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Implementation of Lean Maintenance Method on High Pressure Boiler Feed Pump (HP BFP) PLTGU Block I Machine to Improve Overall Equipment Effectiveness (OEE) at PT PLN Nusantara Power UP Gresik

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Abstract

This study was conducted at PT PLN Nusantara Power UP Gresik, focusing on enhancing the effectiveness of the High Pressure Boiler Feed Pump (HP BFP) at PLTGU Block I. The main issue addressed was the high level of maintenance waste, negatively impacting Overall Equipment Effectiveness (OEE). To overcome this, Lean Maintenance was applied in conjunction with Value Stream Maintenance Mapping (VSMM), Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), and Root Cause Failure Analysis (RCFA). Findings revealed dominant wastes such as Unproductive Work, Delay in Motion, and Poor Inventory Management. Post-improvement, OEE increased from 67% to 87%, while maintenance time was reduced from 9,780 minutes to 3,300 minutes. The study proves that Lean Maintenance implementation significantly enhances operational efficiency and reduces downtime.

Introduction

PT PLN Nusantara Power UP Gresik is a power generation unit under PT PLN Nusantara Power that operates PLTG, PLTU, and PLTGU. Machine maintenance is very important to maintain the performance and continuity of energy production. One of the machine performance indicators used is Overall Equipment Effectiveness (OEE), which assesses efficiency from the aspects of availability, performance, and quality, and helps identify the causes of the Six Big Losses (Al Hazza et al., 2021; Ullah et al., 2023; Gymnastiar & Hartono, 2025; Sobirov, 2025; Sathler et al., 2023; Kechaou et al., 2024).

Lean Maintenance is a method that focuses on eliminating waste in the maintenance process, such as wasted time, excess labor, and inefficient use of spare parts (Subandi et al., 2023; Gomaa, 2025; Ramiya & Suresh, 2021; Karningsih et al., 2023; Quiroz-Flores et al., 2023). With the application of Lean Maintenance, it is expected that the engine maintenance system at the PLTGU can be more efficient and effective. This becomes very relevant in the context of PT PLN Nusantara Power Gresik Generating Unit (UP) which must be able to maintain and increase the availability of electrical energy.

In energy production at PT PLN Nusantara Power UP Gresik, the High Pressure Boiler Feed Pump (HP BFP) machine often experiences downtime and a decrease in performance from 85% to 70% due to more than 20 years of age and component wear. This has an impact on operational efficiency and achievement of production targets. The implementation of Lean

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Maintenance is an important strategy to reduce waste, improve machine reliability, and increase the overall OEE value (Almahdy et al., 2021; Jurewicz et al., 2023; Singha Mahapatra & Shenoy, 2022; Quiroz-Flores & Vega-Alvites, 2022; Bakri et al., 2021).

Gas and Steam Power Plant (PLTGU)

PLTGU (Gas and Steam Power Plant) is a combination of PLTG and PLTU which functions to convert heat energy into electrical energy. The process starts from burning fuel in the PLTG which produces hot gas to heat water in the Heat Recovery Steam Generator (HRSG) to become steam (Syahrir et al., 2024; Subati, 2022; Hernawan, 2022; Muhammad et al., 2024). The steam is used to rotate the steam turbine in the PLTU, which then drives the generator to produce electricity. PLTGU can use fuel oil (BBM) or natural gas such as LNG, and the efficiency of the system is greatly influenced by the type of fuel and combustion process. The hot gases from combustion are also directed to the turbine to turn the generator, while the remaining hot gases are exhausted through a chimney, and the turbine is cooled to prevent damage from high temperatures (Wachjoe, 2023; Chopra, 2021).

High Pressure Boiler Feed Pump (HP BFP)

HP BFP is a type of high-pressure centrifugal pump designed to deliver feedwater to boilers at high pressure and temperature. This pump usually has several stages (multi-stage) to achieve the required pressure. The design prioritizes hydraulic efficiency, material strength against high pressure and temperature, and operational reliability. The performance of the HP BFP is critical as its failure can lead to the cessation of the generating unit operation (Sari et al., 2024; Yazdi, 2024; Osuchukwu et al., 2024; Radwan et al., 2024).

Distribution of Reliability

Each machine component has its own failure characteristics. The reliability distribution can be determined from the time interval between machine or component failures. In analyzing and identifying the reliability of a machine or component, there are four distributions used to recognize the data patterns formed, including Normal, Lognormal, Weibull, and Exponential distributions (Erlangga, 2023; Woo, 2023; Yazdi, 2024; Radwan et al., 2024).

Mean Time Between Failures (MTBF)

MTBF (Mean Time Between Failures) is the average system operating time between two failures, which reflects the level of equipment reliability. MTBF is calculated by dividing the total operating time by the number of failures. A high MTBF value indicates the system is more reliable and rarely experiences breakdowns. This metric is useful for planning maintenance, determining repair intervals, and reducing the risk of downtime (Kumar et al., 2013; Schneidewind, 2002; Moghadam et al., 2024; Bafandegan Emroozi et al., 2024; Mohad et al., 2025).

Mean Time to Repair (MTTR)

MTTR (Mean Time to Repair) is the average time it takes to repair a system until it is back in operation. This metric shows the speed and efficiency of repairs, calculated as the total repair time divided by the number of repairs. A low MTTR indicates a good repair process and helps minimize downtime. Strategies to reduce it include technician training, proper use of tools, and effective maintenance planning (Aguilar, 2023; Rahman, 2024; Gulati & Smith, 2009).

Maintenance

In operations management, maintenance is an important activity to keep facilities ready and reliable. Maintenance has a direct effect on capacity, production costs, quality, safety and customer satisfaction. Depending on its strategic role, this function can fall under the

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operations department or be directly supervised by the board of directors, and is usually divided into building and machinery maintenance (Harsanto, 2017).

Lean Maintenance

Lean Maintenance is a maintenance system that aims to eliminate waste in the maintenance process, making it more efficient and effective. It manages inputs such as labor, parts, and energy to improve quality, machine performance, and profitability (Wicaksono, 2023). In contrast to lean manufacturing, the main focus is efficiency in machine repair through MVSM, 5S method, and visual management (Wijaya, 2019).

Maintenance Value Stream Mapping (MVSM)

MVSM (Maintenance Value Stream Mapping) is a technique to systematically identify and eliminate waste in the machine maintenance process. By mapping all maintenance activities from start to finish, MVSM helps to develop a more efficient preventive maintenance plan, reduce costs, and improve efficiency, productivity, and product quality (Roysen et al., 2024; Ramadhania et al., 2024).

Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is a method to assess how effectively operations management is running in a company. OEE is not an absolute measurement tool, but it can be used to evaluate the performance of an operational process and find ways to improve it. In addition, OEE can also be used as a Key Performance Indicator (KPI) in the company (Ahmad, 2018).

Root Cause Failure Analysis (RCFA)

Root Cause Failure Analysis (RCFA) is the process of identifying the root cause of a failure, then using that information to determine corrective or preventive measures so that a similar failure does not occur again. A simplified flowchart of the RCFA process is shown in the figure below, which helps illustrate the process flow in the analysis (Hidayat and Warjito, 2019).

Methods

This research was conducted at PT PLN Nusantara Power UP Gresik from January 2025. The study used qualitative and quantitative approaches.

Identification and Operational of Variables

The dependent variable in this research is the level of maintenance waste, which is expected to decrease through Lean Maintenance implementation. This waste is identified based on eight categories: Unproductive Work, Delay in Motion, Poor Inventory Management, Overprocessing, Unnecessary Transportation, Excessive Waiting, Defect Rework, and Underutilized Talent. The independent variables are improvement strategies derived from Lean Maintenance principles, including the application of Value Stream Maintenance Mapping (VSMM), calculation of Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and Root Cause Failure Analysis (RCFA).

