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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 research focuses on improve OEE by reducing start-up duration using Lean Six Sigma methodology. By applying Lean Six Sigma tools and techniques, manufacturers can systematically analyse the start-up process, identify root causes of delays, and implement targeted improvements.
Methodology/approach: The research presented in this journal comprises a comprehensive study conducted within a manufacturing setting to demonstrate the effectiveness of the proposed approach. The study involves the collection and analysis of data related to start-up durations, downtime reasons, and other relevant parameters. Through the DMAIC (Define, Measure, Analyse, Improve, Control) framework of Lean Six Sigma, the root causes of prolonged start-up durations are identified and addressed.
Results: The results demonstrate the potential for significant OEE improvements through the elimination of bottlenecks and inefficiencies in the start-up process. Manufacturers can leverage the findings of this research to develop strategies that enhance operational effectiveness, increase production output, and ultimately drive competitive advantage in the dynamic landscape of modern manufacturing.
Conclusions: Lean Six Sigma, through the DMAIC approach, effectively reduces start-up time and improves OEE. Addressing root causes leads to better equipment utilization and increased productivity.
Limitations: This research limitation is only for manufacturing or production area that having OEE as their main key performance indicator.
Contribution: This research will contribute to the manufacturing operation excellency.

Keywords: *DMAIC, Lean Manufacturing, Lean Six Sigma, OEE, Start-up improvement.*

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1. Introduction

Tobacco industry in Indonesia facing harder challenge year by year, especially for continuously tax and excise increase for all tobacco related product. It is slowly putting pressure on cigarette or tobacco companies. Figure below show the trend of cigarette excise in Indonesia and declining trend of tobacco processing industry GDP.

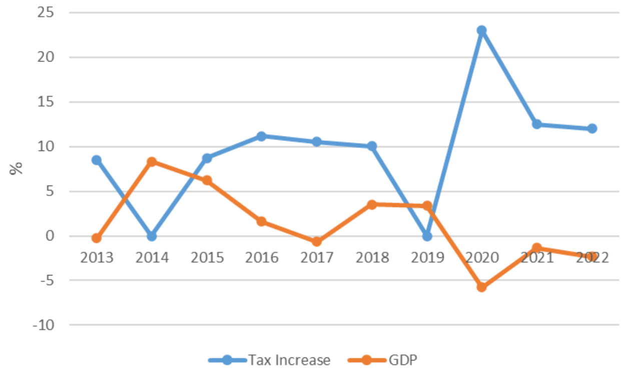


Figure 1. Chart Tax increase vs GDP tobacco industry

PT.XYZ as one of cigarette company in Indonesia, facing 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 production line having by XYZ in their Manufacturing Facilities. In the first quartal of 2023, Line 14 Capacity Utilization (CU) is below 80%, due to volume decrease. It makes XYZ management decide to optimize its capacity utilization to reduce its production cost.
Line 14 is run by 4G (4 Group) pattern that has production schedule 24 hours and 7 days per week. Due to lower production demand, the Production line is often off due to no production demand. To reduce the cost, since June 2023, XYZ decide changes the pattern to 3G (3 Group) and only running for weekdays and off on weekend. By changing the production pattern, XYZ can reduce the labor cost by reducing one group of production team and increase capacity utilization by 90%.

4G Calendar

Sep	W35			W36							W37				
Day	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shift I	B	B	B	B	B	C	C	C	C	C	D	D	D	D	D
Shift II	C	C	C	D	D	D	D	D	A	A	A	A	A	B	B
Shift III	D	A	A	A	A	A	B	B	B	B	B	C	C	C	C

Sep	W37		W38							W39					
Day	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Date	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Shift I	A	A	A	A	A	B	B	B	B	B	C	C		C	C
Shift II	B	B	B	C	C	C	C	C	D	D	D	D		A	A
Shift III	C	D	D	D	D	D	A	A	A	A	A	B		B	B

3G Calendar

Sep	W35			W36							W37				
Day	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shift I	B	B		C	C	C	C	C	C		A	A	A	A	A
Shift II	C	C		A	A	A	A	A	A		B	B	B	B	B
Shift III	A	A		B	B	B	B	B	B		C	C	C	C	C

Sep	W37		W38							W39					
Day	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Date	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Shift I	A		B	B	B	B	B	B		C	C	C		C	C
Shift II	B		C	C	C	C	C	C		A	A	A		A	A
Shift III	C		A	A	A	A	A	A		B	B	B		B	B

Figure 2. Working pattern calendar

Due to the changes of production pattern, there is one problem occurring, as the production line starts on weekdays and off at weekend, it is now requiring start up and shut down activities every week. This activity makes the machine efficiency of Line 14 decline. The machine efficiencies are reported as OEE.

