Effect of lean maintenance to reduce cost of sugar firms

Pedalian Halilintar[1*], *Moses Laksono* Singgih[1]

[1]Management Technology Department, Interdisciplinary School of Management and Technology, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia

Abstract. Maintenance plans are crucial for enhancing the operational efficiency of technological advancements and global competitiveness. This study focuses on improving efficiency and productivity in the refined sugar industry, specifically at Pabrik Gula Rafinasi (PGR). Refined sugar plants often struggle with maintaining equipment properly, which impacts the raw material processing sector. The proposed approach uses Lean Maintenance techniques to enhance maintenance efficiency and effectiveness by eliminating waste, improving processes, and enhancing quality. Lean Maintenance aims to thoroughly examine maintenance processes, identify waste areas, and implement relevant changes. The research has two primary objectives: first, to apply the maintenance concept at PGR to improve overall maintenance performance and streamline the maintenance procedure; second, to optimize the maintenance process using Lean Maintenance techniques to increase efficiency and responsiveness to production demands. The study found that by implementing alternative solutions using smart tools, maintenance costs can be reduced by 4% and maintenance time can be accelerated by 42%. These improvements address three types of waste: transportation (remote tool storage from the toolroom to the production area), transportation (technicians repeatedly borrowing measuring tools), and motion (technicians searching for suitable tools). The understanding and application of Lean Maintenance principles in the refined sugar industry, particularly at PGR, have practical implications. This research offers recommendations and guidance for similar businesses aiming to enhance their maintenance performance. Consequently, this study significantly contributes to the advancement of the refined sugar sector and the discipline of maintenance management.

1 Introduction

This research aims to increase efficiency and productivity at the Refined Sugar Factory (PGR) by implementing the Lean Maintenance method. In the face of increasingly fierce competition, companies need to reduce costs and optimize maintenance processes to make operations more efficient.[1] Refined sugar factories often face challenges in keeping equipment functioning optimally, so solutions are needed to increase production efficiency and reduce maintenance costs.

This research proposes optimizing the maintenance process with Lean Maintenance to eliminate waste, improve processes, and improve quality. It is hoped that this method will improve understanding of maintenance workflows, identify areas of waste, and design appropriate solutions. Currently, the ratio of Preventive Maintenance (PM) to Corrective Maintenance (CM) at PGR is still below standard (6:1) [2], so it needs to be increased. This research also focuses on pump category machines which record the highest maintenance time.

The formulation of the problem raised in this research is: how to implement Lean Maintenance in refined sugar factories. How to optimize the maintenance process in refined sugar factories. How to reduce maintenance costs in refined sugar factories. This research aims to apply Lean Maintenance to reduce maintenance costs, optimize the maintenance process using the Value Stream Mapping method, and provide feedback to PGR to reduce maintenance costs and implement effective and efficient maintenance. In addition, this research aims to provide information that can increase maintenance productivity in the refined sugar industry and increase understanding of the role of maintenance in this industry.

The scope of this research includes the use of internal PGR maintenance data, focusing on the maintenance process in the engineering department, and especially on the maintenance process for pump category assets. Thus, it is hoped that this research can make a real contribution to increasing efficiency and productivity at PGR through the implementation of Lean Maintenance.

2 Research methods

2.1 Sugar refinery

The refined crystal sugar industry an important role in the food and beverage sector, including pharmaceuticals, hotels, restaurants, catering, and others. This sugar is processed through various stages of

* Corresponding author: pedalianhalilintar@gmail.com

refining to achieve high purity, making it safe and compliant with standards. The production process includes stages such as screening, remelt, carbonation, crystallization, and curing. Regulations stipulate that refined sugar may only be traded to certain industries such as food and beverage processing, under Minister of Trade Regulation Number 01 of 2019. This sugar may not be sold directly to the public.

Even though it is safe for direct consumption, public perception of refined sugar varies. Refined and white crystal sugar must meet strict standards and have certifications such as ISO 22000, ISO 14000, ISO 9001, POM Agency, SNI, and a halal certificate from MUI. 11 refined crystal sugar producers in Indonesia are members of the Indonesian Refined Crystal Sugar Association (AGRI) in 2024.