Data Collection Methods

Data was collected through three primary methods: (1) Direct observation of maintenance activities on HP BFP units to identify real-time workflow inefficiencies; (2) Analysis of maintenance records and documentation to obtain failure frequencies, repair times, and work order history; and (3) Structured interviews with technicians and assistant managers to gather insights into root causes and improvement ideas.

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All collected data was then processed through the VSMM framework to map valuable and non-valuable activities. Failure data was statistically adjusted using Weibull, Lognormal, and Exponential distributions to determine the best model for reliability analysis. The findings from this analysis became the basis for the proposed improvement actions in the Lean Maintenance strategy.

Results and Discussion

Data Collection

Researchers collect data and information from the company PT PLN Nusantara Power UP Gresik to solve the problem. The data collected are primary and secondary data. Primary data is obtained from direct interviews with field supervisors in the form of qualitative and quantitative data, while secondary data is data that has been collected in advance by someone and becomes the company's historical data. The data needed includes High Pressure Boiler Feed Pump (HP BFP) machine maintenance activities, failure records, data related to waste and weighting questionnaires, machine running time data, machine downtime, machine breakdown, actual production, ideal production, average production, production defects, and production scrap.

Table 1. Company machine data collection

Machine	Total Service Hours (Hours)	Total Standby Time (Hours)	Total Period Hours (Hours)	Total Flow Output (Ton/Hours)	Total Ideal Flow Output (Ton/Hours)	Total Average Flow Output (Ton/Hours)
HP BFP 1A	10918.17	6292.67	17544	3306.65	4464.00	3582.20
HP BFP 1B	7962.25	9185.83	17544	2946.17	4392.00	3191.68
HP BFP 1C	8282.17	9087.17	17544	3085.99	4344.00	3343.15
HP BFP 1D	9056.58	8172.08	17544	3025.07	4320.00	3277.16

Source: PT PLN Nusantara Power UP Gresik Company

Based on the data in Table 1, it shows operational data and production results over a period of 2 years.

Table 2. Company machine data collection

Machine	Total Breakdown Time (Hours)	Ideal Cycle Time (Hours/Ton)	Total Defect (Ton/Hours)	Total Scrap (Ton/Hours)
HP BFP 1A	333.17	0.0134	0.00	0.00
HP BFP 1B	395.92	0.0137	0.00	0.00
HP BFP 1C	174.67	0.0138	0.00	0.00
HP BFP 1D	315.33	0.0139	0.00	0.00

Source: PT PLN Nusantara Power UP Gresik Company

Based on the data in Table 2, it shows data on damage time, ideal cycle time, production defects, and production scrap within a period of 2 years.

Table 3. Collection of company machine failure data

Machine Name	Start	Finish	TBF	TTR
ST 1.0 HP *Boiler Feed Pump* (A)	17/04/2023 08:45	28/04/2023 00:00		255.25
ST 1.0 HP *Boiler Feed Pump* (A)	29/05/2023 08:47	31/05/2023 00:00	1008.03	39.22
ST 1.0 HP *Boiler Feed Pump* (A)	28/08/2023 09:04	04/09/2023 00:00	2184.28	158.93
ST 1.0 HP *Boiler Feed Pump* (A)	11/09/2023 09:56	21/09/2023 00:00	336.87	230.07
ST 1.0 HP *Boiler Feed Pump* (A)	16/07/2024 09:01	22/07/2024 00:00	7415.08	134.98
ST 1.0 HP *Boiler Feed Pump* (B)	20/03/2023 09:25	29/03/2023 14:45		221.33
ST 1.0 HP *Boiler Feed Pump* (B)	24/03/2023 12:38	12/04/2023 00:00	99.22	443.37

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ST 1.0 HP *Boiler Feed Pump* (B)	26/05/2023 08:51	29/05/2023 15:08	1508.22	78.28
ST 1.0 HP *Boiler Feed Pump* (B)	11/09/2023 09:27	12/10/2023 14:09	2592.60	748.70
ST 1.0 HP *Boiler Feed Pump* (B)	09/10/2023 09:20	24/10/2023 00:00	671.88	350.67
ST 1.0 HP *Boiler Feed Pump* (B)	17/10/2023 08:49	07/07/2024 15:51	191.48	6343.03
ST 1.0 HP *Boiler Feed Pump* (B)	21/11/2023 09:22	08/01/2024 15:09	840.55	1157.78
ST 1.0 HP *Boiler Feed Pump* (B)	06/12/2023 08:41	03/06/2024 00:00	359.32	4311.32
ST 1.0 HP *Boiler Feed Pump* (B)	16/05/2024 08:43	31/07/2024 16:11	3888.03	1831.47
ST 1.0 HP *Boiler Feed Pump* (B)	21/05/2024 14:00	28/05/2024 00:00	125.28	154.00
ST 1.0 HP *Boiler Feed Pump* (B)	03/07/2024 08:59	07/07/2024 15:17	1026.98	102.30
ST 1.0 HP *Boiler Feed Pump* (B)	30/07/2024 08:48	30/08/2024 15:52	647.82	751.07
ST 1.0 HP *Boiler Feed Pump* (B)	05/09/2024 17:46	06/09/2024 15:07	896.97	21.35
ST 1.0 HP *Boiler Feed Pump* (B)	26/09/2024 10:02	15/05/2025 11:00	496.27	5544.97
ST 1.0 HP *Boiler Feed Pump* (B)	15/10/2024 08:54	17/10/2024 00:00	454.87	39.10
ST 1.0 HP *Boiler Feed Pump* (C)	06/04/2023 08:44	28/04/2023 00:00		519.27
ST 1.0 HP *Boiler Feed Pump* (C)	27/07/2023 08:43	20/09/2023 15:58	2687.98	1327.25
ST 1.0 HP *Boiler Feed Pump* (C)	11/09/2023 09:54	20/12/2023 00:00	1105.18	2390.10
ST 1.0 HP *Boiler Feed Pump* (C)	28/11/2023 09:19	06/07/2024 15:49	1871.42	5310.50
ST 1.0 HP *Boiler Feed Pump* (C)	27/02/2024 08:54	28/02/2024 15:07	2183.58	30.22
ST 1.0 HP *Boiler Feed Pump* (C)	27/02/2024 09:00	25/03/2024 00:00	0.10	639.00
ST 1.0 HP *Boiler Feed Pump* (C)	28/02/2024 10:50	26/04/2024 00:00	25.83	1381.17
ST 1.0 HP *Boiler Feed Pump* (C)	08/05/2024 08:52	09/05/2025 10:00	1678.03	8785.13
ST 1.0 HP *Boiler Feed Pump* (C)	16/05/2024 09:09	17/05/2024 00:00	192.28	14.85
ST 1.0 HP *Boiler Feed Pump* (C)	11/07/2024 09:08	27/08/2024 15:58	1343.98	1134.83
ST 1.0 HP *Boiler Feed Pump* (C)	15/07/2024 09:23	07/08/2024 15:01	96.25	557.63
ST 1.0 HP *Boiler Feed Pump* (C)	03/10/2024 08:46	08/10/2024 00:00	1919.38	111.23
ST 1.0 HP *Boiler Feed Pump* (C)	21/11/2024 08:45	04/12/2024 15:08	1175.98	318.38
ST 1.0 HP *Boiler Feed Pump* (D)	22/05/2023 08:47	23/05/2023 15:11		30.40
ST 1.0 HP *Boiler Feed Pump* (D)	04/06/2023 09:04	05/06/2023 09:00	312.28	23.93
ST 1.0 HP *Boiler Feed Pump* (D)	21/11/2023 09:18	25/11/2023 00:00	4080.23	86.70
ST 1.0 HP *Boiler Feed Pump* (D)	06/12/2023 08:46	26/03/2024 14:09	359.47	2669.38
ST 1.0 HP *Boiler Feed Pump* (D)	27/12/2023 09:33	13/12/2024 15:19	504.78	8453.77
ST 1.0 HP *Boiler Feed Pump* (D)	13/02/2024 10:14	22/04/2024 15:01	1152.68	1660.78
ST 1.0 HP *Boiler Feed Pump* (D)	26/02/2024 09:44	01/03/2024 15:09	311.50	101.42
ST 1.0 HP *Boiler Feed Pump* (D)	07/03/2024 09:10	07/03/2024 14:09	239.43	4.98
ST 1.0 HP *Boiler Feed Pump* (D)	06/05/2024 09:02	13/12/2024 15:06	1439.87	5310.07
ST 1.0 HP *Boiler Feed Pump* (D)	26/08/2024 09:11	16/10/2024 15:30	2688.15	1230.32
ST 1.0 HP *Boiler Feed Pump* (D)	30/12/2024 22:48	28/02/2025 00:00	3037.62	1417.20

