Application of Failure Mode and Effect Analysis (FMEA) for Functional Failure Analysis of a Reach Stacker: A Case Study at a Container Terminal Service Company

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Abstract

Logistics and cargo handling activities at ports require reliable equipment to maintain operational efficiency. One of the primary handling machines used in container terminals is the reach stacker, which functions to lift and move containers. However, the high intensity of operation frequently causes component failures that interrupt loading and unloading activities. This study aimed to identify critical components and dominant failure causes in reach stacker unit number 73 operating at a container terminal company. Historical breakdown and utilization data from 2021–2023 were analyzed using the Failure Mode and Effect Analysis (FMEA) method. A Functional Block Diagram (FBD) was first developed to describe the relationship among system components and to support the identification of functional failures. The FMEA method was then applied by evaluating severity, occurrence, and detection parameters to obtain the Risk Priority Number (RPN) of each failure mode. The results indicate that the spreader subsystem has the highest risk level, particularly the failure mode of a jammed or unresponsive twist-lock mechanism during lock/unlock operation, with an RPN value of 360. Other high-risk components include the brake system, chassis, hydraulic system, air conditioning, horn, and wiring system. The findings show that most failures are associated with low detectability and intensive operating conditions. Therefore, maintenance activities should prioritize the spreader and other safety-related components through risk-based maintenance and predictive inspection strategies.

Keywords: FMEA, Reach Stacker, Risk Priority Number, Maintenance, Port Equipment

1. Introduction

The logistics and port sectors play a vital role in supporting goods distribution activities in Indonesia (Dwitasari et al., 2021; Sunitiyoso et al., 2022). Container terminal companies rely heavily on cargo handling equipment to ensure that loading and unloading operations are carried out smoothly and efficiently. One of the primary pieces of equipment used in these activities is the reach stacker, a machine designed to transport, stack, and handle containers in port terminals due to its flexibility , ability to stack containers at various heights, and capability to operate efficiently in limited terminal areas (“Enhancing Container Terminal Operations,” 2022).

However, the intensive utilization of reach stackers frequently increases the likelihood of component failures and functional breakdowns (Aji et al., 2017). In particular, reach stacker unit number 73 was selected as the object of this study because it experienced the highest number of failures among the available units, with 153 recorded incidents

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during 2021–2023. These failures may result from component wear, environmental working conditions, overload, and operational errors. Inadequate predictive maintenance may further increase the frequency of failures and prolong repair time. Disruptions in one component can directly stop or delay loading and unloading activities, thereby reducing operational productivity, increasing maintenance costs, and lowering the overall efficiency of terminal operations (Bermejo et al., 2020; Hadi et al., 2024; Ponidi & Makhfud, 2018).

Although the company has implemented preventive and corrective maintenance systems, historical data from 2021–2023 indicate that there were 153 incidents of component failure in reach stacker unit number 73. This condition shows that the existing maintenance strategy has not been fully effective in preventing repeated failures. Most maintenance actions are still performed after the damage occurs, while the company does not yet have a systematic method to identify which components are most critical and should receive priority attention. As a result, maintenance activities tend to be reactive, causing repeated downtime and inefficient use of maintenance resources.

Previous studies have shown that the application of FMEA to reach stackers is effective in identifying dominant failure modes and prioritizing maintenance activities based on RPN values (Rahmani et al., 2023). Nevertheless, most previous studies focused only on ranking component failures and did not clearly describe the functional relationships among subsystems. Consequently, the interaction between component failures and their impact on the overall reach stacker operation has not been fully explained. In addition, few studies have used actual historical failure data over a long operating period to establish a practical maintenance priority framework.

This gap becomes the main problem addressed in the present study. The company requires a method that not only identifies the most critical components, but also explains how failures propagate through the reach stacker system and how maintenance priorities should be determined. Therefore, this study integrates a Functional Block Diagram (FBD) with Failure Mode and Effect Analysis (FMEA). The FBD is used to illustrate the relationships among subsystems and the functions of each component, while the FMEA method evaluates the severity, occurrence, and detection level of each failure mode to calculate the Risk Priority Number (RPN) (Suwignjo et al., 2022).

Through the integration of FBD and FMEA, this study aims to identify the critical components and dominant failure modes in reach stacker unit number 73 and to propose a more effective maintenance strategy based on the obtained RPN values. Unlike previous studies, this research combines a simplified FBD, FMEA, and historical operational data from 153 failure incidents to establish a maintenance priority framework for reach stacker unit number 73.

2. Material and Methods

This study was conducted to identify the dominant failure modes and determine the maintenance priorities of reach stacker unit number 73, Figure 1, operated by a container terminal company. The research adopted a descriptive-analytical approach by integrating field observations, historical maintenance data, and expert judgement. The analysis procedure was performed systematically through several stages, namely data collection, development of a Functional Block Diagram (FBD), identification of component failures, preparation of the Failure Mode and Effect Analysis (FMEA) worksheet, calculation of the Risk Priority Number (RPN), and formulation of maintenance recommendations. Through this approach, the study aimed to provide a comprehensive basis for improving the effectiveness of maintenance activities and enhancing the operational reliability of the reach stacker.

Figure 1. *Reach Stacker* number 73

2.1 Research Object and Data Collection

The object of this study was reaching stacker unit number 73 operated by a container services company. The unit was selected because it experienced the highest number of recorded failures during the observation period. Reach stacker unit number 73 is one of the primary pieces of cargo handling equipment used to lift, transport, and stack containers in port terminal operations. The technical specifications of the investigated unit are shown in Table 1.

Table 1. Technical specifications of reach stacker unit number 73

Parameter	Specification
Brand	Konecranes SMV 4531 TCE5
Engine	Volvo TAD1171VE
Maximum Horizontal Reach	6.35 m
Maximum Lifting Height	15.3 m
Lifting Capacity	45–31–16 ton
Spreader Function	20–40 ft container

The data used in this study consisted of both primary and secondary data. Primary data were obtained through direct field observation and interviews with experts. Observations were conducted during the operation of the reach stacker to understand the interaction between subsystems, the actual working conditions, and the operational sequence during container handling activities. Particular attention was given to the spreader, hydraulic system, braking system, chassis, electrical system, and other supporting components.

Interviews were conducted with maintenance experts, including senior mechanics, maintenance supervisors, and experienced operators who had been directly involved in the maintenance and operation of reach stackers for more than five years. The interviews aimed to identify the most frequent failures, their causes, their operational effects, and the maintenance actions previously carried out. In addition, the experts were involved in assessing the severity, occurrence, and detection scores used in the FMEA analysis.

Secondary data were obtained from the company’s maintenance records and consisted of breakdown reports, maintenance histories, and utilization data for reach stacker unit number 73 during the 2021–2023 period. A total of 153 incidents of component failure were recorded during this period. These data were used to determine the frequency of occurrence of each failure mode and to validate the information obtained through interviews and field observations.

2.2 Research Procedure

The research was carried out through a sequence of stages designed to systematically identify and evaluate the critical failures of the reach stacker. The overall research procedure is illustrated in Figure 2.

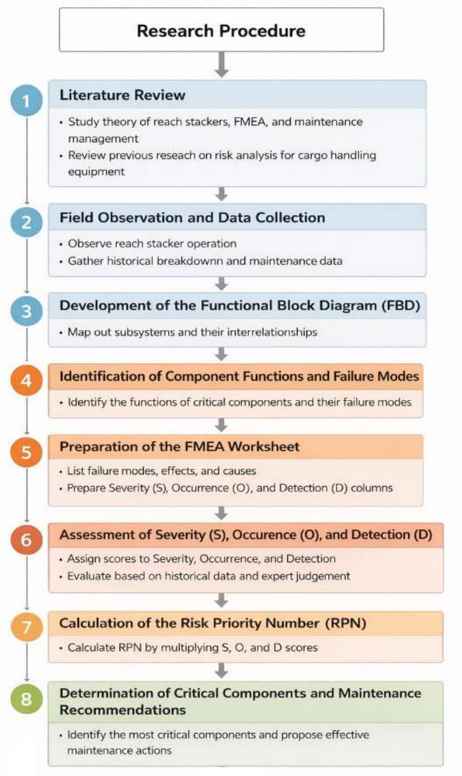

Figure 2. Research procedure

The literature review was first conducted to obtain theoretical knowledge regarding reach stacker systems, maintenance management, FMEA, and Functional Block Diagram techniques. Previous studies related to risk analysis and maintenance of cargo handling equipment were also reviewed to support the research framework (Rahmani et al., 2023; Suwignjo et al., 2022). After the literature review, field observations and data collection were carried out. The collected data were then analyzed to identify the relationship among components and their contribution to the overall system operation. Based on these data, the Functional Block Diagram was developed as the basis for the FMEA analysis.

2.3 Functional Block Diagram (FBD)

The Functional Block Diagram (FBD) is a series of diagrams used to describe the relationships and workflow among component functions within a system, thereby clarifying the stages of the working process of the system or equipment as a whole (Marimin & