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OEE improvement through reducing start up duration using lean Six Sigma methodology in manufacturing

Wijaya Khisbulloh[1], **Gatot Yudoko**[2]
Institut Teknologi Bandung, Indonesia[1&2]
wijaya_khisbulloh@sbm-itb.ac.id[1], gatot@sbm-itb.ac.id[2]

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Abstract

Purpose: This study aims to improve Overall Equipment Effectiveness (OEE) by reducing start-up duration through the application of Lean Six Sigma methodology. This study focuses on identifying delays in the start-up process, determining their root causes, and implementing systematic improvements to enhance operational efficiency.

Research Methodology: A comprehensive case study was conducted in a manufacturing environment. Data related to the start-up duration, downtime causes, and other performance parameters were collected and analyzed. This study applied the Lean Six Sigma Define, Measure, Analyze, Improve, Control (DMAIC) framework to diagnose bottlenecks, identify inefficiencies, and design corrective actions that optimize start-up operations.

Results: The findings demonstrate that applying Lean Six Sigma tools significantly reduces startup delays, thereby improving OEE. The elimination of bottlenecks and process inefficiencies contributes to increased production output, enhanced operational performance, and greater competitiveness in a dynamic manufacturing environment.

Conclusions: Reducing the start-up duration using the Lean Six Sigma methodology provides a structured and effective approach to achieving operational excellence. This study confirms that targeted interventions in the start-up process can substantially improve equipment efficiency and overall manufacturing productivity.

Limitations: This research is limited to manufacturing industries where OEE is used as a primary performance indicator and may not be fully generalizable to the service sector.

Contribution: This study contributes to manufacturing excellence by combining Lean and Six Sigma practices to improve process efficiency and offer practical insights for industry practitioners.

Keywords: *E-commerce, Influencer Marketing, Local Culture, Security and Privacy, Social Commerce*

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1. Introduction

The tobacco industry in Indonesia is facing increasingly difficult challenges, especially with the continuous increase in tax and excise for all tobacco-related products. This is slowly putting pressure on cigarette and tobacco companies. The figure below shows the trend of cigarette excise in Indonesia and the declining trend of tobacco processing industry GDP (Bella et al., 2024; Mulyapradana, Aghus Jamaludin, Farikhul, Safna, & Nafiatul, 2025).

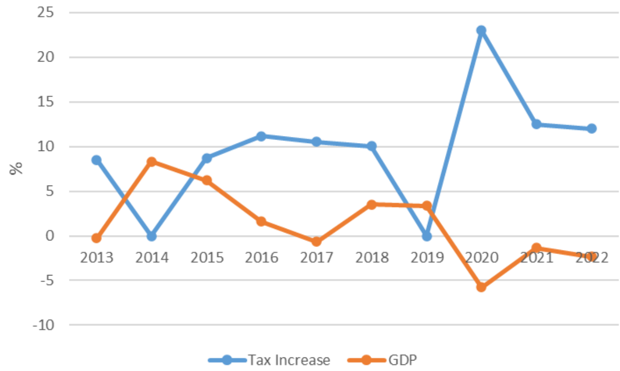


Figure 1. Chart Tax increase vs GDP tobacco industry

PT. XYZ, an Indonesian cigarette company, faces the same pressure. Several brands from PT.XYZ have a declining demand as well, one of them is "XYZ super slim" that was produced by machine Line 14, one of the production lines having by XYZ in their Manufacturing Facilities. In the first quarter of 2023, the Capacity Utilization (CU) of Line 14 was below 80% due to a decrease in volume. This led the XYZ management to decide to optimize its capacity utilization to reduce its production cost.

Line 14 is run by a 4G (4 Group) pattern with a production schedule of 24 h and 7 days per week. Owing to the lower production demand, the production line is often off due to no production demand. To reduce costs, since June 2023, XYZ decided to change the pattern to 3G (3 Group) and only run on weekdays and off on weekends. By changing the production pattern, XYZ can reduce the labor cost by reducing one group of the production team and increasing capacity utilization by 90%.

4G Calendar

Sep	W35			W36							W37							W38							W39					
Day	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Shift I	B	B	B	B	B	C	C	C	C	C	D	D	D	D	D	A	A	A	A	A	B	B	B	B	B	C	C		C	C
Shift II	C	C	C	D	D	D	D	D	A	A	A	A	A	B	B	B	B	B	C	C	C	C	C	D	D	D	D		A	A
Shift III	D	A	A	A	A	A	B	B	B	B	B	C	C	C	C	C	D	D	D	D	D	A	A	A	A	A	B		B	B

3G Calendar

Sep	W35			W36							W37							W38							W39					
Day	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Shift I	B	B		C	C	C	C	C	C		A	A	A	A	A	A		B	B	B	B	B	B		C	C	C		C	C
Shift II	C	C		A	A	A	A	A	A		B	B	B	B	B	B		C	C	C	C	C	C		A	A	A		A	A
Shift III	A	A		B	B	B	B	B	B		C	C	C	C	C	C		A	A	A	A	A	A		B	B	B		B	B

Figure 2. Working pattern calendar

Due to the changes in the production pattern, there is one problem that occurs, as the production line starts on weekdays and off at weekends, it now requires start-up and shut-down activities every week. This activity reduces the machine efficiency of Line 14. Machine efficiencies are reported as OEE.

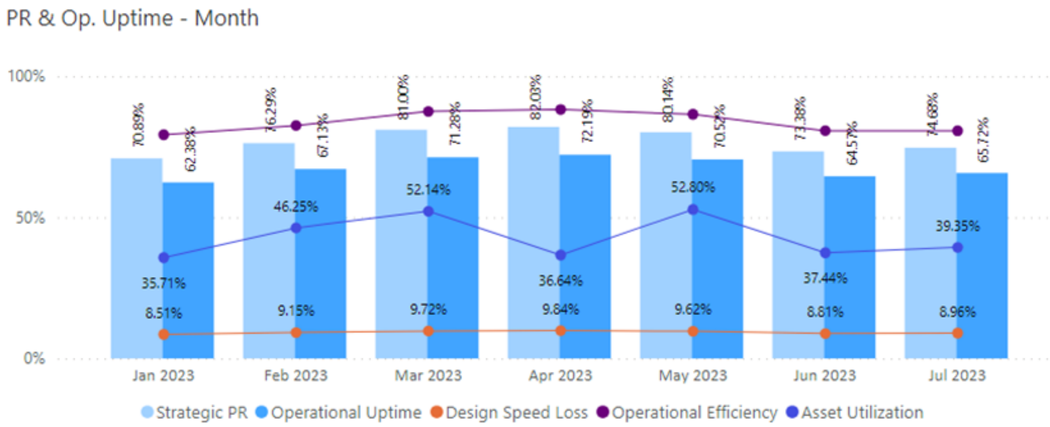


Figure 3. PR and Uptime (OEE) Line 14

OEE is a metric that measures production performance and is an indicator of process improvement activities in manufacturing production (Ahire & Relkar, 2012). It provides a comprehensive view of how efficiently manufacturing equipment and resources are utilized to produce high-quality products. Achieving high OEE scores is a fundamental goal for XYZ, aiming to maximize productivity, reduce costs, and meet customer demands efficiently. Owing to several challenges, it is important for manufacturers to continuously increase their overall performance to minimize their production costs (Andersson & Bellgran, 2015; Basera, Mwenje, & Ruturi, 2019; Ghorbani & Khanachah, 2020).

