process were systematically compiled and summarized in Table 4. This table provides a comprehensive overview of the revised workflow, highlighting which tasks have been reclassified, the sequence in which activities should now be performed, and the anticipated impact on overall setup time. By presenting the information in this structured format, Table 4 serves as a clear reference for operators and process engineers, facilitating the implementation of the SMED methodology and supporting more efficient, streamlined, and time-effective changeover procedures.

Table 4 Proposed Sequence of Setup Activities After SMED Implementation

No	Setup Changeover Activity	Activity Category
1	Material preparation	External
2	Plate preparation	External
3	Fetching ink	External
	Machine Stop	
4	Input machine parameters & open unit	Internal
5	Removing & installing printing plates 1 & 2	Internal
6	Removing & installing printing plates 3 & 4	Internal
7	Cleaning ink	Internal
8	Filling ink	Internal
9	Loading system	Internal
10	Setting OS-DS, folding, press gap	Internal
11	Feeding material	Internal
	First Trial	
12	Setting print layout	Internal
13	Color adjustment	Internal
14	Plate polishing	Internal
	Mass production	
15	Washing plates from previous order	External
16	Fetching ink	External

The activities "Material preparation," "Plate preparation," and "Fetching ink" are now categorized as external activities, meaning they can be carried out before the machine is stopped. Once the machine is halted, the internal setup changeover process begins with "Input machine parameters & open unit" and continues sequentially until "Feeding material". Next, the first trial phase takes place, involving "Set printing layout," "Color adjustment," and "Plate polishing". After the output meets the required specifications, the machine can enter mass production. Meanwhile, while the machine resumes production, the operators can perform external tasks such as "Washing plates from the previous order" and "Returning ink from the previous order". This strategy ensures that these tasks do not prolong the machine's downtime, thereby enhancing overall setup efficiency.

E. Simulation Using Arena Software

Subsequently, a simulation was conducted using Arena software to compare the setup changeover durations between the current condition and the proposed improvement using the SMED method. This simulation aimed to validate the effectiveness of the improvement proposals [30]. In the simulation, only internal activities were modeled, excluding external ones. This decision was based on the fact that internal activities are the only ones performed while the machine is halted—thus directly contributing to downtime [9].

To determine the duration of each internal activity, observational data previously collected were input into Arena software. These data were used to construct an accurate simulation model, supported by the Arena Input Analyzer feature. The Input Analyzer is used to identify the probability distribution that best fits the observed data [33]. Once the data are processed through the Input Analyzer, the software generates an expression that represents the distribution of each activity. These expressions, which include the type and parameters of each distribution, are then directly applied to the simulation model [34]. Furthermore, tables 5 and 6 show the probability distributions for each internal activity, both for the current condition and the proposed SMED model.

Table 5 Probability Distributions of Internal Setup Activities Before & After SMED