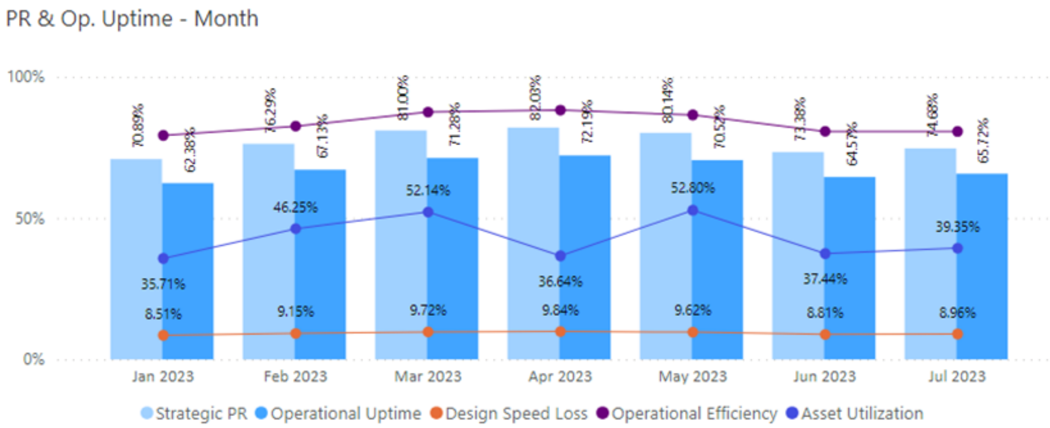


Figure 3. PR and Uptime (OEE) Line 14

OEE is a metric that measures production performance and indicator of process improvement activities in manufacturing production (Ahire & Relkar, 2012). It provides a comprehensive view of how efficiently manufacturing equipment and resources are being 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. Due to several challenges, it is important for manufacturer continuously increase their overall performance in order to minimize their production cost (Andersson & Bellgran, 2015). 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. It is shown since June and July, Line 14 performance is in declining trend and below 80%. Most of the Process Reliability (PR) loss is driven by Planned downtime and unplanned downtime.

It is required to improve process reliability (PR) by reducing downtime due to ineffective start up activities. This is critical to achieve the PR and OEE targets. The impact of ineffective start up shut down and lower OEE is as follows.

1. Capacity utilization
   The increment of OEE will impact the overall capacity and output form production line can deliver. Increment 1% of OEE in Line 14 that run with targeted speed 450 pack cigarette per minute is equal to 6,480 pack cigarette per day.
2. Energy consumption
   Line 14 runs with supplies of energy such as electricity, vacuum, and compressed air. Improving the OEE means the production time required for producing the same amount of product will be shorter, hence it will require lower energy consumption that affecting lower energy cost and carbon emission generation.
3. Labor Productivity
   There are 2 operators and 2 technicians per shift that run the production line of Line 14. Like the above explanation, if the OEE increased, the time for producing the same amount of product will decrease, then the team can be utilized to other activities.
4. Customer Service Level
   The correlation between customer service level and the OEE is quite tight. By having a higher OEE, it can be assumed that the delivery time to deliver the same amount of product will be shortened and improve the customer service level to the market.

Based on those explanations, the problem of ineffective start up duration that impacting OEE loss needs to be solved, as XYZ like other companies that having profit oriented need to improve their performance (Fernando & Surjandari, 2021). Therefore, this research will focus on finding solutions to improve startup duration and show the benefit after its OEE improved.

2. Literature review and hypothesis/es development

This research and project will be based on several theories that it is believed will be the tools and references to solve the issue and being the guidance of this project.

2.1 Six Sigma Methodology

Six Sigma is a methodical and structured problem solving strategy to improve overall process, product or services by using statistical and scientific method (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 (Roderick et al., 2020). Six Sigma is recognized as corelate with the overall concept of continuous improvement by minimize mistake and optimized value (Ganesh P. Jadhav et al., 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 the achieved improvements. The utilization of Six Sigma focuses on customer requirements, defect prevention, cycle time reduction, and cost savings. Thus, the benefits from Six Sigma go straight to the bottom line. Many organizations initiate the implementation of Six Sigma by adopting the DMAIC (Define, Measure, Analyze, Improve, Control) methodology. Subsequently, they incorporate the DFSS (Design for Six Sigma, also referred to as DMADV) methodologies when the organizational cultural level are conducive to such integration (Krishnan & Prasath, 2014).