One of the significant challenges that XYZ faces in achieving a high OEE number is the duration of equipment start-ups and its impact afterward. Since June and July, Line 14 performance has been on a declining trend and below 80%. Most of the Process Reliability (PR) loss is driven by planned and unplanned downtimes.

It is necessary to improve process reliability (PR) by reducing downtime due to ineffective start-up activities. This is critical for achieving PR and OEE targets. The impact of ineffective start-up and shutdown and lower OEE is as follows (Lestari, Artisa, Nurliawati, & Maulana, 2025; Rizky, Suparto, & Florina, 2025).

1. Capacity utilization
   The increment of OEE will impact the overall capacity and output of the production line. An increment of 1% of OEE in Line 14 that runs with a targeted speed of 450 packs per minute is equal to 6,480 packs per day.
2. Energy consumption
   Line 14 operates with energy supplies such as electricity, vacuum, and compressed air. Improving the OEE means that the production time required to produce the same amount of product will be shorter; hence, it will require lower energy consumption, which affects lower energy costs and carbon emission generation.
3. Labor Productivity
   There are two operators and two technicians per shift that run the production line of Line 14. As explained above, if the OEE increases, the time for producing the same amount of product decreases, and the team can be utilized for other activities.
4. Customer Service Level
   The correlation between the customer service level and OEE is quite strong. A higher OEE can shorten the delivery time to deliver the same amount of product and improve the customer service level to the market.

Based on these explanations, the problem of ineffective start-up duration that impacts OEE loss needs to be solved. Therefore, this research focuses on finding solutions to improve the startup duration and demonstrate the benefits after the OEE is improved.

2. Literature review

This research and project will be based on several theories that are believed to be the tools and references to solve the issue and guide this project.

2.1 Six Sigma Methodology

Six Sigma is a methodical and structured problem-solving strategy to improve overall processes, products, or services using statistical and scientific methods (De Mast & Lokkerbol, 2012). Its objective is to enhance overall performance by identifying and eliminating the root causes of errors and defects within business processes (Adil, Sapar, Marhani, & Rosa, 2024; Latunusa, Timuneno, & Fanggidae, 2023; Munro, Ramu, & Zrymiak, 2015).

Six Sigma is recognized as being correlated with the overall concept of continuous improvement by minimizing mistakes and optimizing values (Jadhav, Jadhav, & Bhagat, 2015). Continuous improvement is characterized by the application of problem-solving techniques and swift deployment to enact enhancements, accompanied by the utilization of process behavioral studies to sustain these improvements. The utilization of Six Sigma focuses on customer requirements, defect prevention, cycle time reduction, and cost-saving. Thus, the benefits of Six Sigma go straight to the bottom line. Many organizations initiate the implementation of Six Sigma by adopting the Define, Measure, Analyze, Improve, Control (DMAIC) methodology. Subsequently, they incorporate the DFSS (Design for Six Sigma() (DFSSalso referred to as DMADV) methodologies when the organizational cultural level is conducive to such integration (Beemaraj & Prasath, 2018; Nuzulianto & Sukalumba, 2025; Otariyani, Nofrima, & Febriyanti, 2025; Rizky et al., 2025).

An overview of the DMAIC methodology is as follows:

a. Define Phase
   The Define phase focuses on a high-level overview of the problem to understand customer requirements and pain points. This phase is critical for understanding the outline of the organization. Several tools and methods that can be utilized in this phase are Project Charter, 5W1H, Voice of Customer, and SIPOC model.

b. Measure Phase
   The second step is to quantify the current condition of the process. In this phase, it is important to gather relevant data and metrics to create a baseline performance level. Example activities in the measure phase are as follows.

- Process analysis and documentation, such as process maps, flowcharts, and relationship diagrams.
- Probability and statistics; for example, basic probability concept, central limit theorem.
- Statistical distribution: for example, Binomial, Poisson distributions.
- Collecting and summarizing data; for example, sampling and data collection methods, graphical methods.
- Measurement system analysis
- Process and performance capability: for example, process capability study.

c. Analyze Phase
   After data are collected in the measure phase, the data need to be reviewed and verified to understand the root cause of the problem in this phase. There are several activities or method in six sigma that can be used in this phase such as

- Exploratory Data analysis; e. a. multi-vari studies, correlation, and linear regression.
- Hypothesis testing; for exampl, basic hypothesis test (one-tail test, null and alternative hypothesis), test for means variance and proportion, paired comparison test, ANOVA, chi-square.

d. Improvement Phase
   After identifying the root cause of the problem in the Analyze phase, the next step is to collect improvement ideas in this phase to solve the issue. It also involves achieving the project or organization goals that have been set at the beginning. In this phase, we can elaborate on several ways to conduct the improvement.

- Developing a Design of Experiment (DOE) before conducting an experiment for improvement or a project.
- Conducting Root cause analysis tools using root cause analysis methodology, such as Fishbone Diagram, 5-whys, root cause tree, etc.
- Utilize lean tools that focus on loss elimination such as, Total productive Maintenance (TPM), kanban system, Kaizen, Workflow analysis, Process Design and etc.

e. Control Phase
   The last phase, the control phase, is similar to process management, which focuses on documenting the entire standard output of the project to ensure that the entire result is sustained.

2.2 Lean Management System

The Lean Management System is a continuous improvement concept to achieve long-term organizational goals (Mulla, Bhatwadekar, and Pandit 2014) by focusing on eliminating waste that does not add value to the customer and providing maximum value to the customer. The lean approach is based on the Toyota Production System (TPS), whose philosophy can be implemented in the industry. It focuses on waste elimination, inventory reduction, improved throughput, and reduced process cycle time while enhancing process flexibility and product quality (Daniyan, Adeodu, Mpofu, Maladzhi, & Katumba, 2022; Komakech, Obici, & Mwesigwa, 2021; Seran, Kase, & Nursalam, 2022). Several tools are used in lean management. Here are some examples.

2.2.1 Total Productive Maintenance

Total productive maintenance (TPM) improves the maintenance activities and implementation for equipment, machinery, and infrastructure, and is able to predict and prevent anticipated failure (Munro et al., 2015). The purposes of these activities are as follows:

1. Prevent any reduced, idled, or stopped performance due to equipment breakdowns.
2. Minimize or reduce setup time and changeover of equipment, which can idle machine operations and create bottlenecks in the production process.
3. Avoiding stoppages arising from the processing or discovery of unacceptable products or services;
4. Ensure that the processes and equipment operate at the design speed.
5. Increase the yield of acceptable materials to reduce material waste, scrap, rework, and the need for material reviews.

TPM is a part of the lean maintenance strategy for maximizing equipment reliability. The key matrix of TPM is OEE, which is the abbreviation of Overall Equipment Effectiveness). OEE can be maximized by reducing machine breakdown, improve throughput and quality, reduce inventory, reduce lead time and lowering operational cost Munro et al. (2015), OEE can be measure with following formula

$$OEE = Availability \times Performance\ efficiency \times Quality\ rate$$

Availability is defined in several references as uptime or machine utilization. Availability or uptime is used to track unplanned downtime losses in machines. The availability rate is equal to the actual runtime divided by the net operating time. The performance efficiency indicates whether the equipment is operating at full capacity. Performance efficiency can be calculated by dividing the actual output by the target output.

2.2.2 Single-minute exchange of die (SMED)

Single-minute exchange of die (SMED) is a system that reduces the time required to complete a setup. (Munro et al., 2015). The purpose of SMED is to convert as many working steps as possible into "external" and simplify or streamline the remaining steps. The single minute in SMED does not mean that all the set-up times should take only one minute, but that they should take less than 10 minutes or single-digit minutes (Seran et al., 2022). This means that external activities in the setup can be performed when the machine is still running. There are three main activities in SMED.

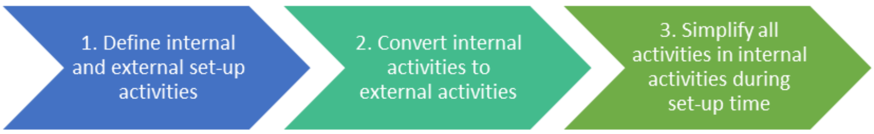


Figure 4. SMED Framework

The benefits of the SMED program are as follows:

1. A faster setup time means less equipment downtime. This will contribute to lower production costs.
2. Faster setups enable more frequent product changes. This will increase production planning agility and the ability to produce small batch sizes.
3. Improving production planning agility will be beneficial for faster response to customer demand and increased flexibility.
4. Smaller lot sizes can impact lower inventory levels.
5. Standardized setup activities can significantly increase process consistency and quality.

Eliminate, Combine, Rearrange, Simplify (ECRS)

ECRS is a motion study technique and methodology for improving production activities. The principles of ECRS are as follows:

1. Unnecessary items and activities are eliminated.

2. Combining several activities or operations.
3. Rearrange sequence of activities
4. Simplify the necessary activities

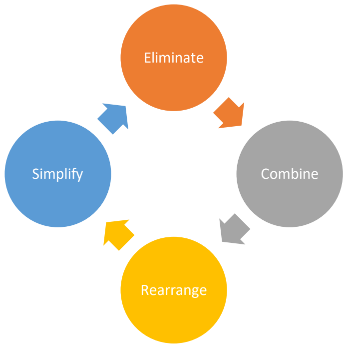


Figure 5. ECRS Method

Several practitioners combine the utilization of the ECRS technique with the SMED method to reduce idle time during production Bârsan and Codrea (2019), while others use it to improve labor efficiency, which impacts the reduction of labor costs (Kasemset, Pinmanee, & Umarin, 2014). ECRS is a basic effective tool that can be utilized for improving manufacturing efficiency. Thus, ECRS was applied for bottleneck improvement in this study (Kasemset et al., 2014).

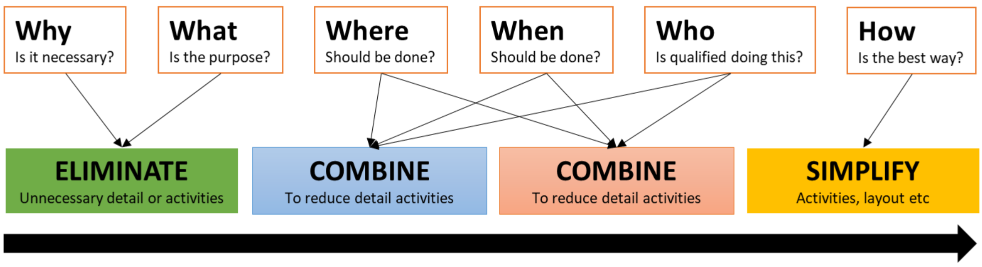


Figure 6. Step conducting ECRS

2.3 Lean Six Sigma

Lean six sigma is a business improvement methodology that combines two management philosophies: Lean Management and Six sigma Tenera and Pinto (2014), to improve the entire result. While Six Sigma focuses on finding errors and defects, lean management focuses on waste reduction during the manufacturing process and creates standardization (Kubiak & Benbow, 2016). This approach usually gives zero tolerance for waste generation (da Silva, Godinho Filho, Agostinho, & Junior, 2019; Daniyan et al., 2022; Odeyinka, Ipinnimo, & Ogunwolu, 2024; Schweikhart & Dembe, 2009; Zulfiqar, 2021).

3. Research methodology

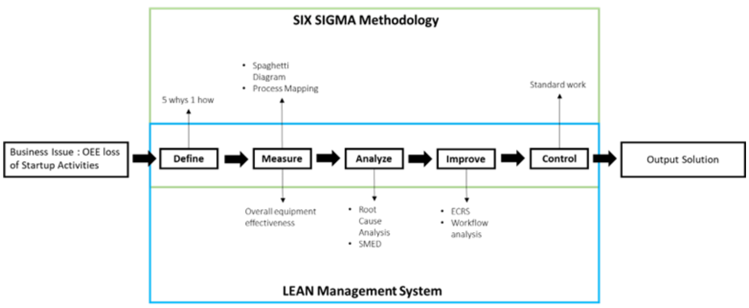


Figure 7. Research Methodology and Conceptual Framework

This research mainly utilizes the DMAIC methodology from Six Sigma, combined with several lean tools from the lean management system. This study was triggered by OEE loss during start-up activities that impacted performance below the target. Then, we continued with several improvement steps that refer to the DMAIC methodology from Six Sigma. The first step is to understand the issue, which requires asking several questions and elaborating on the problem using the 5W1H method. It is required to detail the problem through a comprehensive problem statement frow this method. This activity is in the Define phase of the Six Sigma methodology.

The second step is to conduct the measure phase to capture the magnitude of losses by calculating the losses during current activities; the number will be the baseline before improvement, which becomes the initial milestone. On the other hand, it is required to understand the current situation by creating a process map of the activities and calculating the current number of movements using a spaghetti diagram. The third step is to analyze the data gathered in the previous step and examine it using root cause analysis to identify the main problem. Meanwhile in term of activities and movement it can be analyse the entire movement during activities using SMED methodologies and also focus on value added and non-value added activities (Daneshjo, Rudy, Malega, & Krnáčová, 2021; Gomaa, 2024; Karam, Liviu, Cristina, & Radu, 2018).

After all the data and activities are mapped, workflow analysis can be conducted to determine the improvement proposal based on the data. In addition, the ECRS method can be utilized to maximize the improvement solution by eliminating, combining, rearranging, and simplifying activities. To deliver a sustainable result, create a new work procedure or standard from the proposed solutions. Cascade it to the team and monitor the results using the PDCA cycle.

4. Results and discussion

The details of the project journey and explanation will follow the DMAIC framework from lean six sigma as the core of the problem-solving process of the OEE loss issue due to start-up activities. DMAIC works as a closed-loop system, eliminating unnecessary activity, emphasizing new measurements, and leveraging technology Azizi (2015) with the following phases:

4.1 Define Phase

Due to the change in the working pattern from 4G (4 groups) to 3G (3 groups), Line 14 needs to conduct start-up and shutdown activities almost every week. With four groups of workers, the machine will run 24/7 continuously, whereas with three groups, the production line will run Monday to Friday full day and Saturday half day. Hence, it will require a shutdown and start-up activity at the end of every week and the beginning of the next week. It affects the overall equipment effectiveness (OEE), which reduces its capacity and triggers other losses, such as labor productivity and energy consumption. Here are the details of the actual startup duration in line 14 from July to September 2023.

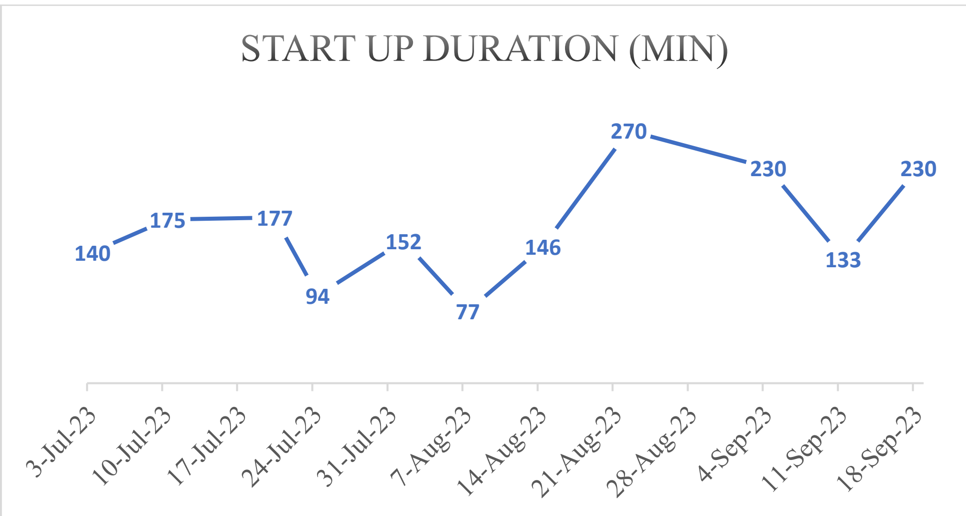


Figure 8. Start up duration

The data show that the overall losses per day during start-up activities are unstable and have high fluctuations, with the fastest start-up conducted on August 7th, 2023, in 77 minutes, and the longest start-up conducted two weeks later in 270 minutes on August 21st, 2023. The overall average startup duration was 165.8 min. Referring to the fastest start-up ever conducted, there are many losses during start-up activities. These losses need to be defined, and using 5W1H, here are the details of the problem from the perspective of What, When, Where, Who, Why, and How (Knop & Mielczarek, 2018). The problem is defined as follows.

1. Issue : Loss of capacity utilization
2. What : High OEE loss after changing production pattern from 4 group to 3 group
3. Who : All members of production team in Line 14
4. When : During start up activities in every beginning of production week
5. Where : Line 14 secondary processing machinery that produces super slim product
6. Why : Mainly due to higher start up duration and frequency
7. How : Long and inconsistent start up duration, due to the lack of standards and ineffective implementation of start-up strategy

Compiling all the information from 5W1H above it can be summarize that problem definition of the issue of capacity utilization loss is *"High OEE loss in Line 14 secondary processing after changing production pattern from 4G to 3G due to more frequent, longer and inconsistent start up duration, mainly caused by lack of standards and ineffective implementation of start-up strategy."*

4.2 Measure Phase

After determining the problem definition in the Define phase, the next step is to measure the magnitude of the issue and collect data that mainly contribute to the problem. Before that, it is important to understand the current sigma level of the process and whether the current process is capable of meeting customer expectations. To analyze the overall start-up performance, we need to calculate the sigma level of the current process. Here is the graphic of historical start-up performance compared to the target.

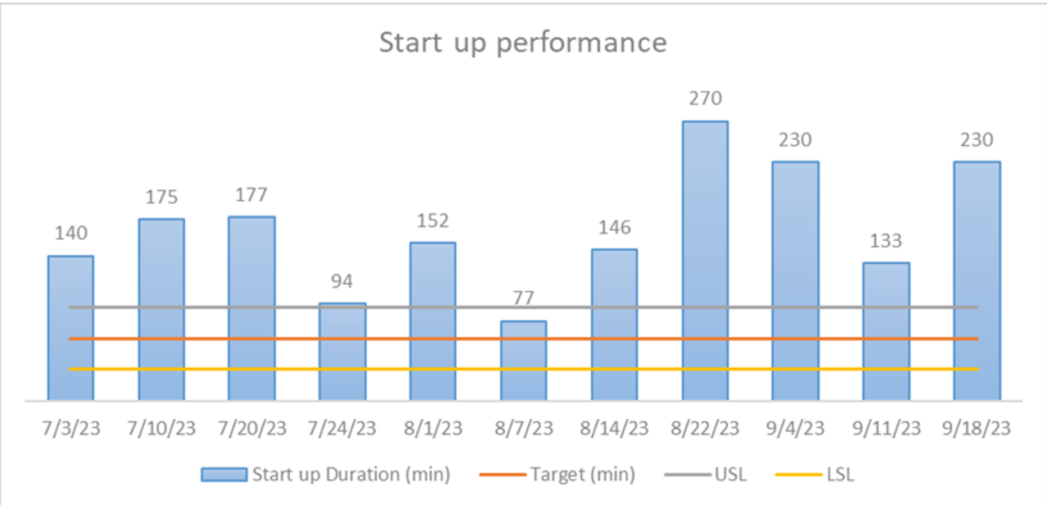


Figure 9. Start up performance

The expected target of the startup duration defined by management is 60 min, with upper and lower limits of ± 30 min, or upper specification limit (USL) of 90 min and lower specification limit (LSL) of 30 min. The following table summarizes the startup performance of line 14 from July 2023 to September 2023, including the target, upper specification limit (USL), lower specification limit (LSL), mean ($\bar{x}$), and standard deviation (σ). The formula to calculate the mean ($\bar{x}$) is Lee, In, and Lee (2015):

$$(\bar{x}) = \frac{Total\ start\ up\ duration}{no.of\ event} = \frac{1824}{11} = \mathbf{165.82\ minute} \quad ; \quad \sigma = \sqrt{\frac{\sum|x-\bar{x}|^2}{N}} = \mathbf{56.14} \qquad (1)$$

Table 1. Start up performance data

Date	Startup duration (min)	Target (min)	USL (min)	LSL (min)
3-Jul-23	140	60	90	30
10-Jul-23	175	60	90	30
20-Jul-23	177	60	90	30
24-Jul-23	94	60	90	30
1-Aug-23	152	60	90	30
7-Aug-23	77	60	90	30
14-Aug-23	146	60	90	30
22-Aug-23	270	60	90	30
4-Sep-23	230	60	90	30
11-Sep-23	133	60	90	30
18-Sep-23	230	60	90	30
Total	**1824**			
Mean	**165.82**			
SD	**56.14**			

The next step is calculating process capability (Cp) from the data with following formula,

$$Cp = \frac{(USL-LSL)}{6\sigma} = \frac{(90-30)}{6\times 56.14} = \mathbf{0.178} \tag{2}$$

While the process capability index (Cpk) is (Kotz & Johnson, 2017),

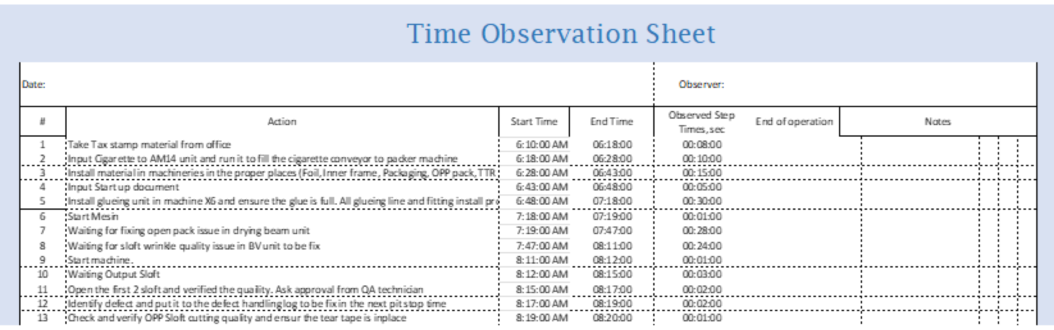
$$Cpk = \min(CpU, CpL) = \min\left(\frac{USL-\bar{x}}{3\sigma}, \frac{\bar{x}-LSL}{3\sigma}\right)$$

$$Cpk = \min\left(\frac{90-165.82}{3\times 56.14}, \frac{165.82-30}{3\times 56.14}\right) = \mathbf{-0.45} \tag{3}$$

Based on the calculation above, both Cp and Cpk from the startup process in Line 14 are below 1, indicating that the process is not capable of conducting the task and fulfilling customer expectations, as most of the data are outside the specification limit. While the sigma level of this process is as follow,

$$sigma\ level = \left|\frac{(USL-\bar{x})}{\sigma}\right| = \left|\frac{(90-165.82)}{56.14}\right| = \mathbf{1.35} \tag{4}$$

The sigma level was 1.35, which means that only **45%** of the process output met customer requirements. This was categorized as a poor performance. Hence, it is important to improve the startup performance. To understand the exact activity during startup, direct observation is required, and the entire detailed activity of all the production teams during startup must be documented. The secondary production line is divided into a manufacturing line and a packing line. The activity of the startup is divided by the activity in the cigarette-making and packing lines. The total production team conducting the activity is 5 people.


Time Observation Sheet

Date: Observer:

#	Action	Start Time	End Time	Observed Step Times, sec	End of operation	Notes
1	Take Tax stamp material from office	6:10:00 AM	06:18:00	00:08:00		
2	Input Cigarette to AM14 unit and run it to fill the cigarette conveyor to packer machine	6:18:00 AM	06:28:00	00:10:00		
3	Install material in machineries in the proper places (Foil, Inner frame, Packaging, OPP pack, TTR	6:28:00 AM	06:43:00	00:15:00		
4	Input Start up document	6:43:00 AM	06:48:00	00:05:00		
5	Install glueing unit in machine X6 and ensure the glue is full. All glueing line and fitting install pr	6:48:00 AM	07:18:00	00:30:00		
6	Start Mesin	7:18:00 AM	07:19:00	00:01:00		
7	Waiting for fixing open pack issue in drying beam unit	7:19:00 AM	07:47:00	00:28:00		
8	Waiting for sloft wrinkle quality issue in BV unit to be fix	7:47:00 AM	08:11:00	00:24:00		
9	Start machine.	8:11:00 AM	08:12:00	00:01:00		
10	Waiting Output Sloft	8:12:00 AM	08:15:00	00:03:00		
11	Open the first 2 sloft and verified the quality. Ask approval from QA technician	8:15:00 AM	08:17:00	00:02:00		
12	Identify defect and put it to the defect handling log to be fix in the next pitstop time	8:17:00 AM	08:19:00	00:02:00		
13	Check and verify OPP Sloft cutting quality and ensur the tear tape is inplace	8:19:00 AM	08:20:00	00:01:00		

Figure 9. Time observation sheet worker 1

Based on the Time observation sheet, there are several waiting and idle activities. This occurs due to several issues that prolong the startup activity. If we summarize the activity in the process flow map, the ideal flow is as follows:

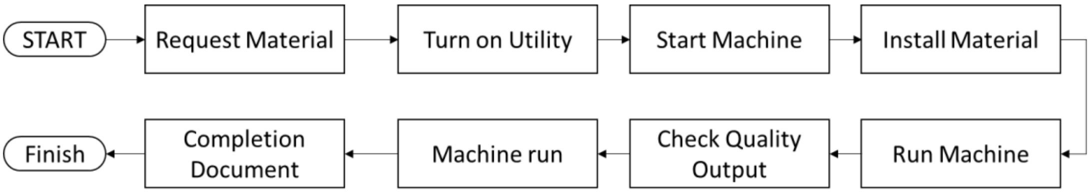


Figure 10. Ideal flow process

However, the actual activity in the startup during observation is different, and there are several additional activities that are conducted and make the duration longer, such as looking for tools, finding and fixing defects in machines, and improper quality products that need adjustment and fine-tuning. Here is a summary of the actual start-up activity.

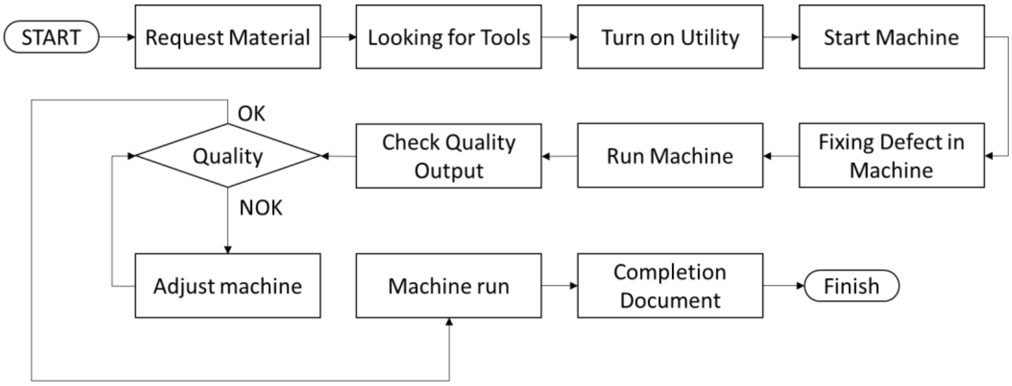


Figure 11. Current flow process

Here is a summary of the total duration of the start-up activity by each personnel.

Table 2. Start up duration each personnel

Position	PO Packer	PT Packer	PO Maker	PT Maker	Electrician
Duration (min)	136	106	96	89	131

4.2 Analyze Phase

Based on the data in the measure time, it can be analyzed further by categorizing every activity captured in the Time Observation Sheet (TOS). It can be summarized that there are many waiting activities for each personnel during the startup activities.

4.2.1 Pareto Analysis

Here is a summary of the overall activities of worker 1 during the execution of the start-up task.

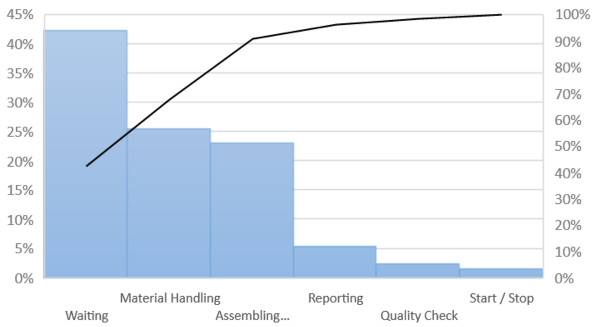


Figure 12. Pareto chart worker 1

After conducting a similar analysis for the entire 5 worker, the summary of the total waiting time for each personnel is presented.

Table 3. Waiting duration during start up

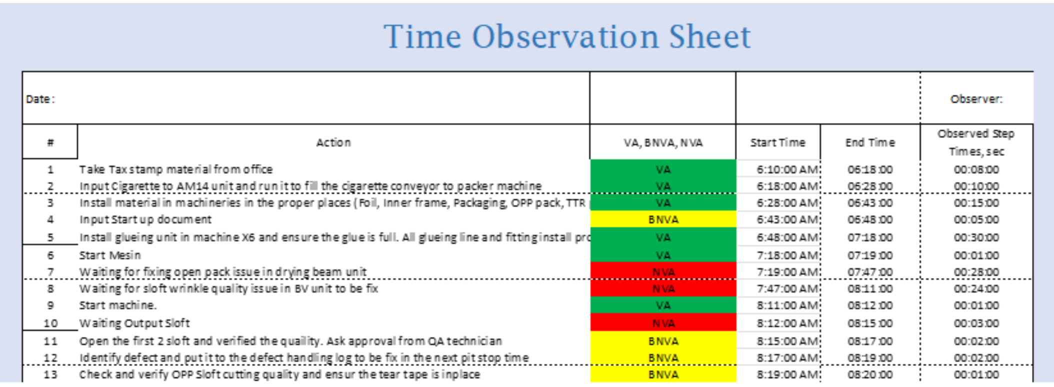
Personel	Duration of Waiting	% of waiting time
Worker 1	43 minute	48.3 %
Worker 2	34 minute	43.8 %
Worker 3	55 minute	42.3 %
Worker 4	32 minute	26.9 %
Worker 5	31 minute	24.6%
Average	39 minute	

According to the Pareto analysis, it can be concluded that the startup activity has a lot of waste of time due to waiting. This is the main reason why the startup activity takes a long time, impacting the OEE.

4.2.2 Value added analysis

After it was analyzed using the Pareto analysis, it was concluded that most of the time spent during the startup activity was waiting. All activities must add value to the main objective of the startup. Hence, a value-added analysis is required.

During the observation, every activity is categorized as value-added (VA), non-value-added (NVA), or business non-value-added (BNVA). Value added increases the overall product value and contributes to overall delivery and quality (Eakin and Gladstone, 2020), while non-value added does not. Business non-value added is nonvalue added activities that are still required by the business. Here are the results of the brainstorming activity that classified the step-by-step start-up activity into VA, NVA, or BNVA.



Time Observation Sheet

Date : | Observer:

#	Action	VA, BNVA, NVA	Start Time	End Time	Observed Step Times, sec
1	Take Tax stamp material from office	VA	6:10:00 AM	06:18:00	00:08:00
2	Input Cigarette to AM14 unit and run it to fill the cigarette conveyor to packer machine	VA	6:18:00 AM	06:28:00	00:10:00
3	Install material in machineries in the proper places (Foil, Inner frame, Packaging, OPP pack, TTR	VA	6:28:00 AM	06:43:00	00:15:00
4	Input Start up document	BNVA	6:43:00 AM	06:48:00	00:05:00
5	Install glueing unit in machine X6 and ensure the glue is full. All glueing line and fitting install pr	VA	6:48:00 AM	07:18:00	00:30:00
6	Start Mesin	VA	7:18:00 AM	07:19:00	00:01:00
7	Waiting for fixing open pack issue in drying beam unit	NVA	7:19:00 AM	07:47:00	00:28:00
8	Waiting for sloft wrinkle quality issue in BV unit to be fix	NVA	7:47:00 AM	08:11:00	00:24:00
9	Start machine.	VA	8:11:00 AM	08:12:00	00:01:00
10	Waiting Output Sloft	NVA	8:12:00 AM	08:15:00	00:03:00
11	Open the first 2 sloft and verified the quality. Ask approval from QA technician	BNVA	8:15:00 AM	08:17:00	00:02:00
12	Identify defect and put it to the defect handling log to be fix in the next pit stop time	BNVA	8:17:00 AM	08:19:00	00:02:00
13	Check and verify OPP Sloft cutting quality and ensur the tear tape is inplace	BNVA	8:19:00 AM	08:20:00	00:01:00

Figure 12. value added analysis worker 1

After conducting a similar assessment for the other four workers, table is the summary of above classification.

Table 4. Summary of value-added activities.

Position	# Activity	# VA	# NVA	# BNVA
Worker 1	13	6	3	4
Worker 2	19	10	5	4
Worker 3	35	12	10	13
Worker 4	21	7	12	2
Worker 5	25	14	5	6
TOTAL	**113**	**49**	**35**	**29**

Based on the data above, 43.3% of the total activity is categorized as value-added activity, 31% is non-value-added activity, and 25.7% is business non-value-added activity.

4.3 Improve phase

To reduce the overall start-up duration and improve the OEE from line 14, it is important to eliminate these issues. In this phase, Lean Six Sigma tools will be utilized to reduce the ad hoc issue by finding the root cause and defining the countermeasure using a fishbone diagram and 5 whys analysis. Meanwhile, the ineffective start-up activity will be improved by using lean six sigma tools, such as SMED and ECRS.

4.3.1 Eliminating ad hoc issue

During the startup process, the sloft is wrinkled and does not meet the quality requirement of the product; hence, the QA department demands that the issue be solved before continuing the process. The root cause analysis of this issue is as follows.

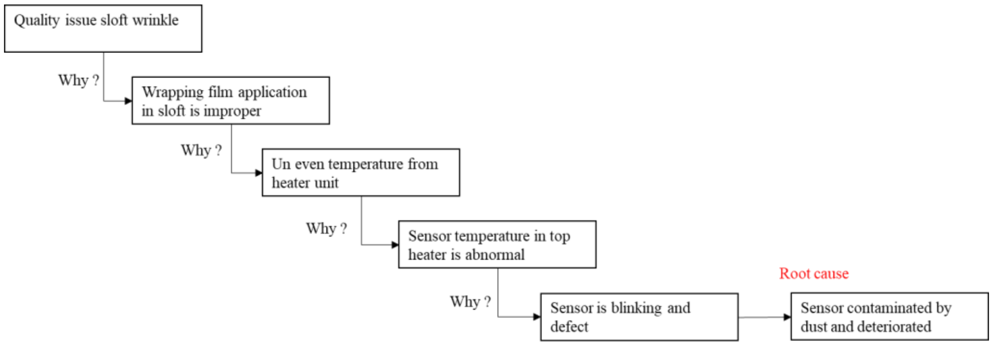


Figure 13. why-why analysis solving ad hoc issue

Based on the 5-why analysis, the main issue of the sloft wrinkle is due to the defect on the sensor in the top heater area. To ensure that a similar issue does not occur again in the future, the following countermeasures were developed:

1. The sensor was replaced with a new one.
2. Cleaning and inspection tasks for the sensor to remove dust and contamination should be performed once a month.

The other finding is the open pack issue. An open pack issue is a quality and runnability issue in the packing machine that occurs when the packaging is not completely sealed by glue and is opened again. This condition prevents the pack from being transferred to the next step and jammed, causing the machine to stop running. Based on the direct observation on floor, the root cause of open pack issue is as follows

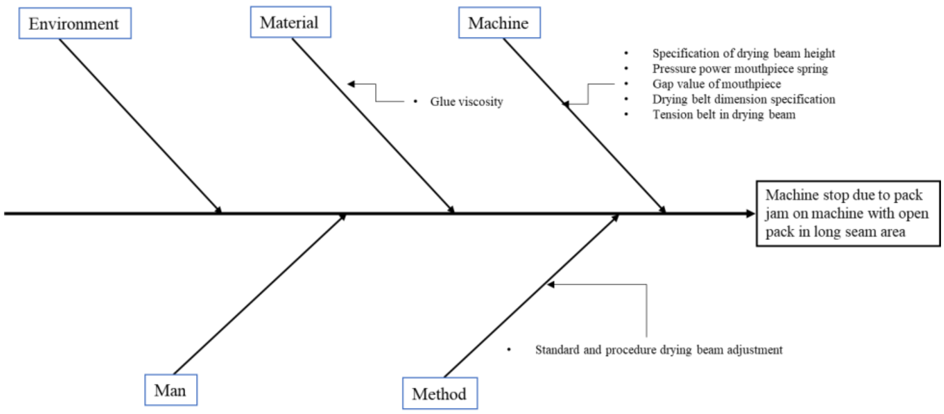


Figure 14. Fishbone diagram analyzing ad hoc issue

Based on the fishbone diagram above, it can be concluded that the main issue of open pack is

1. Machine
   a) There was no set point for adjusting the drying beam height. During the observation, it was found that the drying beam height had a certain gap that made the drying process of the package suboptimal.

b) The use of a spring plate is to be flexible following the pack dimensions to maintain the pack position firmly and stick properly. In this case, the team found that the spring plate was inflexible and stiff.
c) The mouthpiece width should be fitted with the pack dimensions and cannot be too loose or too tight. During the observation, the mouthpiece was too loose.
d) The belt in the drying beam becomes the transport medium from the pack during the drying process; thus, the specification, dimension, and tension of the belt become important to ensure that the transfer process is proper. During the observation, it was found that the transfer process was improper, which impacted the drying process and made it less optimal.

2. Material
   a) Open packs can occur when the glue does not work properly. During observation, the glue viscosity became uneven owing to a long shutdown.
3. Method
   a) Procedure fine-tuning and adjustment between teams are not standardized; hence, team perceptions sometimes differ.

Based on the discussion and fine-tuning adjustments on floor here it is the countermeasure and standard
1. Create an adjustment point for the drying beam height.
2. Fixing defect by replacing spring plate and create standard maintenance for spring plate replacement per 20 week
3. Set the standard gap mouthpiece drying beam to 0.1 mm from the packaging.
4. The belt is worn out and elongated. The standard of belt replacement was set to 24 weeks, and the tension standard for the belt was set to 35 Hz.
5. Kaizen by adding stirer active in glue tank to ensure uniformity of glue before applied to product.
6. Create technical instruction standards for standardizing the way of working in teams to adjust the machine.

4.3.2 Improving start up duration
Several Lean Six Sigma tools can be utilized to improve the startup duration. In this project, it is focused on the utilization of SMED (Single minute exchange to die) and ECRS (eliminate, combine, re arrange and substitute). The focus of SMED is to analyze whether the task can be performed internally or externally (Karam et al., 2018), and the focus of ECRS is to simplify and optimize the overall task. The process of eliminating activities using ECRS (eliminate, combine, rearrange, and substitute) is referred to as the lean method, as mentioned by Suhardi, Anisa, and Laksono (2019) and Kasemset et al. (2014).

Table 5. Question for conducting ECRS

Eliminate	Combine and Re-arrange	Simplify
Why is this task necessary? What is the purpose of this task?	Where should be done? When should be done? Who is the best and qualified doing this?	How is the best way doing this?

Using FGD and brainstorming with the team, here is the summary of the activities of each personnel that can be Keep (K), Eliminate (E), Combine (C), Rearrange (R) or simplify (S) or the task can be taken externally or keep internally.

Table 6. ECRS and SMED summary for worker 1 task

Activity	VA	Time Before (sec)	I/E	Why	What	Where	When	Who	How	Improvement	K	E	C	R	S	Time After (sec)
Take Tax stamp material from office	VA	480	I						v	Improve procedure tax stamp transaction	v				v	120
Input Cigarette to AM14 unit and run it to fill the cigarette conveyor to packer machine	VA	600	I						v	Helped by General Worker to feed the cigarette to AM14	v				v	300
Install material in machineries in the proper places (Foil, Inner frame, Packaging, OPP pack, TTR pack, OPP slof, TTR slof, Tax stamp and sticker)	VA	900	I					v		Split the task, threading material BV, CWL & C800 by PT, PO focus on X6 Material				v		420
Input Start up document	BNVA	300	I								v					300
Install glueing unit in machine X6 and ensure the glue is full. All glueing line and fitting install properly and tight, Make sure the glue disk locking bolt is tight	VA	1800	I					v		Split the task with PT	v					900
Start Mesin	VA	60	I								v					60
Waiting for fixing open pack issue in drying beam unit	NVA	1680								Eliminate issue open pack		v				0
Waiting for sloft wrinkle quality issue in BV unit to be fix	NVA	1440								Eliminate issue sloft wrinkle		v				0
Start machine.	VA	60								No need double start machine		v				0

After conducting the ECRS method for all workers in the actual start-up task, the summary of the start-up task is as follows.

Table 7. Summary before after improvement

Position	Before		After	
	# of step	Duration (Sec)	# of step	Duration (sec)
Worker 1	14	7800	10	2580
Worker 2	35	7140	9	2200
Worker 3	19	5340	17	1715
Worker 4	21	4740	14	1319
Worker 5	25	7560	20	1440

Based on Worker 1, who had the longest duration and became the bottleneck, the previous start-up duration of approximately 130 min was reduced to 43 min.

***4.4 Control phase*.**

After all the improvement solutions are developed during the improvement phase, the next step is the control phase, where the purpose is to ensure that the new standard solution is applied and implemented. There are three steps in the control phase.

1. Developing standards based on improvement. Determine the new flow process, RACI, and procedure start-up that has already been optimized.
2. Cascade to the team to align understanding between team members to ensure that the entire team understands and follows the new standard that has been developed.
3. An implementation plan was created, and several implementations of the new standard were reviewed to understand the level of implementation between the standard and actual implementation on the floor.

4. Conclusion

Based on the study conducted above regarding OEE improvement through reducing start-up duration using the Lean Six Sigma methodology, the following conclusions and recommendations are obtained.

5.1. Conclusion

According to the analysis, it can be concluded that the Overall Equipment Effectiveness (OEE) loss during start up is due to several issues.

1. Ad hoc issues: Several ad hoc issues occur during the start-up, such as the quality of soft film wrinkles.
2. Inefficient start up activity: It can be concluded that most of the time of startup activity is categorized as waiting and non-value-added activity. This could be due to inefficient activity by the team as well as an unbalanced task load between team members.

To overcome this issue, the proposed solution is.
1. To solve ad hoc issues, proper strategy maintenance for maintaining spare parts is required. An additional inspection task was developed to check the actual condition of the area.
2. The ECRS (eliminate, combine, rearrange, and simplify) and SMED (single-minute exchange to die) methods from lean management were used to identify a better strategy. The result is that several tasks are moved from internal to external, eliminating non-added value tasks, and leveraging the task between the team to balance the task load. The result shows that the startup duration can be reduced from 130 min to 43 min or 67%. The average task and number of activities were reduced from 23 per person to 14 per person, or a 39% reduction.

By solving these issues, the manufacturer will benefit from an improved start-up duration and a higher OEE. It will gain several other benefits that contribute to the overall company performance, such as:
1. *Capacity increase*: Overall, the improvement in startup duration was 67 %, equivalent to 39.150 pack cigarette per week or 1.9 million pack cigarettes of increased capacity. If it is calculated to the COGS around 25,200 IDR per pack, it is equal to 47,35 billion IDR, which is the potential additional revenue without adding any investment in production.
2. *Improve Labor productivity*: Labor productivity will be linearly improved when the OEE is improved. This will reduce the labor costs related to production activities in Line 14.
3. *Decrease Energy Consumption*: When the OEE is improved, it means that to produce the same amount of product, less energy will be consumed. Hence, the improvement of OEE will be aligned with the decline in energy consumption at a certain point.

Other Benefit: When the OEE is better, it means that the machine will be more efficient and reliable, hence it will improve the overall service level to the customer, and at some point, it will improve the confidence level of the supply chain team to reduce the DOI (Day of Inventory), thus reducing the inventory level in the warehouse and logistic system.

5.3. Suggestion
Although the improvement provides several benefits, there are several recommendations that can be implemented to leverage these benefits.
1. To ensure that the new standard is followed and implemented, management should conduct regular checks. Following the Plan, Do, Check, and Act (PDCA) cycle, management should review the implementation of new standards and continuously seek any improvement that can be made.
2. As the condition of tax increase applies to all brands, not only the super slim brand produced by line 14, but also other brands, the management should pay attention to the fact that the brand may be facing a similar condition with line 14. Hence, to avoid similar losses, the newly developed standard of the startup task from this research should be adopted and cascaded to other production lines.

5.3. Limitation
To maintain the focus of the research, the scope and limitations of this study are as follows:
1. This research area focuses on Production Line 14 of the Manufacturing Plant PT. XYZ
2. The research scope is limited to the issue of OEE improvement.
3. The method used in this research is based on the Six Sigma methodology.
4. The data range for the analysis was taken in 2023 only.
5. The actual results of the solution implementation are excluded from this study.

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