Source: PT PLN Nusantara Power UP Gresik Company

Based on the data in Table 3, it shows the failure record data on the PLTGU Block 1 high pressure boiler feed pump (HP BFP) engine within 2 years. The collection of machine failure data is carried out with the aim of documenting the frequency, duration, and type of damage that occurs in the High Pressure Boiler Feed Pump (HP BFP) unit at PLTGU Blok I. The data is obtained through daily log records and maintenance reports during certain operational periods. Data is obtained through daily log records and maintenance reports during certain operational periods. The information collected includes Time Between Failures (TBF) and Time To Repair (TTR), which are key indicators in evaluating the reliability and efficiency of machine maintenance. The results of the data above show that HP BFP Unit A had 5 engine failures, HP BFP Unit B had 15 failures, HP BFP Unit C had 13 failures, and HP BFP Unit D had 11 failures.

It is necessary to analyze failure patterns based on machine type, time of occurrence, and operational conditions. The results of this analysis show that there is a correlation between certain failure modes and the operational characteristics of each machine, which is important

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to serve as a basis for developing predictive maintenance strategies. By identifying recurring patterns and unit-specific vulnerabilities, companies can design more proactive maintenance schedules, reduce downtime, and significantly improve Overall Equipment Effectiveness (OEE).

Maintenance Activity Time Data

Table 4. Observation of Repair Activities on HP BFP machines

No	Maintenance Activities	Time Duration (Minutes)	MMLT Category	Activity Category
1	The operator reported a machine failure	15	MTTO	NNVA
2	Maintenance management assigns a technical team to inspect the damage in detail and identify the cause	30	MTTO	NNVA
3	Maintenance management records incidents in the ILS containing damage, cause, time, and handling plan	30	MTTO	NNVA
4	Maintenance management holds a morning meeting with related teams to discuss ILS, set priorities, prepare work plans, and coordinate between teams.	90	MTTO	NNVA
5	Maintenance management prepares Work Orders containing instructions, schedules, and repair tasks	15	MTTO	NNVA
6	Tool management ensures the availability, suitability and standards of maintenance tools and components	9360	MTTO	NNVA
7	The team (2 mechanics, 2 electricians, 1 tool management) prepares equipment, spare parts, safety equipment, and supporting equipment before repairs	15	MTTO	NNVA
8	Two mechanics disassemble the engine for inspection and repair access	60	MTTR	VA
9	After disassembly, two mechanics clean the engine components to remove dirt that interferes with inspection and repair	30	MTTR	VA
10	Two mechanics repair problematic components through replacement, adjustment, or direct repair	30	MTTR	VA
11	After repair, five personnel (2 mechanics, 2 electrical, 1 control & instrument) test the machine to ensure it functions according to standards	60	MTTY	VA
12	After successful testing, WO is completed as proof of improvement	15	MTTO	NNVA
13	Maintenance management updates machine results and status into SIT ELLIPSE for documentation and monitoring	30	MTTO	NNVA

Source: Data Processing Results

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Based on the data in Table 4, there are 13 activities in the High Pressure Boiler Feed Pump (HP BFP) engine maintenance process. One example of waste is activity no. 6 which has been identified as the activity with the longest waiting time (9360 minutes). Based on the results of direct observations and interviews with parties in the field, it shows that this time is dominated by delays in spare parts procurement due to a less responsive inventory management system. In addition, the approval process for tool procurement takes a long time due to the unavailability of components locally.

Calculation of Current Stream Mapping (VSMM)

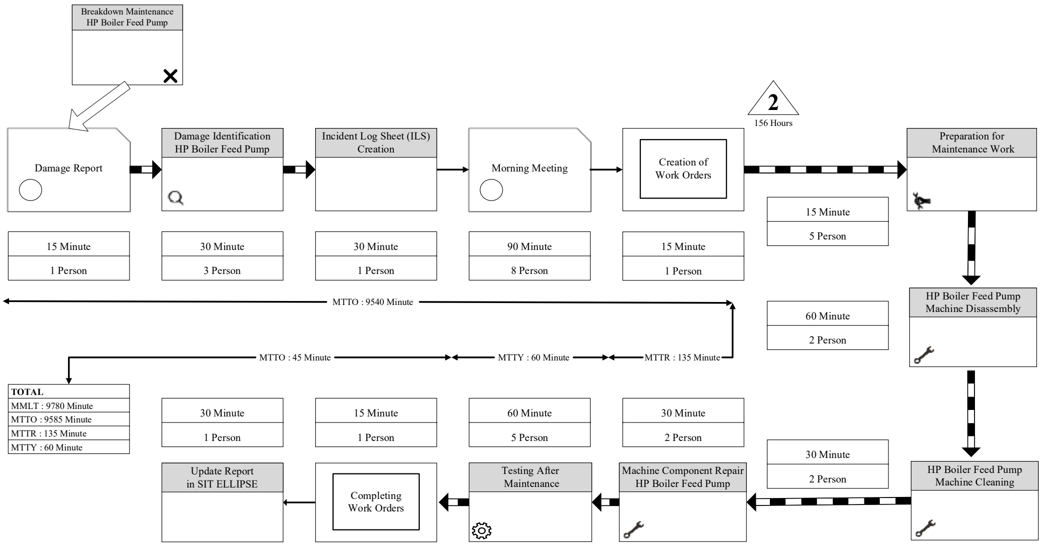

Figure 1. Current Stream Maintenance Mapping of HP BFP Machine Repair

Questionnaire

This questionnaire contains several statements presented in the form of a Likert scale with a range of 1-5. The distribution of the questionnaire was aimed at 10 respondents consisting of the relevant management. The questionnaire was conducted to find out which waste has a large weight or impact on the maintenance process. To ensure the validity of the responses, the questionnaire was distributed to 10 selected respondents who were directly involved in the maintenance process of the High Pressure Boiler Feed Pump (HP BFP) machine, consisting of EQA (Engineering, Quality, and Assurance) performance specialists, PLTGU operation performance specialists, maintenance managers, EQA (Engineering, Quality, and Assurance) managers, Assistant Manager of Maintenance Planning & Control, Assistant Manager of PLTGU Machine & Civil Maintenance, Assistant Manager of PLTGU Control & Instrument Maintenance, Assistant Manager of System Owner, Assistant Manager of Operations Planning & Control, and Assistant Manager of PLTGU Operations. These individuals were selected using a purposive sampling method based on their technical experience and operational knowledge, ensuring that the insights gathered reflect real-world conditions.