The overview of DMAIC methodology is as follow:

a. Define Phase
   Define phase focuses on the high-level overview of the problem to understand what the customers requirement and pain point is. This phase is very critical to understand the outline of the organization to be focused on. Several tools and methods that can be utilized in this phase are Project Charter, 5W1H, Voice of Customer, SIPOC model etc.
b. Measure Phase
   Measurement is the second step to focus on quantifying the current condition of the process. In this phase it is important to gather relevant data and metrics to create baseline performance level. Example activities in measure phase is.
   - Process analysis and documentation; e.a process maps and flowchart, Relationship diagram.
   - Probability and statistics; e.a basic probability concept, Central limit theorem.
   - Statistical distribution; e.a Binomial, Poisson distribution.
   - Collecting and summarizing data; e.a sampling and data collecting method, graphical method.
   - Measurement system analysis
   - Process and performance capability; e.a process capability study.
c. Analyze Phase
   After data is collected in the measure phase, the data needs to be review and verified to really 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; e.a Basic hypothesis test (One-tail test, the null and alternative hypothesis), Test for means variance and proportion, Paired comparison test, ANOVA, chi square.
d. Improvement Phase
   After finding the root cause of the problem in Analyze phase, the next step is collecting improvement ideas in this phase to solve the issue. And achieving project or organization goal that has been set in the beginning. In this phase, we can elaborate several ways to conduct the improvement.
   - Developing Design of Experiment (DOE), before conducting the experiment of improvement or project.
   - Conducting Root cause analysis tools by using root cause analysis methodology such as, Fishbone Diagram, 5-whys, Root cause tree and 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, control phase, is similar with process management that focus on documented the entire standard output of the project to ensure the entire result is sustained.

2.2 Lean Management System

Lean Management System is a continuous improvement concept to achieve long term organization goal (Mulla et al., 2014) by focuses on eliminating waste that not given added value to customer and providing maximum value to the customer. Lean approach is according to Toyota Production System (TPS) whose philosophy can be implemented to industry. It focuses on waste elimination, inventory reduction, improve throughput and reducing process cycle time, while enhancing process flexibility and product quality (Daniyan et al., 2022). The purpose of lean strategy is to perform any operations that using less resource such as tools, time, money and people (Zahedi et al., 2020). There are several tools used in lean management. Here are several examples.

2.2.1 Total Productive Maintenance

TPM or Total productive maintenance improves the maintenance activities and implementation for equipment, machineries and infrastructure, and is able to predict and preventing of anticipated failure

(Roderick et al., 2020). The purpose of these activities is as follows.

- Prevent any reduced, idled, or stopped performance due to equipment breakdown.
- Minimize or reduce setup time and changeover of equipment, which can idle machine operations and create bottlenecks.
- Avoiding stoppages arising from the processing or discovery of unacceptable products or services.
- Ensure the processes and equipment are operate at the design speed.
- Increase the yield of acceptable material to reduce material waste, scrap, rework, and the need for material reviews.

TPM is part of 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 (Roderick et al., 2020), OEE can be measure with following formula

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

Availability is in several reference called uptime or machine utilization. Availability or uptime is used to track the unplanned downtime loss in machine. Availability rate is equal to actual run time divided by net operating time. Performance efficiency shows if the equipment is run at full capacity. Performance efficiency can be calculated by actual output divided by target output.

2.2.2 Single-minute exchange of die (SMED)

Single minute exchange of die or SMED is a system that reduces the time taken to complete a setup. (Roderick et al., 2020). The purpose of SMED is to convert as many working steps in "external" and simplify or streamlining the remaining steps. Single minute in SMED does not mean that all the set-up time should take only one minute, but that they should take less than 10 minutes or single digit minute (Ulutas, 2011). It means the external activities in the set up can be done when the machine is still running. There are 3 main activities on SMED.

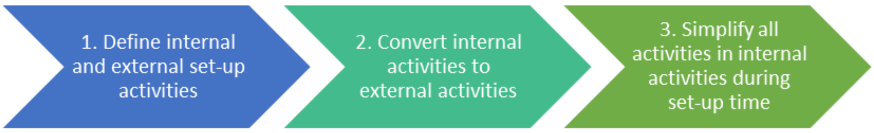


Figure 4. SMED Framework

The benefits of SMED program are as follows.

- Faster set-up time means less equipment downtime. It will contribute to lower production costs.
- Faster set-ups enable more frequent product changes. It will increase production planning agility and ability to produce in small batch sizes.
- Improving production planning agility will be beneficial to faster response to customer demand and increase flexibility.
- Smaller lot sizes can impact lower inventory level.
- Standardized set-up activities can significantly increase process consistency and quality.

Eliminate, Combine, Rearrange, Simplify (ECRS)

ECRS is one of motion study techniques and methodology to improve production activities. The principle of ECRS is as follows.

- Eliminate unnecessary item and activities.
- Combining several activities or operations.
- Rearrange sequence of activities
- Simplify the necessary activities

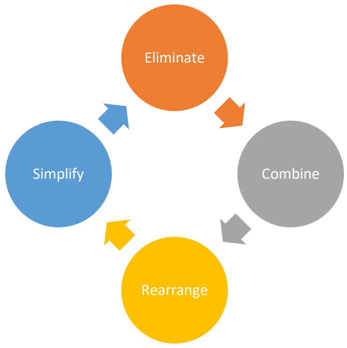


Figure 5. ECRS Method

Several practitioners combine the utilization of ECRS technique with SMED method to reduce idle time during production (Barsan & Codrea, 2019) while the other use it to labor efficiency that impacting the reduction of labor cost (Kasemset et al., 2014). ECRS was a basic effective tool that can be utilized in manufacturing efficiency improvement. Thus, ECRS was applied for the bottleneck improvement in this study (Kasemset et al., 2014).

