Quality Assurance Analysis Using The Six Sigma Dmaic Method To Reduce Product Defects

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Abstract.
Forklifts are essential material handling equipment that play a significant role in supporting operational activities in manufacturing companies. The high intensity of forklift usage increases the risk of equipment failure, resulting in higher downtime and reduced operational effectiveness. This study aims to analyze the operational effectiveness of Forklift 1 using the Overall Equipment Effectiveness (OEE) method and to propose maintenance improvements to enhance forklift reliability and operational performance. This research employs the Overall Equipment Effectiveness (OEE) method, which consists of three main indicators: Availability Rate, Performance Efficiency, and Quality Rate. The data were collected through observations, interviews, documentation, and historical records of Forklift 1 operations and maintenance. The results indicate that before the proposed maintenance improvements were implemented, the OEE values were relatively low, reaching 36.9% in October, 63.8% in November, and 18.8% in December. After implementing a preventive maintenance schedule based on 540 operating hours, the OEE values improved significantly to 99.8% in January, 81.2% in February, and 99.8% in March. These findings demonstrate that the implementation of the OEE method effectively improves forklift operational performance by reducing downtime, increasing equipment reliability, and optimizing maintenance scheduling. Therefore, the OEE method can serve as an effective reference for improving productivity and operational efficiency in manufacturing companies.
Keywords: *Overall Equipment Effectiveness (OEE), Forklift, Preventive Maintenance, Downtime and Operational Effectiveness.*

INTRODUCTION

The manufacturing industry plays a significant role in supporting economic growth through production The manufacturing industry currently faces increasing pressure to achieve higher production efficiency, maintain product quality, and ensure equipment reliability. To remain competitive in a rapidly changing industrial environment, companies are required not only to increase production capacity but also to ensure that operational processes are carried out efficiently by minimizing waste and unnecessary losses (Sidiq *et al.*, 2026). One of the critical factors supporting sustainable production performance is the ability of industrial equipment to operate reliably and consistently according to operational requirements.

Onshore fabrication companies are industrial organizations engaged in the manufacturing and assembly of components, structures, or equipment within land-based facilities. In the oil and gas sector, onshore activities refer to operations conducted on land, such as fabrication yards, workshops, and manufacturing facilities, in contrast to offshore activities that take place at sea or offshore platforms (Asshiddiqie *et al.*, 2023). These companies typically produce various industrial components, including steel structures, pipelines, modules, tanks, skids, and other supporting equipment required for land based projects. Unlike offshore operations, which are characterized by marine environments, onshore fabrication activities are conducted within controlled industrial areas. However, many fabrication companies still experience challenges in maintaining equipment reliability, particularly in machining and threading operations (Simanungkalit *et al.*, 2026).

Operational problems such as high defect frequency, extended repair waiting time, unstable processing speed, and products that fail to meet technical specifications can significantly reduce production efficiency. Therefore, an appropriate analytical approach is required to objectively evaluate equipment performance and identify factors affecting operational effectiveness (Adellia, 2025). One of the approaches widely applied in manufacturing industries is the measurement of equipment effectiveness through systematic performance indicators.

Manufacturing and fabrication companies generally establish Maintenance Facility Departments responsible for maintaining equipment reliability. These departments commonly consist of mechanical maintenance and infrastructure maintenance units that ensure production facilities remain functional and available (Suhendra *et al.*, 2025). Due to the intensive utilization of forklifts and high operational demands, an effective maintenance system is essential. Maintenance activities include pre-operation inspections, routine weekly checks, and periodic servicing based on operational schedules to prevent unexpected failures and reduce equipment downtime (Albar *et al*., 2024).

Based on observations conducted over a three-month period involving ten forklift units with a capacity of seven tons, the company established an operational target requiring forklifts to achieve 80% utilization from 30 working days each month. However, operational data indicated that forklift performance remained below the expected standard, with equipment condition effectiveness ranging from 0.9% to 63%. The lowest performance occurred in February when one forklift unit experienced ten days of operational inactivity. In subsequent months, several forklift units continued to experience considerable downtime. These conditions indicate that the existing maintenance system had not achieved optimal effectiveness, mainly due to delays in implementing preventive maintenance caused by continuous production demands that limited equipment shutdown periods.