Table 5. Waste Maintenance Weighting Value Results

No	Waste	Respondents										Average	Ranking
		1	2	3	4	5	6	7	8	9	10		
1	Unproductive Work	4	4	4	4	3	3	4	4	4	3	34.5	2
		3	3	4	3	3	3	3	3	4	3		
2	Delay in Motion	3	3	4	4	4	4	4	4	4	4	34	3
		3	3	3	3	4	2	5	1	3	3		
3	Unnecessary Motion	2	1	1	1	1	1	1	1	1	1	11.5	8

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		1	1	1	1	1	1	1	1	2	2		
4	Poor Inventory Management	4	4	4	4	4	4	4	4	4	4	40	1
		4	4	4	4	4	4	4	4	4	4		
5	Rework	1	2	2	2	1	1	1	1	1	3	13	6
		1	2	1	1	1	1	1	1	1	1		
6	Ineffective Data Management	1	1	1	1	1	1	1	1	1	1	16	4
		2	2	3	2	2	2	1	3	2	3		
7	Under-utilization of Resource	2	1	2	2	2	1	2	2	2	2	16	4
		2	1	1	1	2	1	1	1	2	2		
8	Misapplication of Machinery	1	1	1	1	1	1	1	1	1	1	12	7
		2	1	1	1	2	2	1	1	2	1		

Source: Data Processing Results

Based on table 5. shows the weight value generated for each type of maintenance waste. Waste with the highest weight is determined as critical waste that causes other waste to appear. In the table above, the 3 highest types of waste are Poor Inventory Management, Unproductive Work, and Delay in Motion.

Identify Maintenance Waste

After weighting, the waste that occurs in the maintenance process will be identified through brainstorming. Identification of waste is based on eight (8) types of maintenance waste, including unproductive work, delay in motion, unnecessary motion, poor inventory management, rework, ineffective data management, under-utilization of resources, and misapplication machines.

Table 6. Types of Waste from HP BFP Machine Maintenance Activities

Maintenance Waste	Waste Indicator	Impact
Unproductive Work	Waiting time in Morning Meeting decision results	Increasing downtime duration
Delay in Motion	No procurement of machine spare parts	Increasing downtime duration
	Long distance and displacement	Maintenance time efficiency decreases
Unnecessary Motion	Less ergonomic layout	Worker fatigue increases
	Inefficient work processes	Waste of processing time
Poor Inventory Management	Lack of spare part inventory control	Over/Under stocking of spare parts
		The repair process is hampered
		Downtime duration increases due to waiting for spare parts availability
Rework	The intensity of breakdowns occurs quite frequently	Downtime increases
Ineffective Data Management	Manual recording on Incident Log Sheet	Inaccurate data complicates maintenance performance analysis
	Reports on SIT ELLIPSE	Prone to input errors

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Under-utilization of Resource	Man Power Maintenance limited	Technicians are overwhelmed because many machines are experiencing breakdowns
		Repairs are slow and need to be prioritized
Misapplication of Machinery	-	-

Source: Data Processing Results

Although the waste category “Misapplication of Machinery” is not accompanied by specific indicators in Table 6, this does not imply negligence. Based on field observations and interviews, it was found that these categories were not significant in the context of HP BFP maintenance. For example, no improper use of machinery was observed during the data collection period. Therefore, these items were deliberately marked with a hyphen (–) to reflect their irrelevance in this specific study.

Calculation of Index of Fit and Distribution Selection for Mean Time Between Failure (MTBF) Data and Calculation of Mean Time To Repair (MTTR)

After collecting the HP BFP engine failure data in table 3. the next step is to determine the distribution of time between failures that will be tested for Goodness of Fit. The distribution that will be tested for Goodness of Fit is in Table 7.

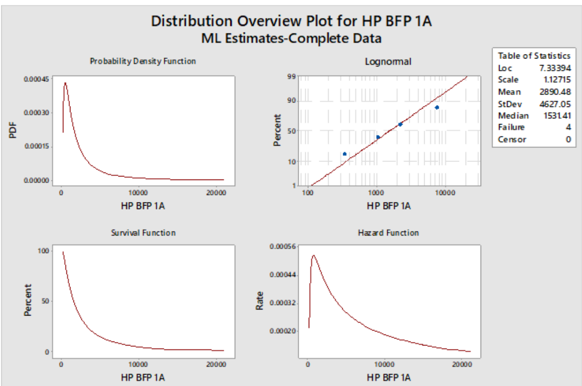
Table 7. Calculation of Index of Fit and Selection of Distribution

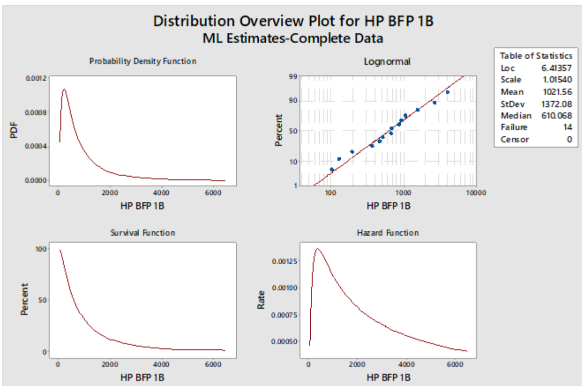
Distribution	Calculation Result			
	HP BFP 1A	HP BFP 1B	HP BFP 1C	HP BFP 1D
Normal	0.92994	0.88814	**0.96504**	0.92968
Lognormal	**0.99927**	**0.98836**	0.80235	0.95511
Eksponensial	0.98965	0.98592	0.89043	**0.96817**
Weibull	0.99538	0.98247	0.89412	0.92932

Source: Data Processing Results

After collecting data on HP BFP engine failures in table 3. the next step is to determine the distribution of time between failures that will be tested for Goodness of Fit. The distribution that will be tested for Goodness of Fit is in Table 7. From the results of the index of fit calculation, it shows that the HP BFP 1A engine has a Lognormal distribution; the HP BFP 1B engine has a Lognormal distribution; the HP BFP 1C engine has a Normal distribution; the HP BFP 1D engine has an Exponential distribution.

The last stage in identifying the distribution is the Goodness of Fit Test (distribution suitability test), which is a statistical suitability test based on the sample time between damages. This distribution suitability test is carried out with the help of Minitab 18 software.





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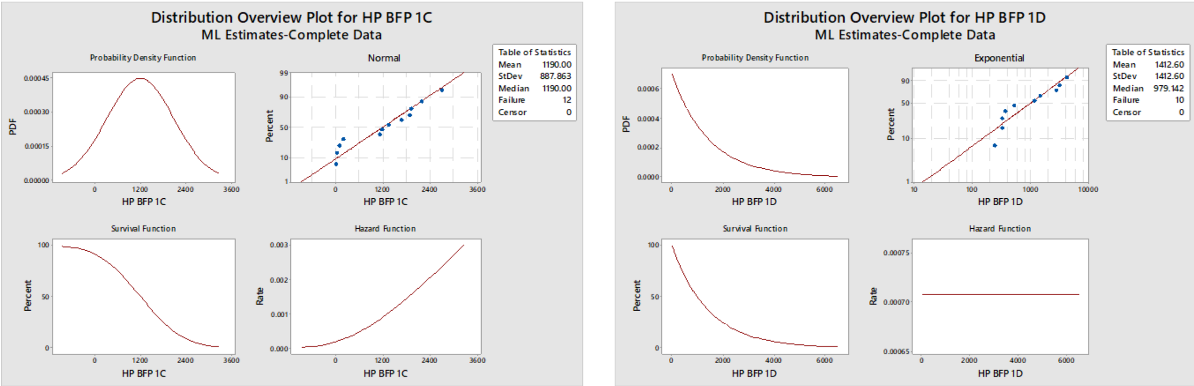

Figure 2. Goodness of Fit Test of High Pressure Boiler Feed Pump (HP BFP) machine

based on figure 2, shows the test results using minitab software. after that, the MTBF recapitulation is based on the selected distribution.