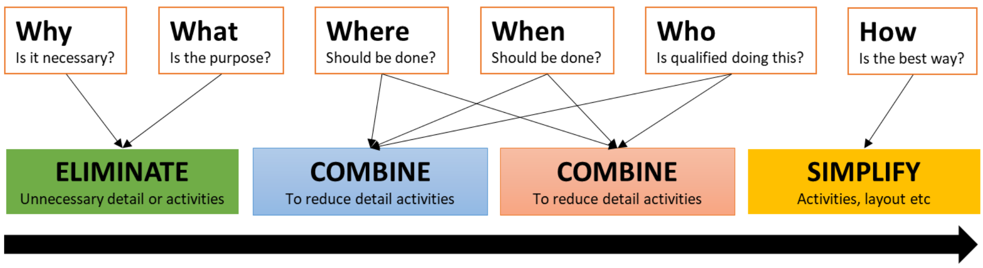


Figure 6. Step conducting ECRS

2.3 Lean Six Sigma

Lean six sigma is a business improvement methodology that combining two management philosophies: Lean Management and Six sigma (Tenera & Pinto, 2014), in order to improve the entire result. While six sigma focus in finding errors and defects , Lean management is focus on waste reduction during manufacturing process and create standardization (Kubiak & Benbow, 2009). This approach usually gives zero tolerance for waste generation (Daniyan et al., 2022).

3. Methodology

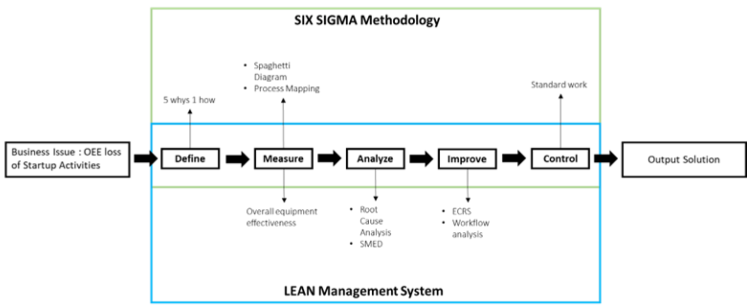


Figure 7. Research Methodology and Conceptual Framework

This research is mainly utilizing DMAIC methodology from six sigma, combined with several Lean tools from lean management system. The research is triggered by OEE loss during start-up activities that impact performance below the target. Then continue with several improvement step that refer to DMAIC methodology from six sigma. The first step is to understand the issue, we need to conduct several questions and elaborate the problem using 5W1H method. It is required to detail the problem through comprehensive problem statement frow this method. This activity is in the Define phase of six sigma methodology.

Second step conducting measure phase to capture the magnitude of loses by calculating the loses during current activities, the number will be the baseline before improvement that become the initial milestone. In other hand it is required to really understand the current situation by creating process map of the activities and calculate the current number of movements using spaghetti diagram. The third step is analysing the entire data gathered in the previous step and examine it using root cause analysis to find the main problem. On of the tools used to find the root cause is fishbone diagram. A fishbone diagram is a tool or methodology used to identify possible inputs for a given output, either variations or outcomes and known as cause-effect diagram (Ardha et al., 2023). 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 (Karam et al., 2018). After all the data and activities is mapped, it can be conducted workflow analysis to determine the improvement proposal based on the data. Beside that ECRS method can be utilized to maximize the improvement solution through eliminating, combining, rearrange and simplify activities. To deliver a sustain result, create a new work procedure or standard from proposed solutions. Cascade it to team and monitor the result using PDCA cycle.

4. Results and discussion

The details of project journey and explanation will be followed the DMAIC framework from lean six sigma as 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 following phase.

4.1 Define Phase

Due to changing of working pattern from 4G (4 Group) to 3G (3 Group), it makes Line 14 need to conduct start up and shutdown activities almost every week, because with 4 group of workers, the machine will run 24/7 continuously, while with 3 group the production line will run Monday to Friday full day and Saturday half day. Hence it will require a shut down and start up activity for every end of week and beginning of the next week. It is impacting the overall equipment effectiveness (OEE) that reduces its capacity and triggers other losses like labor productivity and energy consumption. Here are the details of actual startup duration in line 14 from July to September 2023.