Table 1. Forklift Failure Data

Forklift Unit	Total Failures	Failure Duration (Hours) (18 Hours/Day)	Failure Percentage (%)	Equipment Condition (%)	Company Standard (%)
Forklift 01	20	216	60	40	80
Forklift 02	3	54	10	90	80
Forklift 03	3	54	10	90	80
Forklift 04	12	216	40	60	80
Forklift 05	17	206	56	44	80
Forklift 06	14	232	46	54	80
Forklift 07	15	210	50	50	80
Forklift 08	19	178	60	40	80
Forklift 09	8	144	26	74	80
Forklift 10	8	144	26	74	80

Source: Author's Data

Description:

Time unit (Hour) = 540 hours - time unit of damage

Percentage of damage (%) = (30 days) / (total damage)

Percentage of good condition (%) = 100% - percentage of damage

Calculation Notes:

Failure duration was calculated based on the total available operating time of the forklift, using the following parameters:

a. Total operating time of forklift = 540 hours
b. Maximum performance level = 100%
c. Total working period = 30 days per month

The failure analysis shows that several forklift units did not achieve the operational effectiveness target established by the company, which was set at 80% equipment availability. Forklift 01 and Forklift 08 recorded the highest failure percentages, reaching 60%, resulting in only 40% equipment condition effectiveness. These findings indicate that excessive downtime and inadequate maintenance scheduling affected forklift operational reliability. Furthermore, several technical problems were identified during the observation period, including fuel leakage, hydraulic oil leakage, sudden engine shutdown caused by fuel filter blockage, bearing failure, and damaged tie rod components. These failures negatively affected operational continuity by increasing downtime, reducing equipment performance, and interrupting production activities (Tiara *et al.*, 2023).

Table 2. Forklift Damage Types and Their Impact on Production Performance

Damage Type	Impact on Production Process	Damage Illustration
Fuel leakage	Fuel pressure loss causes unstable engine performance, temporary equipment stoppage, and increased operational downtime.	
Hydraulic oil leakage	Reduced hydraulic pressure affects the lifting and movement system, resulting in suboptimal forklift performance during material handling activities.	
Fuel filter blockage	Blocked fuel filters may cause sudden engine shutdowns, interrupt production activities, and increase machine setup and recovery time.	
Broken bearing	Bearing failure causes unstable spindle rotation, excessive vibration, and a decline in equipment performance and product quality.	
Damaged tie rod	Tie rod failure reduces clamping accuracy and stability, potentially causing product defects and interrupting production operations.	

Source: Author's Data

From the table and image of the causes of damage caused by constraints in forklift engine maintenance above, we can see how many percent are in good condition and how many percent are in damaged condition, which due to the level of damage that does not meet the company's standards, will have an impact on production delays that can have a negative impact on consumers, wasted time waiting for repair tools, increasing company expenses due to increasing damage costs. Based on the background above, the researcher raised a study entitled "Analysis of the Application of the Overall Equipment Effectiveness (OEE) Method in Forklift Maintenance to Increase Operational Effectiveness".

II. METHODS

Research Design

This study employed a quantitative applied research approach using a case study design to analyze the operational effectiveness of forklift equipment through the Overall Equipment Effectiveness (OEE) method. A quantitative approach was selected because the research focuses on numerical measurements of equipment performance based on three main indicators: Availability Rate, Performance Efficiency, and Quality Rate. The OEE method is widely applied in manufacturing industries because it provides an integrated measurement of equipment utilization and identifies factors that reduce operational effectiveness (Prabowo et al., 2024).

This research focused on Forklift 1 as the main research object. The selection of this unit was based on preliminary observations indicating that Forklift 1 experienced higher breakdown frequency and downtime compared with other forklift units. These conditions affected operational continuity and required a systematic evaluation of the maintenance system using the OEE approach.