2.2 Refinery sugar process

Production of refined sugar from raw sugar through the crystallization process involves several main stages. The first process is affination, where raw sugar is washed to remove molasses and impurities, producing cleaner affinized sugar and raw liquor. The second process is decolorization, where the raw liquor is mixed with lime water and CO2 gas to remove the color, producing fine liquor. The third process is evaporation, where fine liquor is evaporated to produce thick liquor. Next, in the crystallization process, the thick liquor is cooked in a vacuum to form sugar crystals. After crystallization, the curing process separates the sugar crystals from the molasses using centrifugation, producing white crystalline sugar which is then dried and cooled. Finally, the crystal sugar is packed in fifty-kilogram plastic sacks and sent to the product warehouse.

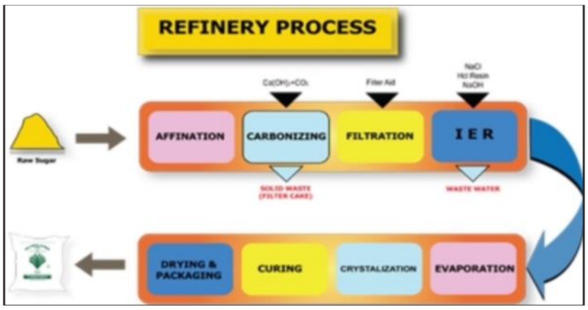

Fig. 1. Flow process sugar refinery.

2.3 Maintenance strategy

Asset maintenance includes activities to maintain the best operational conditions and follow developments in the production system [3] Initially, maintenance focused on corrective maintenance, but today maintenance management is more complex, requiring technical and management skills to respond to dynamic business environments. Maintenance strategies have evolved into preventive maintenance, such as Condition Maintenance (CBM), Time-Based Maintenance (TBM), Design Out Maintenance (DOM), and Total Productive Maintenance (TPM) [4] Corrective maintenance is performed after a failure occurs, while preventive maintenance is performed to prevent failure. Autonomous maintenance is performed by machine operators, while DOM focuses on improving product design to reduce maintenance throughout the product life Maintenance Activity.

2.4 Maintenance activity

Maintenance is a combination of technical, administrative, and management activities throughout the lifetime of an item, to maintain or restore its functional state [5]. The maintenance strategy includes a series of sequential maintenance activities [6]. Key maintenance activities include:

1. Inspection: verify compliance through measuring, observing, or quantifying asset characteristics.
2. Monitoring: Manually or automatically observing the actual condition of assets to evaluate changes in parameters over time.
3. Routine maintenance: Basic maintenance activities such as cleaning, tightening connections, checking fluid levels, and lubrication, which do not require special qualifications.
4. Overhaul: A comprehensive set of controls and actions to maintain asset availability and security levels, usually performed at specified intervals and may involve dismantling the asset.
5. Reconstruction: Actions after disassembly to repair or replace end-of-life parts, aimed at extending the life of the unit compared to the original.
6. Repair: Physical actions to restore the function of damaged equipment, including troubleshooting, error correction, and operational verification.

2.5 Lean maintenance

Lean maintenance emerged as a proactive approach to maintenance at the end of the 20th century. This approach combines Total Productive Maintenance (TPM) practices and Reliability Center Maintenance (RCM) decision logic to optimize maintenance activities.[7] Lean maintenance aims to achieve optimal results by minimizing input consumption and reducing unplanned downtime in Maintenance, Repair & Overhaul (MRO) operations. Lean tools such as Value Stream Mapping (VSM), 5S, and visual management are essential for the effective implementation of Lean maintenance.[8] Although its benefits have been recognized, a review of the literature shows that research on the application of Lean principles in maintenance is still limited. Several previous studies have focused on maintenance strategies using Lean concepts to improve reliability and efficiency, but the practical application of these concepts still requires more research.

2.6 Maintenance waste

Maintenance waste identify of the seven types of waste in the maintenance process according to the lean maintenance approach are as follows:

1. Unproductive maintenance: Performing Preventive Maintenance (PM) and Predictive Maintenance (PdM) tasks too often, results in excessive maintenance work.
2. Waiting for maintenance resources: Maintenance personnel often have to wait to perform service because the necessary tools, parts, or information are not available promptly.
3. Centralized maintenance: Excessive transportation and wasted time due to MRO warehouse locations far from job sites, incomplete parts, and inefficient procedures.
4. Poor inventory management: Improper MRO inventory can cause delays in response, unexpected damage, and increased reactive time.
5. Unnecessary movements: Maintenance activities that do not add value are often a source of waste.
6. Poor maintenance: Repairs that are ineffective or need to be done repeatedly result in suboptimal costs and quality.
7. Poor data management: The collection of irrelevant or unnecessary data can obscure important information for improvement and informed decision-making.

Implementation of lean maintenance principles aims to identify and reduce this waste so that the maintenance process is more efficient, productive, and oriented towards added value [9].

2.7 Overall Equipment Effectiveness (OEE)

Equipment performance is very important in the production process.[10] OEE assesses tool performance. Equipment failure can increase downtime, availability, and maintenance costs. Additionally, loss of speed impacts performance and quality. The OEE value of the world's leading companies is higher at 85%. OEE is calculated using three key metrics: availability level, performance, and quality level.

The OEE value can be obtained by multiplying the three main ratios mathematically with the following formula.

$$OEE = Availability\ (\%) \times Performance\ (\%) \times Quality\ (\%) \quad (1)$$

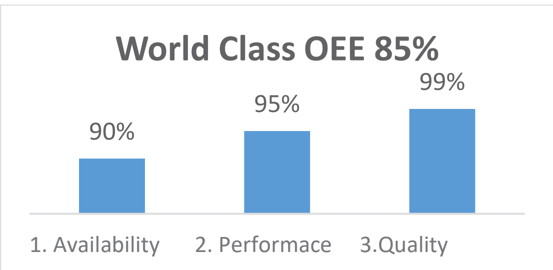

Table 1. World class OEE.

2.7.1 Availability rate

Availability level is the ratio of the time available for machines and machine and equipment operating activities, calculated from equipment downtime and loading time

$$Availability = \frac{Loading\ Time - downtime}{Loading\ Time} \times 100\ \% \quad (2)$$

2.7.2 Performance rate

The formula for calculating performance levels is: Performance levels are ratios that describe the ability of equipment to produce goods with the following formula:

$$Performance = \frac{Output\ x\ ideal\ cycle\ time}{Loading\ Time} \times 100\ \% \quad (3)$$

2.7.3 Quality rate

The formula used to determine the quality level is: Quality level is a ratio that describes the ability of equipment to produce products under standards with the following formula:

$$Quality = \frac{Processed\ Amount\ -\ defects\ amount}{Processed\ Amount} \times 100\ \% \quad (3)$$

2.8 Maintenance cost

Calculation of Maintenance Costs includes three: Overhead Costs, Direct Labour Costs, and Potential Lost Costs.

2.8.1 Maintenance overhead cost

Include all additional costs that occur during the implementation of maintenance activities, but are not directly related to expenditure on labor or materials.

This includes spending on infrastructure, administration, and general arrangements that support the smooth maintenance process. Examples of overhead costs include specialized equipment, equipment maintenance costs, inventory management, administrative costs, equipment rental, and general overhead costs such as utilities and space rental costs. Managing overhead costs efficiently is important to control total costs and increase the effectiveness of maintenance operations.

2.8.2 Direct labour costs

In maintenance include direct costs associated with labor performing maintenance tasks, including salaries, wages, incentives, and employee benefits. It may also include additional costs such as training, work supplies, and insurance for the employees involved. More broadly, direct labor costs can also include direct overhead costs directly related to the execution of maintenance tasks.

2.8.3 Potential lost production

Refers to the amount of production or output that could have been achieved, but failed to be achieved due to operational disruptions such as equipment failure or problems in the production chain. It reflects the difference between actual production and expected production if there were no disruptions. Analysis of potential lost production is often carried out to increase productivity and optimize operational efficiency, as well as minimize disruption in the production process.