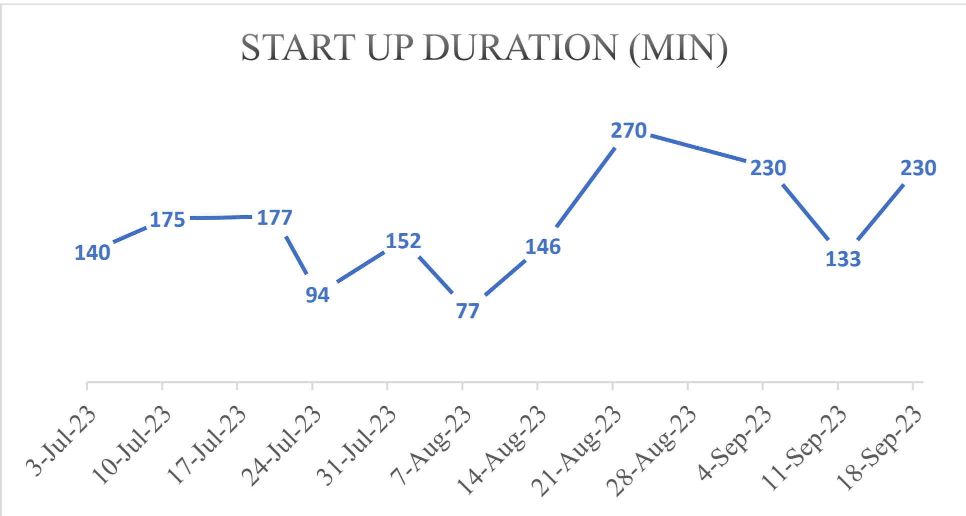


Figure 8. Start up duration

It can show that the data that the overall loses per day during start up activities are unstable and having high fluctuation with the fastest start up conducted on August 7th, 2023, with 77 minute and the longest start up conducted 2 week later with 270 minutes on August 21st, 2023. With overall average of startup duration is 165.8 minutes. Referring to the fastest start up ever conducted, it shows there are a lot of losses during start up activities. Those losses need to be defined, and using 5W1H, here is the detail of problem from perspective What, When, Where, Who, Why and How(Knop & Mielczarek, 2018). The problem definition is as follows.

- Issue : Loss of capacity utilization
- What : High OEE loss after changing production pattern from 4 group to 3 group
- Who : All members of production team in Line 14
- When : During start up activities in every beginning of production week
- Where : Line 14 secondary processing machinery that produces super slim product
- Why : Mainly due to higher start up duration and frequency
- 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."*

3.2 Measure Phase

After finding the problem definition in Define phase, the next step is measuring the magnitude of the issue and collecting data that mainly contributes 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 the customer expectations or not. 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.

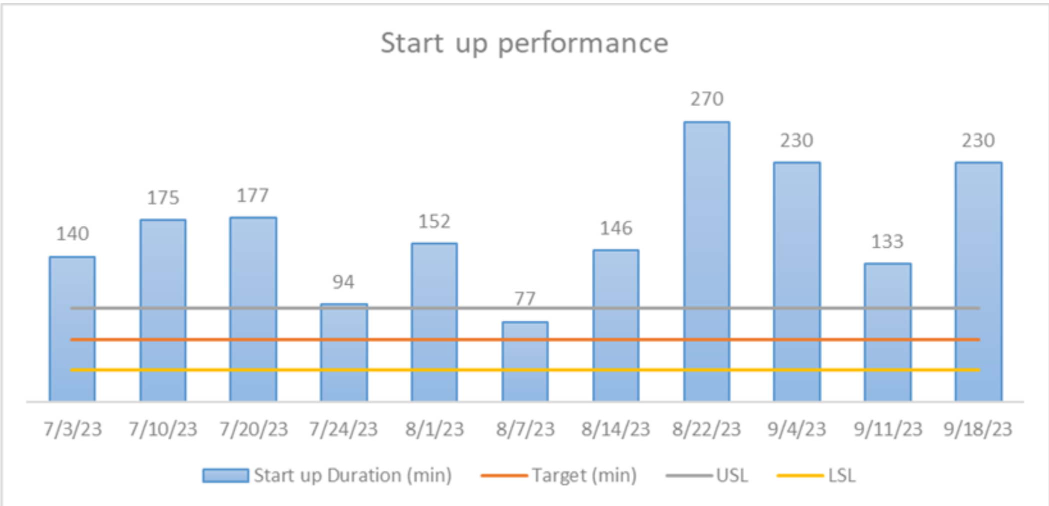


Figure 9. Start up performance

The expected target of startup duration defined by management is 60 minutes with upper and lower limit is +- 30 minute or upper specification limit (USL) is 90 minute and lower specification limit (LSL) is 30 minutes. The following table is the summary of startup performance of line 14 from July 2023 to September 2023, including target, upper specification limit (USL), lower specification limit (LSL), mean ($\bar{x}$) and standard deviation (σ). The formula to calculate mean ($\bar{x}$) is (Lee et al., 2015);