Table 8. Recapitulation of MTBF output from Minitab software and MTTR calculation

Factor of Maintenance	Company Standard	Calculation Result			
		HP BFP 1A	HP BFP 1B	HP BFP 1C	HP BFP 1D
MTBF (Hours)	2000.00	1531.41	610.07	1190.00	979.14
MTTR (Hours)	72.00	163.68	1473.24	1732.27	1908.08

Source: Data Processing Results

Based on table 8. Recapitulation of MTBF output from Minitab software and MTTR calculation, it shows the comparison between Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) on all HP BFP units. When compared to industry standards, the MTBF value should ideally exceed 2000 hours for critical equipment, while the MTTR should not exceed 72 hours. From the table above, it can be seen that only the HP BFP 1A unit is close to the MTBF standard with a value of 1531.41 hours, while the other units are still far below the reliability threshold, indicating a higher frequency of damage. Although the MTBF on this unit is already relatively good, its MTTR value still exceeds the ideal limit of industry standards which generally ranges from 72 hours.

In contrast, the HP BFP 1B unit showed the most critical condition with an MTBF of only 610.07 hours and an MTTR of 1473.24 hours. Similar conditions also occur in HP BFP 1C and 1D, where the MTBF and MTTR of HP BFP 1C machines are in the range of 1190.00 hours and 1732.27 hours. The MTBF and MTTR of HP BFP 1D machines are in the range of 979.14 hours and 1908.08 hours. This significant difference between MTBF and MTTR indicates that the high frequency of damage and the very long duration of repairs in addition to the low level of reliability, the main problem lies in the slow recovery after damage. This indicates the low effectiveness of the maintenance system. After the MTBF and MTTR calculations are carried out, the OEE calculations are then carried out on each High Pressure Boiler Feed Pump (HP BFP) machine.

Calculation of the Overall Equipment Effectiveness (OEE)

Data processing is carried out using the Overall Equipment Effectiveness (OEE) method which is based on three factors, namely availability, performance efficiency, and quality rate. Availability calculation describes the utilization of High Pressure Boiler Feed Pump (HP BFP) machine time available to perform operations, Performance rate describes the actual ability of the machine to operate at ideal speed based on capacity, and quality rate is carried out using data on the amount of water flow that is successfully supplied and the amount that is not successfully supplied.

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After obtaining the availability, performance efficiency, and quality rate values, the OEE value can be measured on each High Pressure Boiler Feed Pump (HP BFP) machine. The results of the OEE calculation can be seen in Table 7.

Table 9. Calculation of Machine OEE at PT Nusantara Power UP Gresik Company and OEE Classification according to JIPM

Factor of OEE	**Standard World Class**	**Calculation Result**				**Average**
		HP BFP 1A	**HP BFP 1B**	**HP BFP 1C**	**HP BFP 1D**	
Availability Rate	90%	98%	98%	99%	98%	98%
Performance Rate	95%	74%	67%	71%	70%	71%
Quality Rate	99%	92%	92%	92%	92%	92%
OEE	85%	67%	61%	65%	63%	67%

Source: Data Processing Results

From table 9 above, it can be seen that the results of the calculation of the OEE value of the High Pressure Boiler Feed Pump (HP BFP) machine at the Company at PT. PLN Nusantara Power UP Gresik for the period January 2023 - December 2024 are still below standard, which is around 67% on the HP BFP 1A machine; HP BFP 1B is 61%; HP BFP 1C is 65%; HP BFP 1D is 67%, this shows that the value is still below the standard recommended by the Japan Institute of Plan Maintenance (JIPM), which is 85%.

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Calculation of the Six Big Losses

The second stage after getting the OEE value from each High Pressure Boiler Feed Pump (HP BFP) machine is to calculate the six big losses. Six big losses are six factors that affect the OEE value. The six big loss values of each High Pressure Boiler Feed Pump machine that are not yet ideal are calculated to determine the most dominant factors that influence the OEE value. The six big losses are represented by downtime losses (damage, preparation, and standby losses), speed losses (losses when idling and minor stops and reduced speed losses), and defect losses (rework losses and scrap losses).

Table 10. Calculation of Six Big Losses of HP BFP Machines at PT Nusantara Power UP Gresik Company

Factor of Six Big Losses	Calculation Result				Total	%	Ranking
	HP BFP 1A	HP BFP 1B	HP BFP 1C	HP BFP 1D			
Equipment Failure Losses	1.899	2.257	0.996	1.797	6.949	2%	3
Setup And Adjustment	35.868	52.359	51.796	46.581	186.604	47%	2
Idling And Minor Stoppage Losses	0.089	0.113	0.099	0.103	0.403	0%	4
Reduce Speed Losses	61.980	45.155	46.965	51.383	205.482	51%	1
Process Defect Losses	0.00	0.00	0.00	0.00	0.00	0%	5
Reduce Yield Losses	0.00	0.00	0.00	0.00	0.00	0%	5
Total					**399.438**	**100%**	

Source: Data Processing Results

Based on the results of the calculation of the percentage of the six big losses factors above, it shows that the biggest root problem that affects the OEE value is caused by Reduce Speed Losses with a value of 51% and Setup and Adjustment with a value of 47%.

Problem Analysis Using Root Causes Failure Analysis (RCFA)

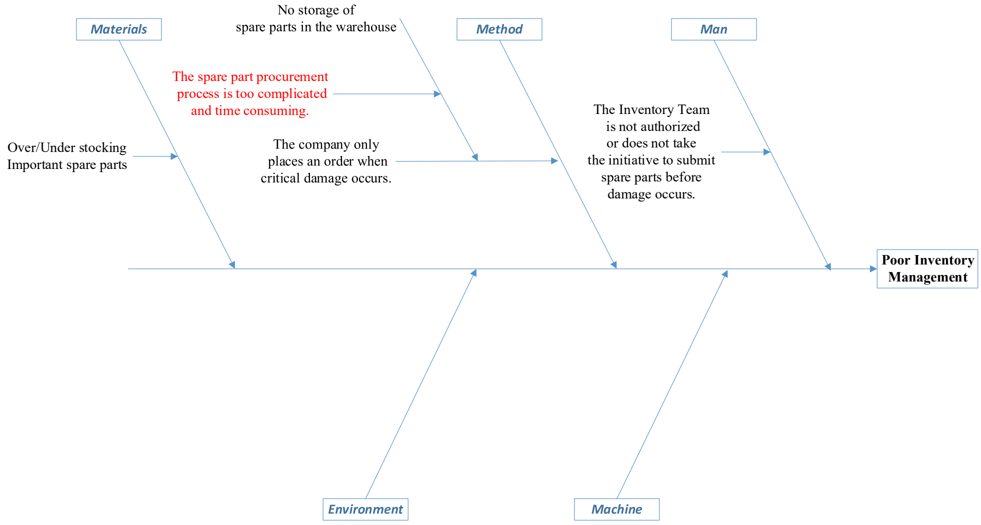

Figure 3. RCFA of Waste Poor Inventory Management

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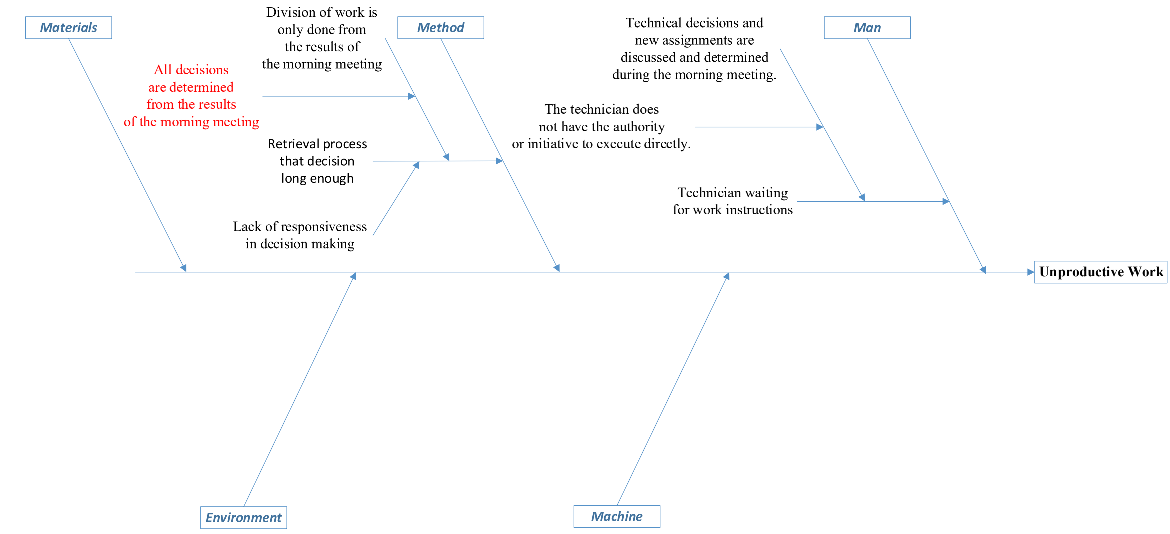

Figure 4. RCFA of Waste Poor Unproductive Work

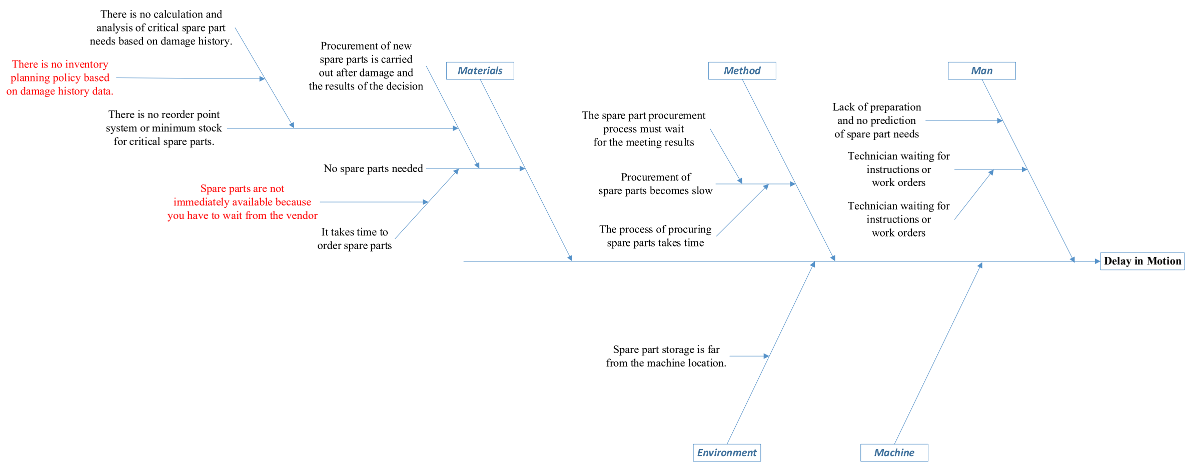

Figure 5. RCFA of Waste Delay in Motion

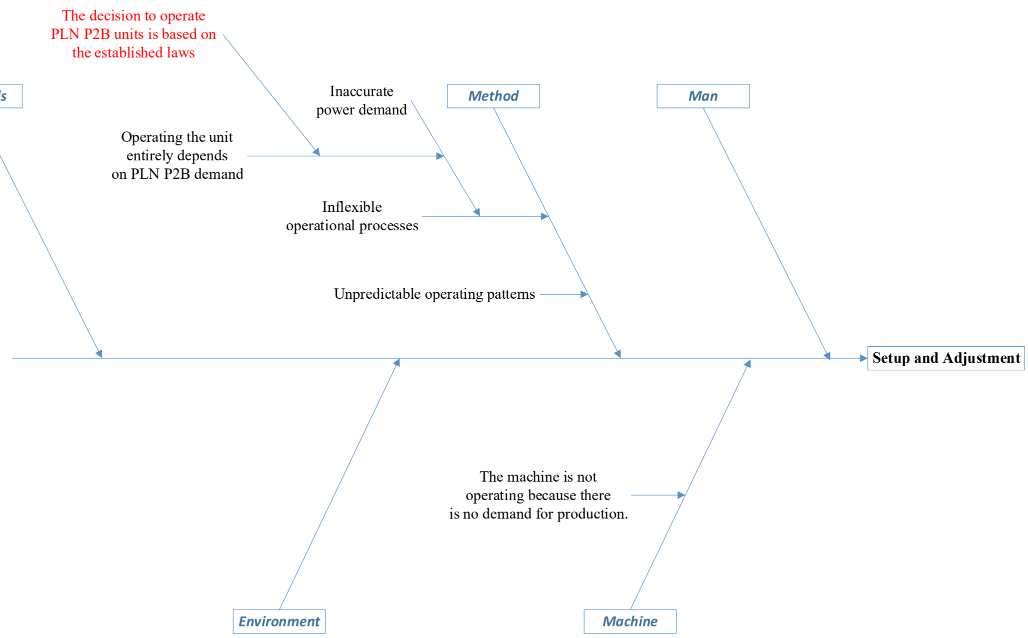

Figure 6. RCFA of Setup and Adjustment Losses

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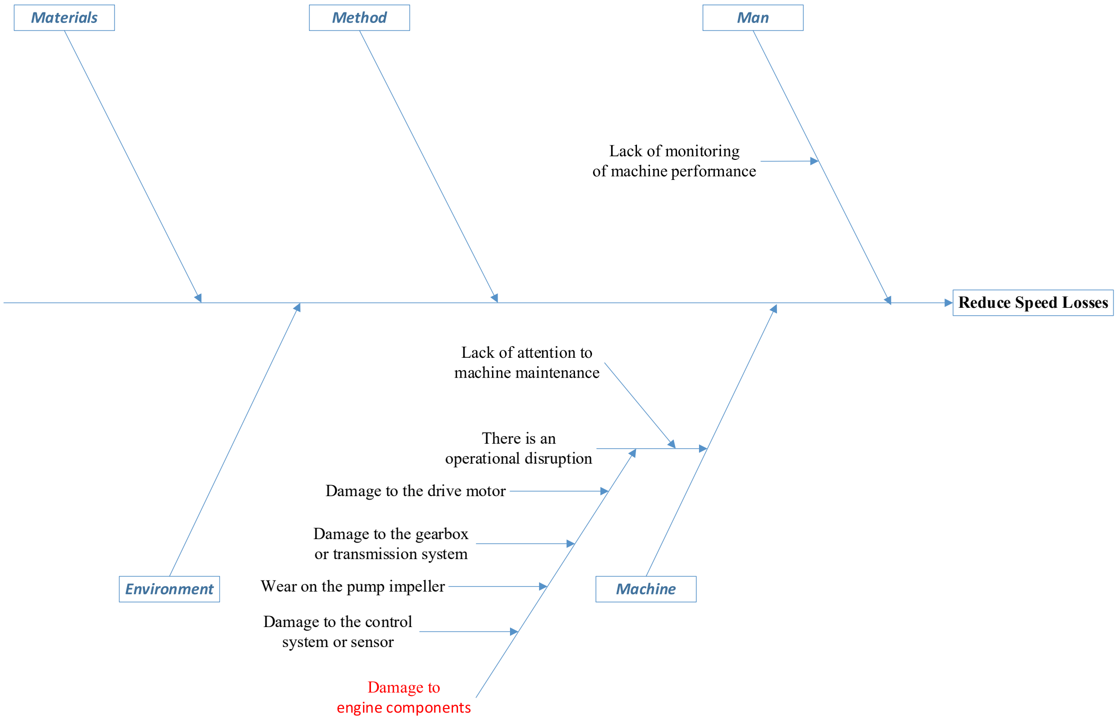