2.9 Research flow

This research focuses on analyzing the performance of production line machine equipment at the Refined Sugar Factory (PGR) using data from maintenance records during the 2023 period. Researchers selected samples based on specific knowledge needs to evaluate current performance. The main objective of the research is to determine the priority of machine categories that have the highest cost impact in the maintenance period. Furthermore, this research plans improvements by determining effective alternative repair solutions.

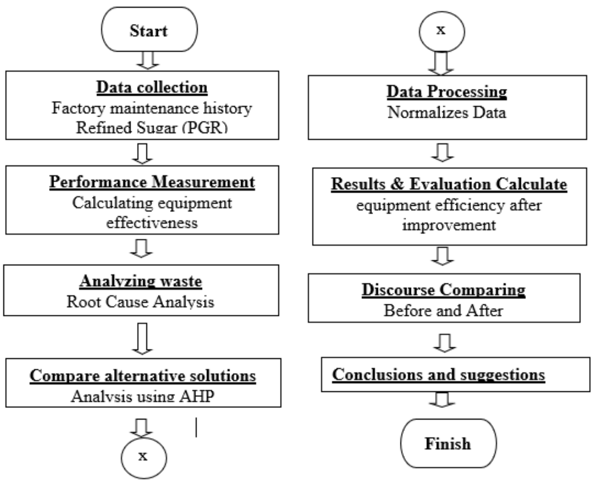

Fig. 2. Flowchart research stage.

2.10 Research conceptual framework

This research focuses on analyzing the performance of production line machine equipment at the Refined Sugar Factory (PGR) using data from maintenance records during the 2023 period. Researchers selected samples based on specific knowledge needs to evaluate current performance. The main objective of the research is to determine the priority of machine categories that have the highest cost impact in the maintenance period. Furthermore, this research plans improvements by determining effective alternative repair solutions

After obtaining the value from the comparison, the priority order of alternative solutions for improvement in Maintenance activities is obtained. Improvement Alternatives in the Refined Sugar Factory (PBR) production line can be seen in Figure 2.

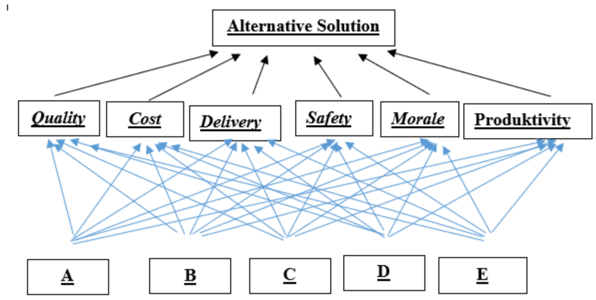

Fig. 3 Research conceptual framework.

After obtaining the value from the comparison, the priority order of alternative solutions for improvement in Maintenance activities is obtained. Improvement Alternatives in the Refined Sugar Factory (PBR) production line.

Table 1. Alternative improvement.

No	Alternative Solution	Description
A	Effective Planing	Procedure Treatment and repair steps are done
B	Availability *Sparepart*	Availability Spare Part Available, Simplfied
C	*Smart Tools*	Usiing updated technology tools
D	*Upgrade Skils*	Technical skill development
E	Digitalization	Convert physical data management to digital.

3 Result and discussion

This research focuses on analyzing the performance of production line machine equipment at the Refined Sugar Factory (PGR) using data from maintenance records during the 2023 period. Researchers selected samples based on specific knowledge needs to evaluate current performance. The main objective of the research is to determine the priority of machine categories that have the highest cost impact in the maintenance period. Furthermore, this research plans improvements by determining effective alternative repair solutions.

3.1 Data collection

Next, Current State Mapping Preventive Maintenance is carried out Figure 4.

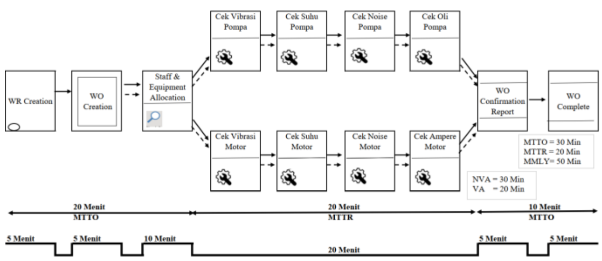

Fig. 4. Current State Mapping Preventive Maintenance.

From this data, identification, and analysis of the causes of waste are carried out.

Table 2. Results of identification and analysis of causes of waste.

No	*Waste Type*	*Sub Waste*	*Cause*
1	*Over Production*	Activity Treatment too much	High Safety Factor, Time Based Maintenance
2	*Waiting*	Waiting for confirmation of execution	Stop time adjusts to actual production
3		Wait for the takeover of spare parts from the inventory	New spare part is known after dismantling
4	*Transport-ation*	Storage tools away from the workshop to the production	No storageplace in production area
5		Technicians borrowing tools to the toolroom	Measurement inspection tools of the machine are limited
6	*Over-processing*	Checking of parameters that are not necessary	Reports of maintenance activity are inaccurate
7		Doing double check on the result of repairs	Technicians unskilled in analyzing damage
8	*Inventory*	Safety stock is not suitable	Data collection on spare parts requirements is inaccurate,
9		*Lots of dead stock*	There are spare parts for machines that are obsolete
10		Procurement of parts exceeds the standard time specified	Procurement of new spare parts goes through many stages
11	*Motion*	Each technician performs a different sequence of steps, overlapping work	Complete machine inspection procedures are standardized, along with accountability
12		Technicians are busy looking for suitable tools	Technicians make a lot of movements
13		Technicians need to think hard about the sequence of equipment assembly	The work area is messy, technicians need to be careful in reassembling equipment
14	*Defect*	Error Identification of damage	Technician knowledge is limited according to flying hours
15		Installation Error	Technicians need careful about parts that are similar but not sam
16		Spare part selection error	There are many variations parts, it is necessary to simplify similar

3.2 Data collection

3.2.1 Calculation of preventive maintenance costs

Calculating Preventive Maintenance costs accurately is very important because it relates to the company's budget and strategic decisions. Preventive maintenance costs include various elements, such as spare parts costs, labor, maintenance equipment, as well as administration and management costs. A deep understanding of these cost components helps companies carry out better and optimal budgeting effectively and efficiently.

Total Preventive Maintenance Costs for 1 Pump Unit in One Year.

Table 3. Preventive maintenance cost.

Total Cost PM / unit year						
No	**Category**	**Type**	**Rate/hour**	**Time [Hour]**	**Manpower**	**Total Cost**
1	Overheads	PM	IDR 900,000	49		IDR 44,100,000
2		CM	IDR 9,100,000			IDR -
3	Direct labour	GL/SPV	IDR 41,618	49	1.00	IDR 2,039,306
4		Tech	IDR 27,746	49	1.00	IDR 1,359,538
5	Potential Lost	Production	IDR 700,000,000			
Total Cost						IDR 47,498,844

3.2.2 Calculation of corrective maintenance costs

Corrective Maintenance is an important part of a maintenance strategy that focuses on repairing or replacing damaged or failed equipment. Although important, Corrective Maintenance can be a significant source of costs for companies. Corrective Maintenance cost analysis includes direct and indirect costs such as production downtime, labor costs, and material costs. With the right approach to calculating Corrective Maintenance costs, companies can increase operational efficiency, increase equipment reliability, and reduce total maintenance costs.

Table 4. Corrective maintenance cost.

Total Cost CM / Unit year						
No	**Category**	**Type**	**Rate/hour**	**Qty**	**Manpower**	**Total Cost**
1	Overheads	PM	IDR 900,000			IDR -
2		CM	IDR 9,100,000	1		IDR 9,555,000
3	Direct labour	GL/SPV	IDR 41,618	90	1.00	IDR 3,726,610
4		Tech	IDR 27,746	90	2.00	IDR 4,968,814
5	Potential Lost	Production	IDR 700,000,000	0.17		IDR 116,666,667
Total Cost						IDR 134,917,091

Total Corrective Maintenance Costs for one pump unit in a year:
Preventive Maintenance Cost: Rp. 47,498,448
Corrective Maintenance Cost: Rp. 134,917,091
Total cost per year per pump: Rp. 182,415,539

Thus, through proper management, companies can optimize overall maintenance costs.

3.3 Waste analyze

In the period January to December 2023, PGR equipment downtime performance was measured, especially in the pump area. Downtime refers to the time during which a pump is not operational or productive due to various problems or failures.

To improve performance, an analysis was carried out using the 4M+1E (Man, Machine, Material, Method, and Environment) approach to identify the root causes of pump downtime. Once the causes are identified, corrective steps are taken to resolve the problem, such as:

- Operator training to improve their skills and understanding.
- Repair or replacement of failed engine components.
- Use of materials that are more durable to increase pump durability.
- Adjusting work procedures to make them more efficient and effective.
- Improved environmental conditions around the pump to reduce the risk of failure.

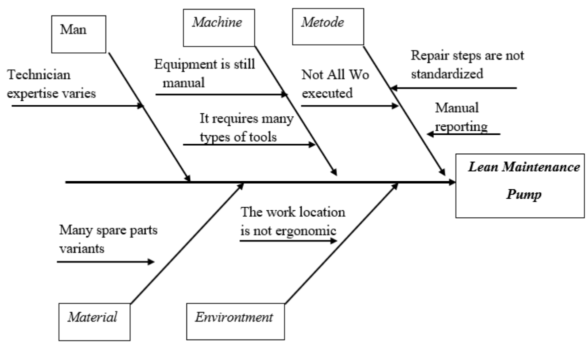

Fig. 5. Fishbone diagram.

3.4 Recommendations for improvement

From the results of identifying 7 wastes in Table 1 Results of Identification and Analysis of Causes of Waste and Figure 4 Fish Bone Diagram that occurs in maintenance activities, 5 alternative solutions were obtained as follows.

Table 5. Alternative solution.

No	Alternative Solution	Description
A	Effective Planing	Procedure Treatment and repair steps are done
B	Availability *Sparepart*	Availability Spare Part Available, Simplfied
C	*Smart Tools*	Usiing updated technology tools
D	*Upgrade Skils*	Technical skill development
E	Digitalization	Convert physical data management to digital.

3.5 Comparison criteria

Determining alternative solutions in research is an important process to ensure that the study is conducted with appropriate and reliable methodology. Assessment criteria are factors that are observed, manipulated, or controlled in research to determine their effect on the variables being studied.

Table 6. Comparison criteria.

No	Variabel	Description	Target
1	*Quality*	Measuring and ensuring products or services meet established standards and customer satisfaction.	Reduce defects, increase equipment reliability, and ensure that maintenance is performed appropriately to prevent quality problems
2	*Cost*	Manage and control operational costs to achieve economic efficiency.	Increase resource use efficiency, reduce unplanned downtime, and minimize waste.
3	*Delivery*	Ensure products or services are delivered on time according to the agreed schedule.	Reduce waiting times and speed up maintenance processes to ensure optimal equipment availability.
4	*Safety*	Guarantee the safety and health of workers as well as a safe working environment.	Reduce accident incidents, ensure compliance with safety standards, and implement safe maintenance procedures.
5	*Morale*	Increase employee morale and job satisfaction to create a positive work environment.	Involve employees in the maintenance process, provide necessary training, and create a collaborative work culture.
6	*Productivity*	Measuring the efficiency and effectiveness of the production process to increase output	Reduce downtime, increase the speed and quality of maintenance work, and optimize resource use.

3.6 Improvement results

By implementing improvements with alternative "Smart tools" solutions, the pump team can reduce the 7 wastes listed in Table 1 Results of Identification and Analysis of Causes of Waste, as follows:

1. Transportation – Storage of tools away from the workshop to the production area
2. Transportation – Technicians go back and forth to borrow measuring tools from the toolroom
3. Motion – Technicians are busy looking for suitable tools.

Table 7. *Downtime* equipment PGR Jan- Mei 2024.

No	Kode Asset	Stop Duration (CM)	Freq Downtime [hour]	Duration x Frequensi	Presentase (%)	Availability	Performance	Quality	OEE	After-Before
1	BODY	3,150	1,409	4,438,844	49.8%	99.1%	95.8%	97.0%	92.1%	10.6%
2	MOT	1,122	1,653	1,855,436	20.8%	99.3%	95.8%	97.0%	92.3%	14.7%
3	GRBX	1,113	1,081	1,203,342	13.5%	99.2%	95.8%	97.0%	92.1%	9.3%
4	DU	1,083	710	769,094	8.6%	99.1%	95.8%	97.0%	92.1%	25.2%
5	PU	1,100	475	522,625	5.9%	99.1%	95.8%	97.0%	92.1%	9.2%
6	PNEU	350	179	62,711	0.7%	99.2%	95.8%	97.0%	92.2%	59.1%
7	PUMP	1,665	27	44,956	0.5%	96.3%	95.7%	97.0%	89.4%	7.6%
8	CTFG	406	18	7,300	0.1%	97.8%	95.7%	97.0%	90.8%	7.7%
9	FLTR	259	22	5,700	0%	98.6%	95.8%	97.0%	91.6%	9.2%
10	MGLR	180	18	3,243	0%	95.4%	95.6%	97.0%	88.5%	14.0%

After improvements were made by improving the quality of the equipment with Smart Tools, OEE in the PUMP category increased to 89.4%.

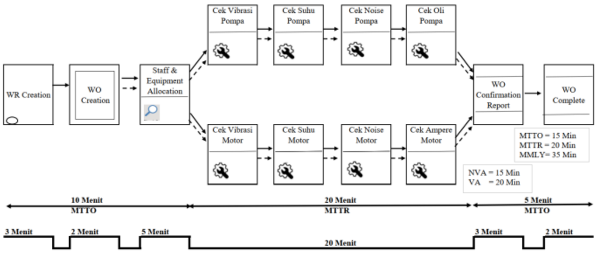

Fig. 6. Future state mapping preventive maintenance.

Table 8. Comparison before- after.

Aktivitas	MTTO (min)	MTTR (min)	MMLY (min)
Preventive Maintenance (Before)	30	20	50
Preventive Maintenance (After)	15	20	35

From the table above, MTTO time efficiency is obtained from 30 minutes to 15 minutes, thereby **speeding up preventive maintenance time to 42%.**

3.7 Cost calculation after improvement

3.7.1 Cost preventive maintenance

Total preventive maintenance costs for 1 pump unit within one year after improvement.

Table 9. Preventive maintenance cost (after).

Total Cost PM / Unit year						
No	Category	Type	Rate/hour	Time [Hour]	Manpower	Total Cost
1	Overheads	PM	IDR 900,000	49		IDR 44,100,000
2		CM	IDR 9,100,000			IDR -
3	Direct labour	GL/SPV	IDR 41,618	49	1.00	IDR 2,039,306
4		Tech	IDR 27,746	49	1.00	IDR 1,359,538
5	Potential Lost	Production	IDR 700,000,000			
Total Cost						IDR 47,498,844

3.7.2 Cost corrective maintenance

Total Maintenance Costs Corrective maintenance for 1 pump unit in one year (Improvement).

Table 10. Corrective maintenance cost (after).

Total Cost CM / Unit Year						
No	Catagori	Type	Rate/huor	Qty	Manpower	Total Cost
1	Overheads	PM	IDR 900,000			IDR -
2		CM	IDR 9,100,000	0.12		IDR 1,079,167
3	Direct labour	GL/SPV	IDR 41,618	90	1.00	IDR 3,726,610
4		Tech	IDR 27,746	90	2.00	IDR 4,968,814
5	Potential Lost	Production	IDR 700,000,000	0.17		IDR 116,666,667
Total Cost						IDR 126,441,258

3.7.3 Total maintenance cost

From the data above, the total maintenance costs for Preventive Maintenance + Corrective Maintenance for one pump in a year are:
Rp. 47,498,844 + Rp. 126,441,258 = Rp. 173,940,102 / Pump Year.

3.7.4 Saving pump maintenance costs for one year

Saving Costs from each Pump Maintenance Cost for one year.
(After - Before) = Rp. 182,415,539 - Rp. 173,940,102
= Rp. 8,475,437 **(- 4 %)**

Total Savings from all PUMP category assets
Total Asset pump x Saving 1 pump
= 190 [unit] x Rp. 8,475,43 **= IDR 1,610,333,033 / year**

4 Conclusion

In 2023, the refined sugar factory experienced 7,432 hours of pump downtime spread over 78 incidents, indicating the need to implement lean maintenance in 2024. Waste analysis identified 15 problems that needed to be fixed, with a focus on the distance between equipment storage from the workshop to the production area, technicians who often borrow measuring tools back and forth, and have difficulty finding suitable tools.

Pairwise comparison for repair alternative values shows that smart tools (31.01%) and skills improvement (27.81%) have high priority, followed by spare parts availability (18.98%), effective planning (14.16%), and digitalization (8.04%). Implementation of this strategy succeeded in reducing MTTO from 30 minutes to 15 minutes and MMLT from 50 minutes to 35 minutes, as well as increasing preventive maintenance by 42%.

In terms of costs, implementing smart tools can reduce maintenance costs by 4%, with total savings reaching IDR 1,610,333,033 per year. Some suggestions for improvement include gradual adoption of light repair methods starting from critical areas, investment in employee training on lean maintenance, use of the latest technology to monitor and analyze equipment conditions, continuous evaluation and improvement, collaboration with similar industries to gain additional insight, and reporting and regular performance measurements to understand the effects of changes and adjust strategies.

The managerial implications of implementing lean maintenance include increasing operational efficiency, saving energy and materials, as well as reducing downtime and maintenance costs. In addition, it will reduce defects, ensure production reliability, and improve product quality. Employee training also increases their involvement in the maintenance process, while equipment that is in good condition improves workplace safety and health. The integration of new technologies and computer-based maintenance management systems will increase the efficiency, competitiveness, and long-term profitability of businesses.

References

1. M. L. Singgih, D. Ahadian, W. Puspitasari, F. A. Ayudinda, A. Aidil, A. L. Pranastya, P. Gamboa, A. F. Rosyidiin, dan H. Prasetyo, *Recent Development and Future Research of Manufacturing Excellence: A Literature Review*, in Proc. 1st Asia Pacific Int. Conf. Industrial Eng. Operations Management, Surakarta, Indonesia, Sept. (2021)
2. S. F. Imam, Jawad Raza, dan R. M. Chandima Ratnayake, *World Class Maintenance (WCM): Measurable indicators creating Opportunities for the Norwegian Oil and Gas industry*, Department of Maintenance and Operations, Apply Sørco, Sandnes, Norway, Department of Mechanical and Structural Engineering and Materials Science, University of Stavanger, Stavanger, Norway, (2014)
3. A. Karim dan K. Arif-Uz-Zaman, *A Optimum maintenance strategy: a case study in the mining industry*, Int. J. Services Operations Management, 12, 368–386, (2012)
4. P. Potes Ruiz, B. Kamsu Foguem, dan B. Grabot, Generating knowledge in maintenance from Experience Feedback, *Knowledge-Based Systems*, (2014)
5. I. Alsyouf, *The role of maintenance in improving companies' productivity and profitability*, Int. J. Production Economics, **105**, 1, 70-78, (2007)
6. A. Muller, A. Crespo Marquez, dan B. Iung, *On the concept of e-maintenance: Review and current research*, Reliability Engineering & System Safety, **93**, 9, 1165-1187, (2008)
7. R. Smith dan B. Hawkins, *Lean maintenance: reduce costs, improve quality, and increase market share*, Elsevier Butterworth-Heinemann, MA, (2004)
8. S. Mostafa, J. Dumrak, dan H. Soltan, *A framework for lean manufacturing implementation*, Production & Manufacturing Research, **1**, 1, 44-64, (2013)
9. C. Davies dan R. M. Greenough, Measuring the effectiveness of lean thinking activities within maintenance (2010) http://www.plantmaintenance.com/articles/Lean_Maintenance.pdf
10. A. Supriatna, M. L. Singgih, E. Widodo, dan N. Kurniati, Overall Equipment Effectiveness Evaluation of Maintenance Strategies for Rented Equipment, *Int. J. Technology*, 619-630, (2020)