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

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,

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

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

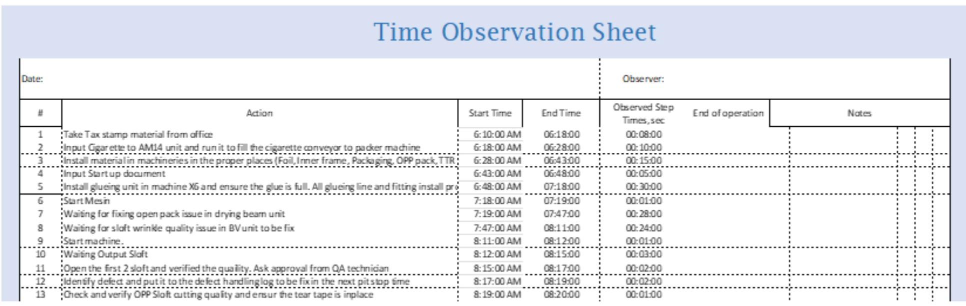
$$Cpk = \min(CpU, CpL) = \min\left(\frac{USL-\bar{x}}{3\sigma}, \frac{\bar{x}-LSL}{3\sigma}\right)$$

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

Based on calculation above it is known that both Cp and Cpk from startup process in Line 14 are below 1, it means that the process is not capable to conduct the task and fulfill customer expectation as most of the data is outside specification limit. While the sigma level of this process is as follow,

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

The sigma level is **1.35** it's mean that only **45%** of the process output meets customer requirements. It is categorized as poor performance. Hence, it is important to really improve the startup performance. To understand what the exact activity during startup, it is required to conduct direct observation and write the entire detail activity of all the production team during start up. The secondary production line is divided into a making line and packing line. The activity of startup is divided by activity in cigarette making line and packing line as well. 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 pit stop 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, it is mentioned there are several waiting and idle activities. It happens due to several issues that make the startup activity become longer. If we summarize the activity in the process flow map, the ideal flow is as follows.

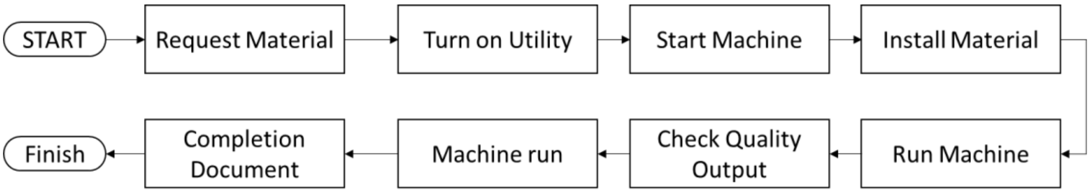


Figure 10. Ideal flow process

But actual activity in startup during observation is different, there are several additional activities that conducted and makes the duration takes longer, such as, looking for tools, finding and fixing defect in machine and improper quality product that need adjustment and fine tuning. Here is the summary of actual start up activity.

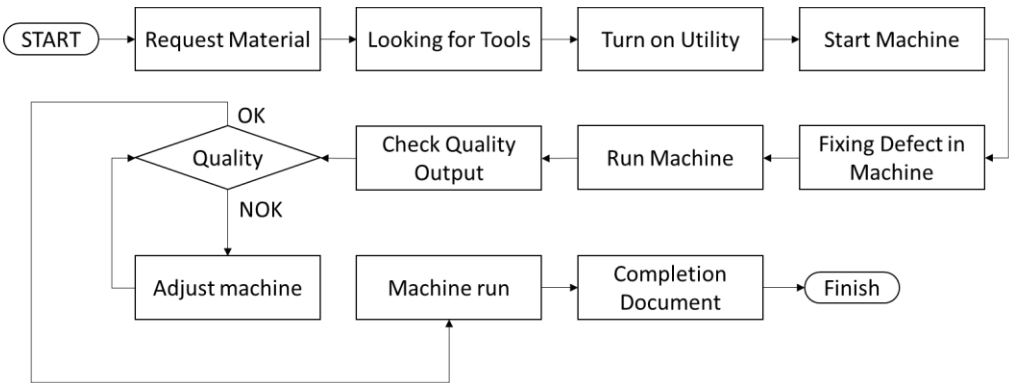


Figure 11. Current flow process

Hereby the summary of total duration during start up activity by each personel.

Table 2. Start up duration each personnel

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

3.2 Analyze Phase

Based on the data in measure time, it can be analyzed deeper by categorizing every activity that captured in Time Observation Sheet (TOS). It can be summarized that there are a lot of waiting activities from each personnel during start up activities.

3.1.1 Pareto Analysis

Pareto analysis is found by Vilfredo Pareto those purpose is to separate the significant aspects of a problem from the trivial ones (Nofrianto & Basri, 2024). To understand the issue, here is the summary of overall activities from worker 1 during executing start up task.

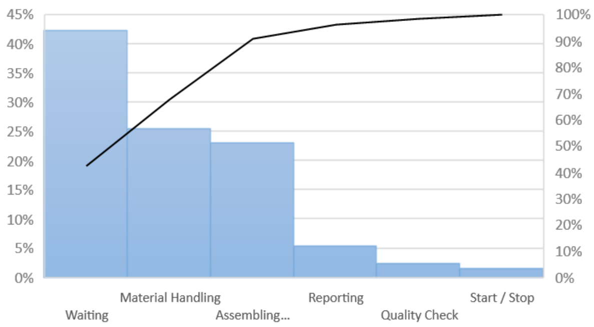


Figure 12. Pareto chart worker 1

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

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

3.1.2 Value added analysis

After it has been analyzed, in the pareto analysis and concluded that most of the time spent during the startup activity is waiting. It is required that all of the activity is giving added value to the main objective of startup activity. Hence it is required to conduct value added analysis.

During observation every activity is categorized as Value added (VA), Non-Value Added (NVA) and Business Non-Value Added (BNVA). Value added is something that increased overall product value and contribute to overall delivery and quality (Eakin & Gladstone, 2020), while Non-Value added is not. Business non-value added is nonvalue added activity that is still required by the business. Here is the result of brainstorming activity that classifying 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 pro	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 to the other 4 workers, the following table is the summary of above classification.

Table 4. Summary value added activity.

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 it is shown that 43.3% of the total activity is categorized as value added activity, 31% is nonvalue added activity and 25.7% is business nonvalue added activity.

3.3 Improve phase

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

3.3.1 Eliminating ad hoc issue

During the process in the startup, the sloft is wrinkled and not passed the quality requirement of the product, hence QA department demand to solve the issue before continuing the process. The root cause analysis of the issue is as follows.

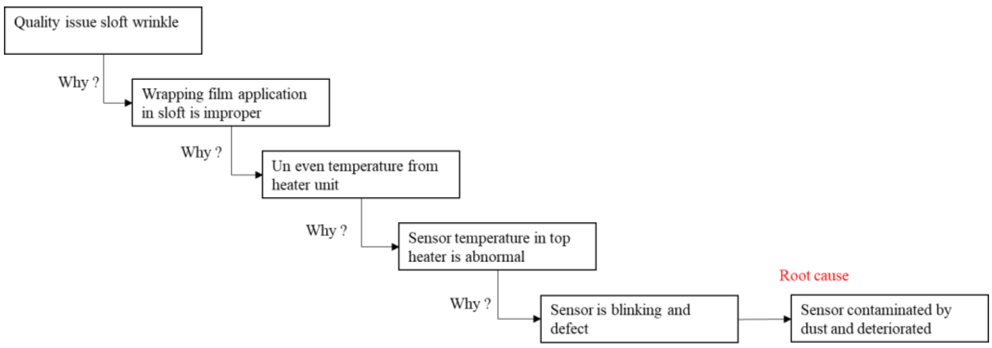


Figure 13. why-why analysis solving ad hoc issue

Based on 5-why analysis, the main issue of the sloft wrinkle is due to the defect on sensor in top heater area. To ensure the similar issue won't happen again in the future, the countermeasure is developed as follows:

- Replace the sensor with the new one.
- Create cleaning and inspection task in the sensor from dust and contamination once per month.

The other finding is the open pack issue. Open pack issue is quality and runnability issue in the packing machine that happens when the packaging is not completely sealed by glue and open again. This condition makes the pack cannot be transferred to the next step and jammed, this condition will makes the machine stop running. Based on the direct observation on floor, the root cause of open pack issue is as follows