No	Initial Setup Changeover Activity (Before SMED)	Activity Category	Selected Distribution	Expression
1	Returning ink from previous order	Internal	Gamma	0.5 + GAMM(0.713, 4)
2	Fetching ink	Internal	Lognormal	1.5 + LOGN(2.62, 3.12)
3	Input machine parameters & open unit	Internal	Beta	0.5 + 7 * BETA(0.634, 1.53)
4	Removing & installing printing plates 1 & 2	Internal	Normal	NORM(7.45, 3.19)
5	Removing & installing printing plates 3 & 4	Internal	Poisson	POIS(6.75)
6	Washing plates from previous order	Internal	Lognormal	0.5 + LOGN(1.77, 0.9)
7	Cleaning ink	Internal	Gamma	0.5 + GAMM(1.39, 2.05)
8	Filling ink	Internal	Lognormal	1.5 + LOGN(1.56, 1.38)
9	Loading system	Internal	Exponential	0.5 + EXPO(0.8)
10	Setting OS-DS, folding, press gap	Internal	Exponential	0.5 + EXPO(1.4)
11	Feeding material	Internal	Beta	0.5 + 6 * BETA(0.8, 1.94)
12	Setting print layout	Internal	Normal	NORM(15.9, 5.17)
13	Color adjustment	Internal	Lognormal	0.5 + LOGN(1.59, 1.81)
14	Plate polishing	Internal	Erlang	1.5 + ERLA(0.9, 4)
No	**Improved Setup Changeover Activity (After SMED)**	**Activity Category**	**Selected Distribution**	**Expression**
1	Input machine parameters & open unit	Internal	Gamma	0.5 + GAMM(0.713, 4)
2	Removing & installing printing plates 1 & 2	Internal	Lognormal	1.5 + LOGN(2.62, 3.12)
3	Removing & installing printing plates 3 & 4	Internal	Beta	0.5 + 7 * BETA(0.634, 1.53)
4	Cleaning ink	Internal	Gamma	0.5 + GAMM(1.39, 2.05)
5	Filling ink	Internal	Lognormal	1.5 + LOGN(1.56, 1.38)
6	Loading system	Internal	Exponential	0.5 + EXPO(0.8)
7	Setting OS-DS, folding, press gap	Internal	Exponential	0.5 + EXPO(1.4)
8	Feeding material	Internal	Beta	0.5 + 6 * BETA(0.8, 1.94)
9	Setting print layout	Internal	Normal	NORM(15.9, 5.17)
10	Color adjustment	Internal	Lognormal	0.5 + LOGN(1.59, 1.81)
11	Plate polishing	Internal	Erlang	1.5 + ERLA(0.9, 4)

Table 5 presents the probability distributions of internal setup activities before and after the implementation of the SMED method. Each activity is categorized as internal, meaning it can only be performed when the machine is stopped, and is associated with a specific statistical distribution to model the variability and uncertainty in its duration. Before SMED, there were 14 internal activities, including tasks such as returning ink from the previous order, fetching ink, inputting machine parameters, removing and installing printing plates, washing plates, cleaning and filling ink, loading the system, setting OS-DS, feeding material, setting print layout, color adjustment, and plate polishing. These activities were modeled using a variety of probability distributions, including Gamma, Lognormal, Beta, Normal, Poisson, Exponential, and Erlang distributions, with expressions indicating their respective parameters. For example, "Returning ink from the previous order" was modeled using a Gamma distribution (0.5 + GAMM(0.713, 4)), while "Setting print layout" followed a Normal distribution (NORM(15.9, 5.17)).

After applying SMED, the table shows the improved internal activities, reflecting the removal of tasks that were successfully converted into external activities, such as “Returning ink from the previous order,” “Fetching ink,” and “Washing plates from the previous order.” The remaining internal activities retain their original probability distributions, though their sequence has been adjusted to reflect the optimized workflow. This reorganization ensures that the setup process is more streamlined, with tasks that can be completed without stopping the machine removed from the internal activity list, thereby reducing overall downtime. The table effectively illustrates how the SMED methodology impacts both the categorization and sequencing of internal setup activities, providing a statistical basis for predicting and improving setup changeover time. The current setup changeover model in Arena was constructed according to the real-world sequence of internal activities for the Flexo 8 machine, as illustrated in Figure 3.

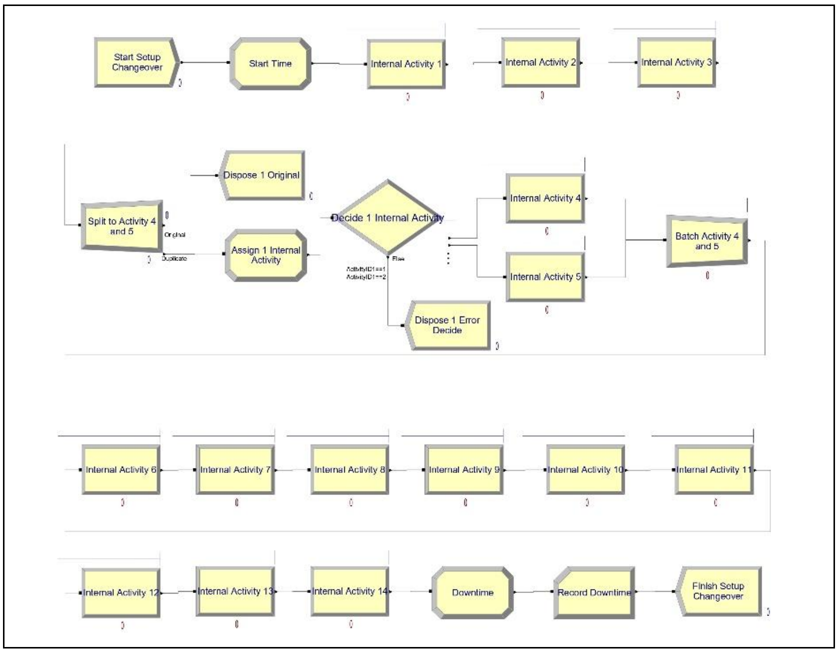

Figure 3 Arena Simulation Model of the Current Setup Changeover Process

The current model represents 14 internal activities. The available resources include four Flexo 8 machine operators. The activities “Removing & installing printing plates 1 & 2” and “Removing & installing printing plates 3 & 4” are performed in parallel, each by two operators. The remaining activities are conducted in series, reflecting the actual procedure on the factory floor. In contrast, the proposed SMED-based simulation model was developed to reduce waste and improve setup changeover efficiency. This model includes 11 internal activities, resulting from the conversion of three previously internal activities to external ones. The same four Flexo 8 operators serve as resources. Several activities are restructured to be performed in parallel, aiming to accelerate the process and enhance resource utilization.

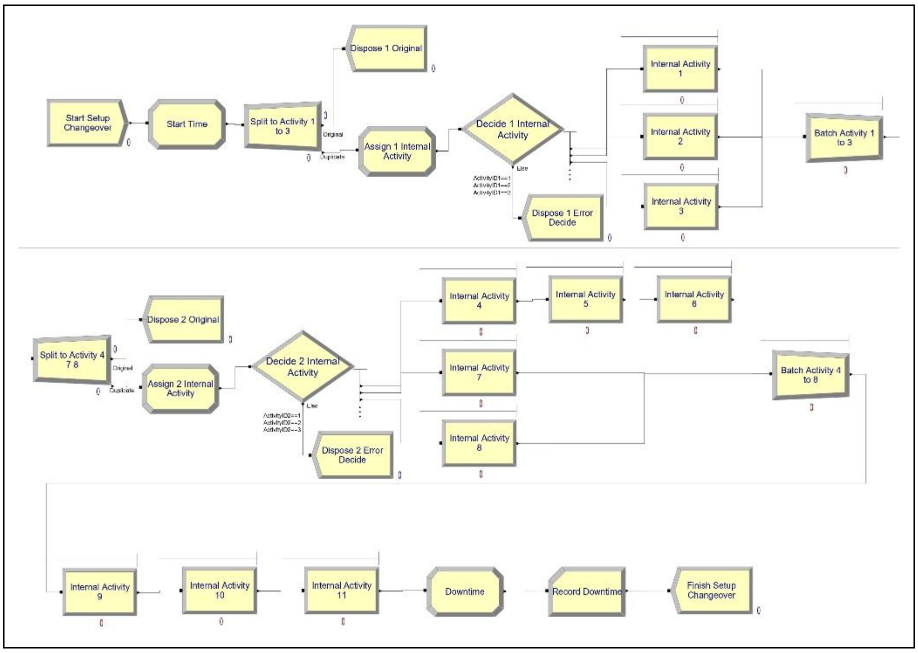

Figure 4 Arena Simulation Model of the Setup Process After SMED Implementation

In the SMED model, the activities “Input machine parameters & open unit,” “Removing & installing printing plates 1 & 2,” and “Removing & installing printing plates 3 & 4” are conducted in parallel. “Cleaning ink,” “Setting OS-DS, folding, press gap,” and “Feed material” are also executed in parallel. Activities such as “Filling ink” followed by “Loading system” are done in series due to dependency on “Cleaning ink” completion. Finally, “Set layout,” “Color adjustment,” and “Plate polishing” are performed sequentially. These proposed improvements are expected to significantly reduce setup changeover time without compromising the quality of the output.

F. Arena Simulation Results

Once the simulation models were constructed, each was executed with the base time unit set to minutes and configured for 30 replications to ensure a more statistically accurate output. The simulation produced setup changeover time results for both the current condition and the proposed SMED improvement. Table 7 compares these results, including average duration, standard deviation, and extreme values.

Table 6 Comparison of Setup Changeover Time Between Current and Improved Conditions

Replications	Without SMED (minute)	With SMED (minute)	Replications	Without SMED (minute)	With SMED (minute)	Replications	Without SMED (minute)	With SMED (minute)
Rep 01	38,39	30,40	Rep 11	50,10	29,30	Rep 21	57,53	34,65
Rep 02	69,38	42,52	Rep 12	50,24	24,20	Rep 22	53,83	37,64
Rep 03	45,65	37,01	Rep 13	56,92	30,75	Rep 23	45,79	23,04
Rep 04	59,43	33,15	Rep 14	56,73	27,72	Rep 24	51,98	45,82
Rep 05	49,64	38,41	Rep 15	45,29	37,14	Rep 25	35,23	32,15
Rep 06	62,98	32,95	Rep 16	55,03	35,34	Rep 26	42,05	35,21
Rep 07	51,73	40,33	Rep 17	67,74	41,33	Rep 27	60,28	28,84
Rep 08	85,33	36,80	Rep 18	41,49	27,50	Rep 28	51,52	34,88
Rep 09	50,97	38,48	Rep 19	56,88	49,21	Rep 29	50,06	32,85
Rep 10	53,42	41,58	Rep 20	47,21	34,74	Rep 30	37,37	40,03
Average							**52,67**	**35,13**
Standard deviation							**10,27**	**6,03**

Replications	Without SMED (minute)	With SMED (minute)	Replications	Without SMED (minute)	With SMED (minute)	Replications	Without SMED (minute)	With SMED (minute)
			Min				**35,23**	**23,04**
			Max				**85,33**	**49,21**

Based on the simulation results, the average setup changeover time in the current condition is 52.67 minutes with a standard deviation of 10.27 minutes. After implementing the SMED-based improvements, the average time drops to 35.13 minutes, with a reduced standard deviation of 6.03 minutes. The shortest simulation time in the current condition was 35.23 minutes, whereas in the improved condition, it was reduced to 23.04 minutes. Conversely, the longest time in the current scenario was 85.33 minutes, which was significantly reduced to 49.21 minutes under the improved scenario. These results clearly demonstrate a substantial improvement in both the central tendency and the variability of setup changeover times. The reduction in standard deviation indicates more controlled and consistent performance following SMED implementation.

G. Comparative Analysis of Simulation Results

A boxplot was employed to visually compare the differences in simulation outcomes between the current setup condition and the proposed improvements following the implementation of the SMED methodology, as shown in Figure 5. This graphical representation provides a clear overview of the distribution of setup times, highlighting key statistical measures such as the median, quartiles, and potential outliers for both scenarios. By examining the boxplot, it is possible to observe the reduction in variability and overall setup time achieved through the proposed SMED improvements, demonstrating the effectiveness of reclassifying internal and external activities and streamlining the changeover process.

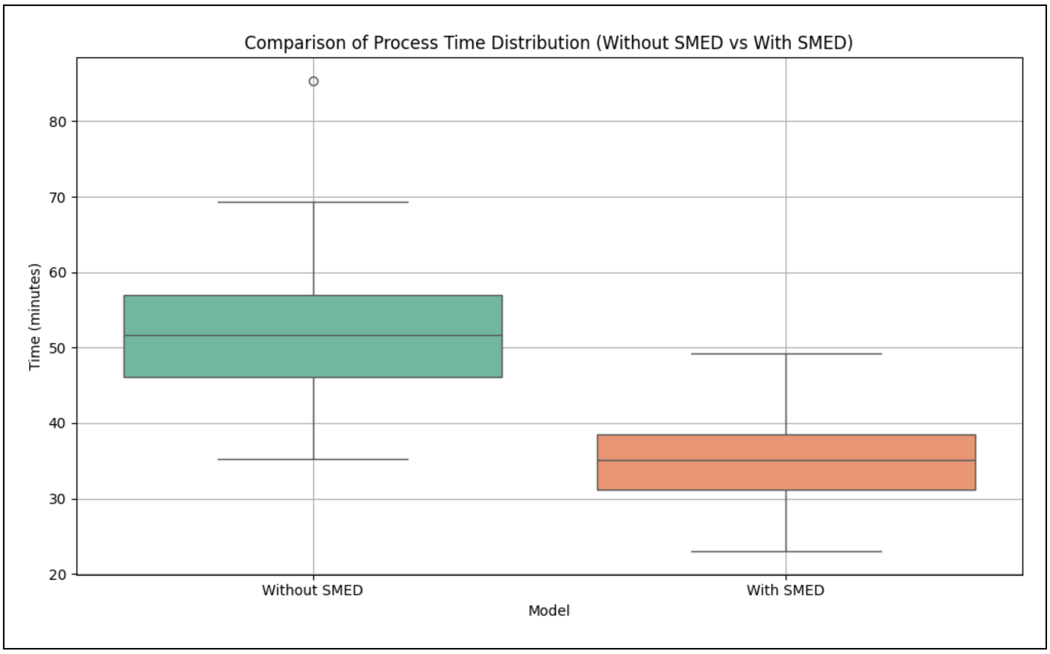

Figure 5 Boxplot Comparison of Setup Time Between Current and SMED-Improved Conditions

The boxplot in Figure 4 clearly highlights the difference in data distribution between the 30 simulation replications of the current and improved conditions. The SMED-based simulation model shows a significant reduction in average setup time, along with a narrower spread, indicating greater process control and consistency. An outlier was observed in the current condition at 85.33 minutes (Replication 8), suggesting the presence of an extreme case in the existing setup changeover model. Such variation is noticeably reduced in the SMED-improved model.

The results from the 30 simulation replications demonstrate a statistically and operationally significant difference in setup changeover durations between the two scenarios. The average time dropped from 52.67 minutes to 35.13 minutes, representing a reduction of approximately 17.54 minutes or 33.3%. These findings are consistent with prior studies that reported efficiency improvements of up to 37.58% through SMED application in simulation environments [35]. In the present study, the simulation converged on optimal results after 30 iterations, reaffirming the effectiveness of SMED in minimizing setup time. Moreover, operator engagement in external activities (such as "Returning ink from the previous order," "Fetching ink," and "Washing plates") increased from 28.26% to 39.43%, indicating better utilization of human resources and improved coordination during changeovers [36].

The use of Arena simulation software proved invaluable in visualizing and quantifying the operational behavior of the system under real-world conditions. It allowed various configuration scenarios to be tested without disrupting actual production [37]. Through simulation, potential performance improvements could be identified in a risk-free and cost-effective manner, avoiding the need for physical trial-and-error [38], [39]. For instance, a simulation study using Arena successfully predicted the impact of Lean-based improvements in a metal surface processing line, resulting in reduced waiting times and increased production capacity, ultimately leading to greater customer satisfaction [40]. Similarly, this study demonstrates that the proposed improvements using the SMED method can significantly reduce setup changeover time and enhance operational performance.

IV. Conclusion

Based on the simulation results, the implementation of the Single-Minute Exchange of Die (SMED) method significantly reduces setup changeover time on the Flexo 8 machine. The simulation using Arena software demonstrated a reduction in average setup time from 52.67 minutes to 35.13 minutes, or approximately 33.3%. These findings confirm the effectiveness of SMED in streamlining setup processes and minimizing downtime, thereby contributing to an overall improvement in production efficiency. Furthermore, the simulation outcomes offer a realistic projection of system performance under actual operating conditions. The boxplot visualization reinforces the improvement by illustrating a narrower time distribution and more consistent results in the SMED-applied model. Additionally, the increased involvement of operators in external activities, such as "Returning ink from the previous order," "Fetching ink," and "Washing plates", demonstrates enhanced utilization of human resources in supporting a smoother setup process. In summary, this study demonstrates that combining the SMED method with Arena simulation serves as an effective approach for optimizing setup changeover processes. It can significantly boost production efficiency and, consequently, strengthen the company's competitiveness.

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