Research Location and Object

The research was conducted in a manufacturing/fabrication company that utilizes forklifts as material handling equipment to support operational activities. The object of this study was Forklift 1, which was selected because of its intensive utilization and relatively low operational performance. The research object was determined using a purposive sampling technique, considering that Forklift 1 represented the equipment with significant maintenance problems, including frequent failures and extended downtime. A case study approach was considered appropriate because it enables an in-depth analysis of equipment reliability, maintenance effectiveness, and improvement strategies within an actual industrial environment (Suhendra & Betrianis, 2025a).

Data Collection

The data used in this study consisted of primary and secondary data.

a. Primary Data

Primary data were collected through direct observation, interviews, and field

documentation. Direct observation was conducted to identify the actual operating conditions of the forklift, including equipment utilization, operational activities, and technical problems occurring during production processes. Interviews were conducted with maintenance personnel and forklift operators to obtain information regarding equipment failures, maintenance procedures, and challenges in implementing preventive maintenance.

Documentation was used to support the observation results by recording the physical condition of forklift components and maintenance activities. The combination of observation, interviews, and documentation is commonly used in industrial maintenance research because it provides both technical measurements and practical information regarding equipment performance (Purba et al., 2024).

b. Secondary Data

Secondary data were obtained from company maintenance records and operational reports. The collected data included:

1) Operating hours,
2) Loading time,
3) Downtime,
4) Breakdown records,
5) Preventive maintenance activities,
6) Corrective maintenance records.

These data were used to calculate the OEE indicators consisting of availability, performance efficiency, and quality rate.

Data Analysis Technique

The data analysis was performed using the Overall Equipment Effectiveness (OEE) method. OEE is a performance measurement framework developed to evaluate equipment effectiveness by integrating three important components: availability, performance efficiency, and quality rate (Ramdhani et al., 2024).

The OEE calculation formula is expressed as:

OEE = Availability×Performance Efficiency×Quality Rate (Ramdhani et al., 2024).

a. Availability Rate Analysis

Availability rate measures the proportion of actual operating time compared with the planned production time. This indicator reflects the impact of equipment downtime and failure duration on operational readiness.

The calculation formula is:

Availability = Loading TimeOperating Time×100%

A higher availability value indicates better equipment reliability and lower time losses caused by breakdowns or maintenance activities (Rohmatin & Wahyuni, 2022).

b. Performance Efficiency Analysis

Performance efficiency measures the ability of equipment to operate according to its ideal performance speed. This indicator evaluates whether the forklift can achieve its expected operational capacity. The formula is:

Performance Efficiency =Operating TimeIdeal Cycle Time×Total Output×100%

Low performance efficiency indicates productivity losses caused by reduced operating speed, technical problems, or inefficient equipment utilization (Geun Lee et al., 2023).

c. Quality Rate Analysis

Quality rate measures the percentage of successful operational activities compared with total operational output. The formula is:

Quality Rate = Total OutputGood Output×100%

This indicator reflects the ability of equipment to perform operational activities without producing failures or quality problems (Prabowo et al., 2024).

OEE Evaluation and Improvement Analysis

After calculating the three OEE components, the obtained values were analyzed by comparing the equipment performance before and after implementing preventive maintenance improvements. The initial OEE calculation showed that Forklift 1 had relatively low effectiveness values, ranging from 18.8% to 63.8%. After implementing a preventive maintenance schedule based on 540 operating hours, the OEE value increased to 81.2%–99.8%. This improvement indicates that scheduled preventive maintenance contributes to reducing downtime, increasing equipment reliability, and improving operational continuity.

III. RESULT AND DISCUSSION

Data Processing

The data processing stage in this study focused on Forklift 01 as the primary research object. The selection of Forklift 01 was based on preliminary observations indicating that this unit experienced a higher frequency of breakdowns and longer downtime compared with other forklift units. These conditions resulted in lower operational effectiveness, requiring further evaluation using the Overall Equipment Effectiveness (OEE) method (Gaol & Irwan, 2026).