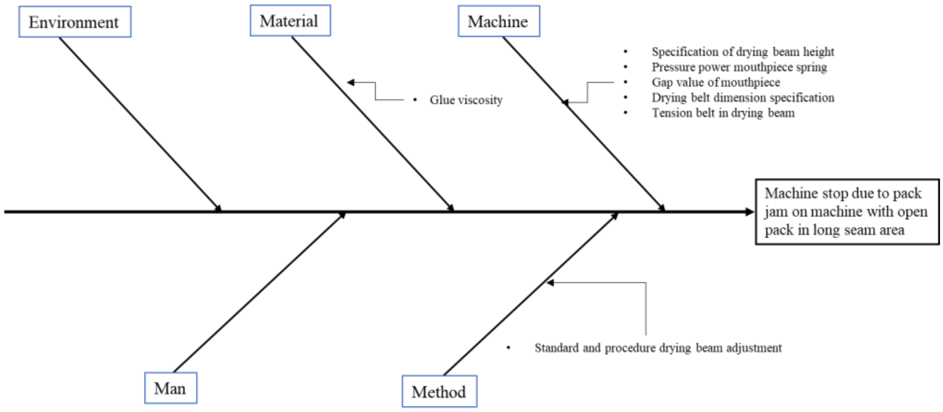


Figure 14. Fishbone diagram analyzing ad hoc issue

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

- Machine
  - There is no set point for adjustment of drying beam height, during observation it is found that the drying beam height is having certain gap that makes the drying proses of pack is not optimal.
  - The use of spring plate is to be able being flexible following the pack dimension in order to maintain pack position to be firm and stick properly. In this case, the team found that the spring plate is inflexible and stiff.
  - Mouthpiece width should be fit with pack dimension, cannot be too loose or too tight. During observation the mouthpiece is too loose.
  - Belt in drying beam become the transport media from pack during drying proses, thus the specification, dimension and tension belt become important to ensure the transfer process is proper. During observation, it is found that the transfer process is improper that impacting the drying process become less optimal.
- Material
  - Open pack can be happen when the glue is not working properly. During observation, the glue viscosity becomes uneven due to long shut down.
- Method
  - Procedure fine tuning and adjustment between teams is not standard, hence the team perception sometimes different.

Based on the discussion and fine-tuning adjustments on floor here it is the countermeasure and standard

- Create adjustment point for drying beam height.
- Fixing defect by replacing spring plate and create standard maintenance for spring plate replacement per 20 week
- Set standard gap mouthpiece drying beam by 0.1 mm from packaging.
- Belt is worn out and getting elongated. Set the standard of belt replacement by 24 week and create tension standard for belt in 35 hz.
- Kaizen by adding stirer active in glue tank to ensure uniformity of glue before applied to product.
- Create technical instruction standard for standardize way of working team to adjust the machine.

3.3.2 Improving start up duration

There are several lean six sigma tools that are 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 done 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 by using ECRS (eliminate, combine, rearrange and substitute) is referred to lean method as mentioned by (Suhardi et al., 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 to all worker in the actual start up task the summary of startup 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 the worker 1 that having the longest duration and become bottleneck, previously the startup duration around 130 minutes, can be reduced to be 43 minutes.

3.4 Control phase.

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

- Developing standard based on improvement. Determine new flow process and RACI and procedure start up that already optimize.
- Cascade to team to aligning understanding between team members to ensure the entire team

understand and follow the new standard that has been developed.
- Create implementation plan and review the several implementations of new standard to understand the level of implementation between the standard and actual implementation on floor.

5. Conclusion

Based on the study conducted above regarding OEE improvement through reducing start up duration using lean six sigma lean six sigma methodology, the following conclusions and recommendations are obtained.

5.1. Conclusion

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

- Ad hoc issue: There are several ad hoc issues happen during the start up like quality issue of sloft film wrinkle.
- 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 doing by the team as well as unbalanced task load between team members.

To overcome the above issue the proposed solution is.

- For solving ad hoc issues, proper strategy maintenance for maintaining the spare part is required. The other thing is an additional inspection task is developed to check the actual condition of the area.
- ECRS (eliminate, combine, rearrange, and simplify) and SMED (Single minute exchange to die) method from lean management is used to find a better strategy. The result is, several tasks are moved out from internal to external, eliminating non added value task, and leveraging the task between the team to balance the task load. The result is startup duration can be reduced from 130 minutes to 43 minutes or 67%. The average task and number of activities is reduced from 23 per person become 14 per person or reduce 39%.

By solving those issues, the manufacturer will gain the benefit of improved start up duration and impacting higher OEE. It will gain several other benefits that contribute to overall company performance such as.

- *Capacity increase*: overall the improvement 67% of startup duration or 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 equal to potential additional revenue without adding any investment in production.
- *Improve Labor productivity*: Labor productivity will be linier improving when the OEE is improved. It will reduce the labor cost that is related to production activity in Line 14.
- *Decrease Energy Consumption*: when the OEE is improved it means that to produce the same amount of product, it will consume less energy. Hence improvement of OEE will be aligned with the declining of energy consumption at certain point.

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

5.2. Limitation

In order to maintain the focus of the research, the scope and limitation of this thesis is as follow:

- This research area focuses on Production Line 14 Manufacturing Plant PT. XYZ
- The research scope only on the issue of OEE improvement.
- Method using on this research based on six sigma methodology.
- Data range for analysis is taken in 2023 only.
- The actual result of solution implementation is excluded from this research.

5.3. Suggestion

Even though the improvement gains several benefits, there are several recommendations that can be taken to leverage the benefit as follows.

- To ensure the new standard is followed and implemented the management should conduct regular checks. Following the PDCA (Plan, Do, Check and Act) cycle, the management should review the implementation of new standards and continuously seek any improvement that can be taken to improve. The successful implementation of any project requires full and comprehensive management and leadership support. (Mosayeb moradi & Ahmad Khan Beigi, 2021)
- As the condition of tax increase apply to all brands, not only in brand super slim that produced by line 14, but also other brand as well, the management should pay attention that the brand may be facing similar condition with line 14. Hence, to avoid similar losses, the newly developed standard of startup task from this research should be taken and cascading to other production line as well.

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