Figure 7. RCFA of Reduce Speed Losses

Improvement Recommendations with Total Productive Maintenance (TPM) Bundle

The TPM bundle is designed to combine various practices to maximize equipment effectiveness. The TPM concept, developed by Seichii Nakajima in Japan, aims to achieve zero losses. TPM can be integrated with a lean approach to identify and eliminate six big losses, namely: breakdown losses, setup losses, idle losses, reduced speed losses, defect losses, and start-up losses. The TPM bundle consists of : 1) Autonomous Maintenance; 2) Planned Maintenance ✓; 3) Root Cause Analysis (RCA) and Problem Solving; 4) Safety Improvement; 5) Overall Equipment Effectiveness (OEE); 6) Work Order System

Table 11. Recapitulation Index of Fit to Failure

Units	**Distribution**	**MTBF (Hours)**	***Index of Fit***	***Reliability***
HP BFP 1A	Lognormal	1531.41	0.999272	100%
HP BFP 1B	Lognormal	610.07	0.988364	99%
HP BFP 1C	Normal	1190.00	0.965044	97%
HP BFP 1D	Eksponential	979.14	0.968166	97%

Source: Data Processing Results

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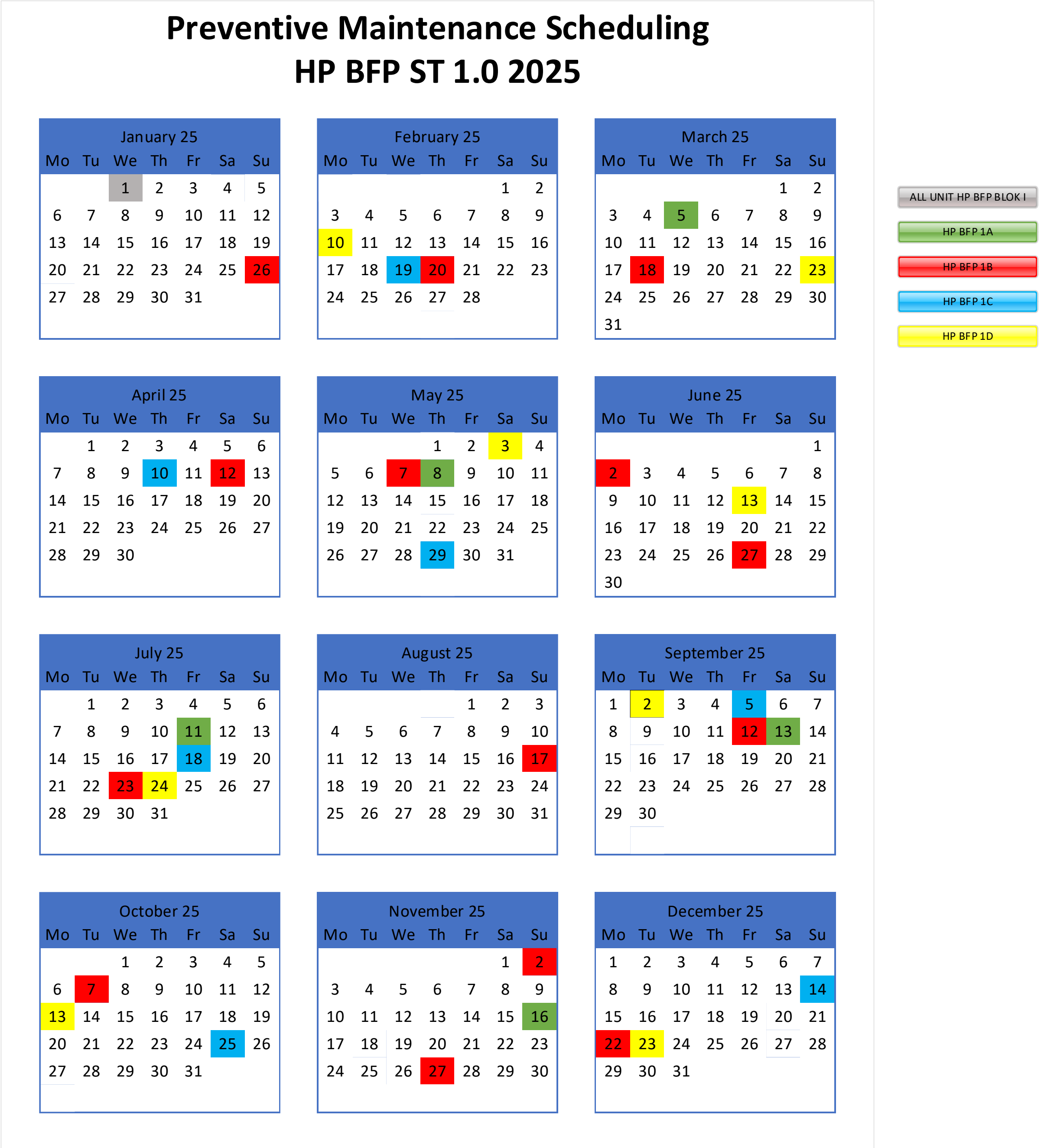

Figure 7. Preventive Maintenance Scheduling

Results After Implementation

After identifying and analyzing various problems in the maintenance process, corrective measures have been implemented to improve the efficiency and effectiveness of machine operations. The researcher evaluated the impact of the improvements that had been made, as well as measuring how much change was achieved in aspects of machine performance and the overall maintenance process.

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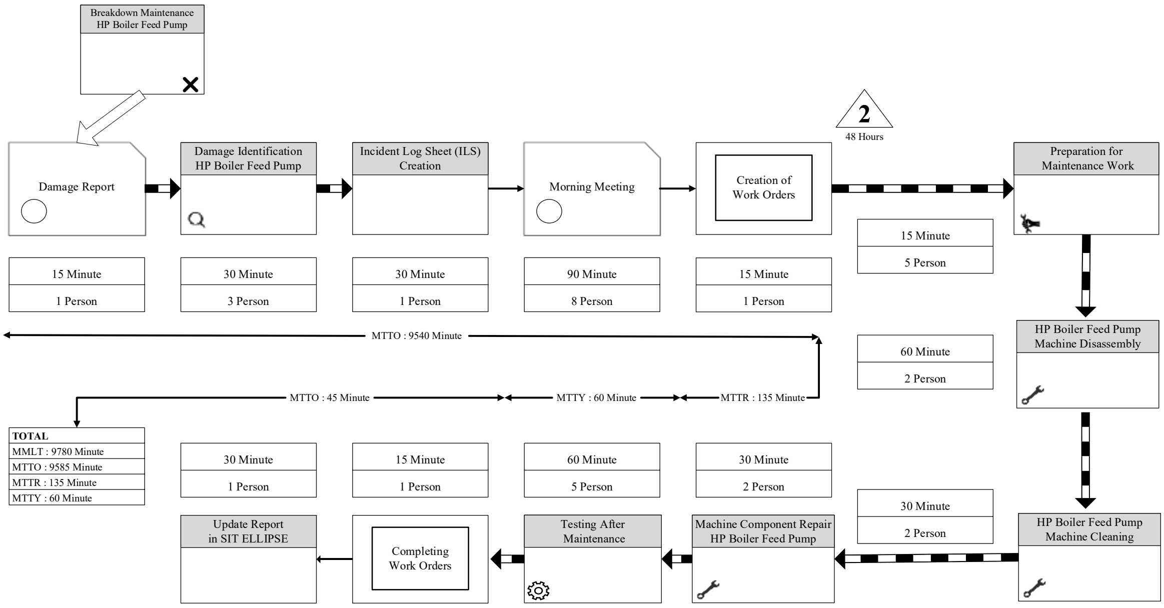

Figure 8. Future State Maintenance Mapping of HP BFP Machine Repair

After evaluating the maintenance activities on the High Pressure Boiler Feed Pump (HP BFP) machine, the next step is to evaluate the direct impact of the improvements made on the three main components of OEE, namely Availability, Performance, and Quality. By measuring OEE after improvements, a clearer picture of the improvement in machine operational performance is expected, as well as how effective the improvement measures are in increasing productivity and reducing downtime.

Table 12. Machine Data Collection After Implementation

Machine	Total Period Hours (Hours)	Total Service Hours (Hours)	Total Standby Time (Hours)	Total Flow Output (Ton/Hours)	Total Ideal Flow Output (Ton/Hours)	Total Average Flow Output (Ton/Hours)
HP BFP 1A	2160.00	804.75	1355.25	483.24	558.00	483.24
HP BFP 1B	2160.00	1609.75	550.25	475.67	549.00	475.67
HP BFP 1C	2160.00	1508.25	651.75	479.97	543.00	479.97
HP BFP 1D	2160.00	1615.17	544.83	470.42	540.00	470.42

Source: Data Processing Results

Table 13. Calculation of OEE of High Pressure Boiler Feed Pump (HP BFP) Machine at PT Nusantara Power UP Gresik Company after Implementation

Factor of OEE	Standard World Class	Calculation Result				Average
		HP BFP 1A	HP BFP 1B	HP BFP 1C	HP BFP 1D	
Availability Rate	90%	100%	100%	100%	100%	100%
Performance Rate	95%	87%	87%	88%	87%	87%
Quality Rate	99%	100%	100%	100%	100%	100%
OEE	85%	87%	87%	88%	87%	87%

Source: Data Processing Results

From table 11 above, it can be seen that the results of the calculation of the OEE value of the High Pressure Boiler Feed Pump (HP BFP) machine after the implementation of the proposed improvements to the Company at PT PLN Nusantara Power UP Gresik for the period January 2025 - March 2025 are still below the standard, which is around 87% on the HP BFP 1A

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machine; HP BFP 1B at 87%; HP BFP 1C at 88%; HP BFP 1D at 87%, this shows that this value is in accordance with the standards recommended by the Japan Institute of Plan Maintenance (JIPM), which is 85%.

Comparison of Results Before and After Implementation

Comparison between the calculation results of the current state maintenance mapping and the future state maintenance mapping on the improvement activities of the High Pressure Boiler Feed Pump machine maintenance activities presented in Figure 1 and Figure 7.

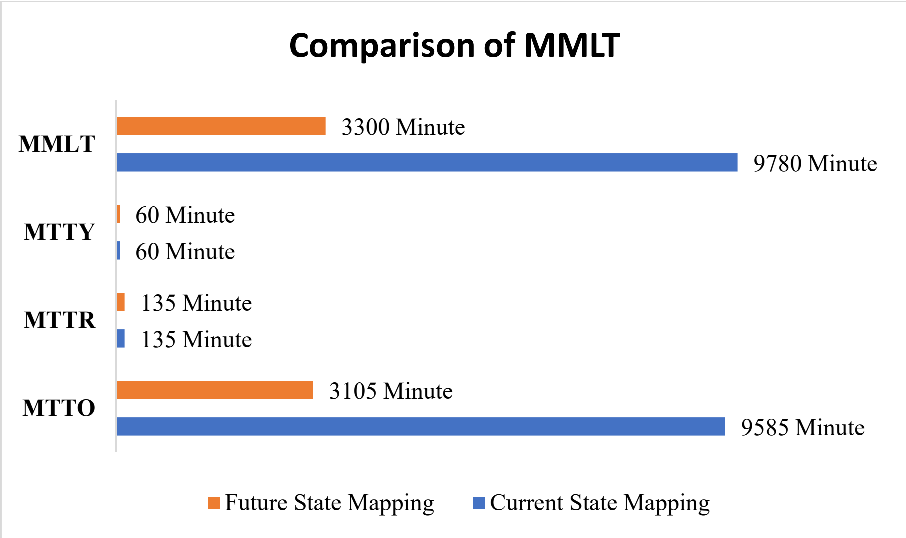

Figure 9. Comparison of MMLT Categories Current State Maintenance Mapping and Future State Maintenance Mapping

Based on Figure 8. shows that the implementation of the improvements made succeeded in reducing the MMLT (Mean Maintenance Lead Time) time showing a significant decrease from 9,780 minutes before improvement to 3,300 minutes after improvement, a decrease of 6,480 minutes or 108 hours. This decrease reflects an increase in efficiency in the maintenance process, which means that the time required to complete the entire series of machine maintenance has become faster after the implementation of improvements. This indicates success in reducing time wastage in the maintenance process.

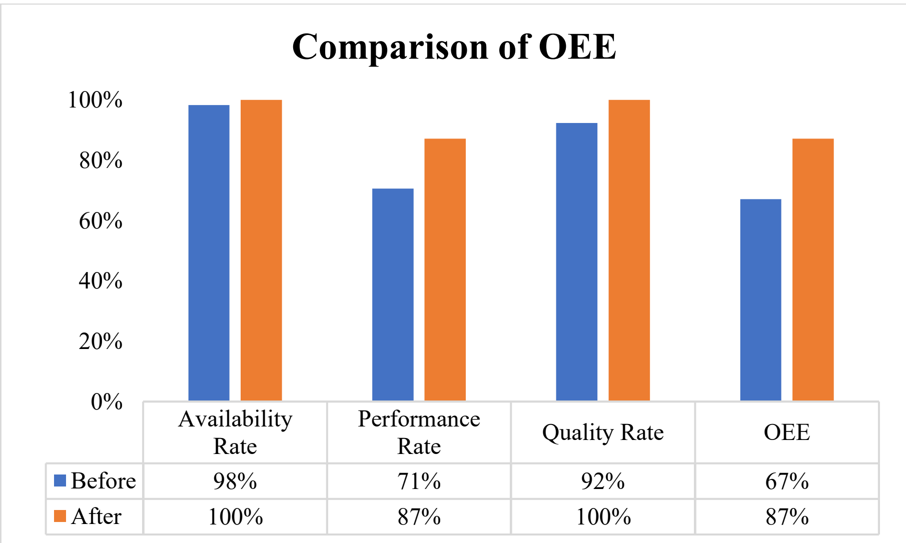

Figure 10. Comparison of OEE on High Pressure Boiler Feed Pump (HP BFP) Machines Before and After Implementation at PT PLN Nusantara Power UP Gresik

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Based on Figure 9, all units experienced a significant increase of 20% from 67% to 87%. This increase indicates effective improvements to the machine's operational performance, reduced waste, and improved overall operational efficiency after the improvements were implemented. This indicates that the corrective measures taken have been successful in improving machine performance, which contributes to reduced downtime and increased machine availability.

Conclusion

This study shows that the implementation of Lean Maintenance at the HP BFP unit of PT PLN Nusantara Power UP Gresik significantly improves operational performance. The implementation of VSMM, MTBF, MTTR, and RCFA successfully identified and reduced critical maintenance waste. As a result, Overall Equipment Effectiveness (OEE) increased from 67% to 87%, and total maintenance time decreased from 9,780 minutes to 3,300 minutes. These improvements indicate the success of the transition to a more efficient and reliable maintenance strategy. Further work is recommended to expand Lean Maintenance practices to other critical units in the power plant and continue to improve documentation and technician training systems.

Acknowledgment

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