The data analyzed in this study consisted of operational and maintenance records, including loading time, operating time, downtime, preventive maintenance records, corrective maintenance activities, and forklift failure data during the research period. The collected data were subsequently processed to determine three main OEE components: Availability, Performance Efficiency, and Quality Rate, which were then used to calculate the overall OEE value.

Availability Analysis

Availability represents the proportion of actual operating time compared with the planned production time. This indicator is used to evaluate the readiness of equipment to perform its operational functions. The calculation of Availability requires the following parameters:

1. Operating Time
2. Planned Downtime
3. Equipment Downtime

The Availability formula is expressed as follows:

Avaibility = (operation time-(Down time+ planned downtime))/(operation time) x 100%

Calculation of Forklift 01 Availability:

a. Forklift 01 in January

$$Availability = \frac{540 - 360 + 2}{540} \; x\ 100\ \% = 33{,}7\ \%$$

b. Forklift 01 in February

$$Availability = \frac{540 - 324 + 2}{540} \; x\ 100\ \% = 40{,}3\ \%$$

c. Forklift 01 in March

$$Availability = \frac{540 - 396 \mp 2}{540} \ x\,100\ \% = 27\ \%$$

d. Forklift 01 in April

$$Availability = \frac{540 - 0 + 2}{540} \ x\,100\ \% = 100{,}3\ \%$$

e. Forklift 01 in May

$$Availability = \frac{540 - 36 + 2}{540} \ x\,100\ \% = 93{,}7\ \%$$

f. Forklift 01 in June

$$Availability = \frac{540 - 0 + 2}{540} \ x\,100\ \% = 100{,}3\ \%$$

Table 3. Availability Rate of Forklift 01

Period	Month	Availability Rate
Before Maintenance Improvement	January	33.7%
	February	40.3%
	March	27.0%
After Maintenance Improvement	April	100.3%
	May	93.7%
	June	100.3%

Results of researcher data processing in 2026

After implementing routine maintenance activities, Forklift 01 showed significant improvement in availability performance. The calculation results indicate that the availability value increased to 100.3% in April, 93.7% in May, and 100.3% in June**.** This improvement demonstrates that scheduled maintenance activities contributed to reducing equipment downtime and improving operational readiness.

Performance Efficiency Analysis

Performance Efficiency measures the ability of equipment to operate according to expected performance levels by considering operating time losses caused by downtime and planned maintenance activities. The calculation formula is:

$$Performance \ = \frac{operation\ time - (down\ time - planned\ downtime\ )}{operation\ time}\ x\ 100\%$$

Calculation of Forklift 01 Performance Efficiency:

a. **January**

$$Performance\ rate = \frac{540 - 360 - 2}{540} \ x\,100\ \% = 32{,}9\ \%$$

b. **February**

$$Performance\ rate = \frac{540 - 324 - 2}{540} \ x\,100\ \% = 39{,}6\ \%$$

c. **March**

$$Performance\ rate = \frac{540 - 396 - 2}{540} \ x\,100\ \% = 26{,}2\ \%$$

d. **April**

$$Performance\ rate = \frac{540 - 0 - 2}{540} \ x\,100\ \% = 99{,}6\ \%$$

e. **May**

$$Performance\ rate = \frac{540 - 36 - 2}{540} \ x\,100\ \% = 92{,}9\ \%$$

f. **June**

$$Performance\ rate = \frac{540 - 0 - 2}{540} \ x\,100\ \% = 99{,}6\%$$

Table 4. Performance Efficiency Rate of Forklift 01

Period	Month	Performance Efficiency
Before Maintenance Improvement	January	32.9%
	February	39.6%
	March	26.2%
After Maintenance Improvement	April	99.6%
	May	92.9%
	June	99.6%

Results of researcher data processing in 2026

Quality Rate Analysis

Quality Rate indicates the proportion of successful operational performance compared with total operational time. This indicator reflects the ability of equipment to operate effectively without experiencing operational losses. The Quality Rate formula is calculated as follows:

$$Quality\ rate = \frac{operation\ time - down\ time}{operation\ time} x\ 100\%$$

Calculation of Forklift 01 Quality Rate:

a. January

$$Quality\ rate = \frac{540 - 360}{540}\ x\ 100\ \% = 33{,}3\ \%$$

b. February

$$Quality\ rate = \frac{540 - 324}{540}\ x\ 100\ \% = 40\ \%$$

c. March

$$Quality\ rate = \frac{540 - 396}{540}\ x\ 100\ \% = 26{,}6\ \%$$

d. April

$$Quality\ rate = \frac{540 - 0}{540}\ x\ 100\ \% = 100\ \%$$

e. May

$$Quality\ rate = \frac{540 - 36}{540}\ x\ 100\ \% = 93{,}3\ \%$$

f. June

$$Quality\ rate = \frac{540 - 0}{540}\ x\ 100\ \% = 100\ \%$$

Table 5. Quality Rate of Forklift 01

Period	Month	Quality Rate
Before Maintenance Improvement	January	33.3%
	February	40.0%
	March	26.6%
After Maintenance Improvement	April	100.0%
	May	93.3%
	June	100.0%

Results of researcher data processing in 2026

Overall Equipment Effectiveness (OEE) Calculation

Overall Equipment Effectiveness (OEE) is a performance measurement method used to evaluate the actual effectiveness of equipment or production systems. After obtaining the values of Availability, Performance Efficiency, and Quality Rate for each month, the overall OEE value was calculated to determine the operational effectiveness level of Forklift 01. The OEE calculation formula is expressed as:

a. January

$OEE = availability\ x\ performance\ rate\ x\ quality\ rate$

$OEE = \% \ x \ \% \ x \ \%$
OEE = 33,7 % x 32,9 % x 33,3 %
= 36,9 %

b. February

$OEE = availability \ x \ performance \ rate \ x \ quality \ rate$
$OEE = \% \ x \ \% \ x \ \%$
OEE = 40,3 % x 39,6 % x 40 %
= 63,8 %

c. March

$OEE = availability \ x \ performance \ rate \ x \ quality \ rate$
$OEE = \% \ x \ \% \ x \ \%$
OEE = 27 % x 26,2 % x 26,6 %
= 18,8 %

d. April

$OEE = availability \ x \ performance \ rate \ x \ quality \ rate$
$OEE = \% \ x \ \% \ x \ \%$
OEE = 100,3 % x 99,6 % x 100 %
= 99,8 %

e. May

$OEE = availability \ x \ performance \ rate \ x \ quality \ rate$
$OEE = \% \ x \ \% \ x \ \%$
OEE = 93,7 % x 92,9 % x 93,3 %
= 81,2 %

f. June

$OEE = availability \ x \ performance \ rate \ x \ quality \ rate$
$OEE = \% \ x \ \% \ x \ \%$
OEE = 100,3 % x 99,6 % x 100 %
= 99,8 %

Analysis and Discussion

Based on the OEE calculation results for Forklift 01 during the January to June period, different levels of operational effectiveness were identified across each month. The highest OEE values were achieved in April and June, both reaching 99.8%**,** while May recorded an OEE value of 81.2%**.** According to the effectiveness benchmark established by the Japan Institute of Plant Maintenance (JIPM)**,** an OEE value above **85%** is generally considered as a world-class performance indicator for equipment effectiveness. Therefore, the OEE values obtained after maintenance improvement in April, May, and June indicate that Forklift 01 achieved a significant improvement in operational performance and exceeded the expected effectiveness target.

The improvement in OEE performance demonstrates that the implementation of a structured maintenance system contributed to reducing equipment losses, improving operational reliability, and increasing forklift availability. The comparison between forklift conditions before and after implementing the OEE-based maintenance approach is presented in Table 6.

Table 6. Comparison of Forklift Conditions Before and After Implementing the OEE Method

Before Maintenance Improvement	Description	After Maintenance Improvement
	The engine was repaired, reassembled, and restored to operational condition.	

Before Maintenance Improvement	Description	After Maintenance Improvement
	Equipment restoration activities were conducted to improve operational condition.	

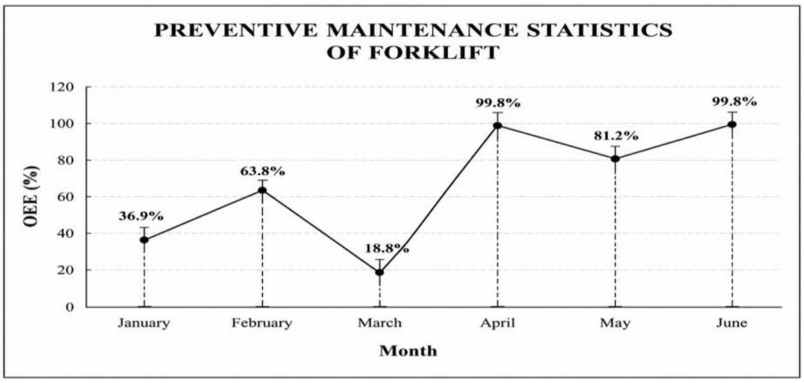
Results of researcher data processing in 2026

Table 7. Comparison of OEE Values Before and After Maintenance Improvement

	Before Implementation of OEE-Based Maintenance		
Year	Month		
	January	February	March
2025	36,9%	63,8%	18,8%
Year	After Implementation of Overall Equipment Effectiveness (OEE) Method		
	April	May	June
2025	99,8%	81,2%	99,8%

Results of researcher data processing in 2026

The comparison results indicate a substantial improvement in forklift operational effectiveness after implementing the OEE based maintenance strategy. Before improvement actions were conducted, the OEE values remained low due to high downtime, frequent equipment failures, and ineffective maintenance scheduling. After implementing preventive maintenance based on operational requirements, the OEE values increased significantly. The findings confirm that the application of the OEE method can be used as an effective approach to evaluate equipment performance and determine appropriate maintenance strategies. The improvement was mainly achieved through better maintenance planning, reduced equipment failures, and increased operational reliability of Forklift 01.



As seen in Table 4 and Graph 2 above, forklift maintenance data shows that forklift maintenance that has not been carried out regularly for the previous three months is still far from effective, resulting in frequent downtime. The author conducted research using the OEE method to determine the effective maintenance period for forklifts, thus helping the company to focus on the production process. Initially, the irregular maintenance process was 36.9% in January, 63.8% in February, and 18.8% in March. Using the Overall Equipment Effectiveness (OEE) method, the author proposed a maintenance period that exceeds working hours, namely 540 hours in one month of forklift maintenance, namely in April with a percentage of 99.8%, May with a percentage of 81.2%, and June with a percentage of 99.8%. By proposing to use the Overall Equipment Effectiveness (OEE) method for Forklift maintenance, the company will be able to better manage existing maintenance and also maximize and optimize the company's profits in the future.

IV. CONCLUSION

Based on the analysis and discussion in the previous chapter, it can be concluded that the implementation of the Overall Equipment Effectiveness (OEE) method can improve the operational effectiveness of Forklift 1 through improvements to a more planned maintenance system. OEE measurements, based on three main components: Availability, Performance Efficiency, and Quality Rate, indicate that forklift operational effectiveness increased after the implementation of a preventive maintenance schedule based on working hours. The OEE value, which initially ranged from 18.8% to 63.8%, increased to 81.2% to 99.8% after the proposed maintenance system improvements. These results indicate that the operational effectiveness target has met and even exceeded the OEE standard recommended by the Japan Institute of Plant Maintenance (JIPM), which is 85%.

This increase in the OEE value indicates that implementing scheduled preventive maintenance based on forklift operating hours can reduce the frequency of breakdowns, reduce downtime, and increase equipment reliability. Therefore, the application of the OEE method can be used as a reference in managing forklift maintenance systems to make company operations more effective, efficient, and sustainable. In addition to increasing productivity, implementing this method also has the potential to reduce repair costs, extend the lifespan of forklifts, and support the smooth running of the company's production process.

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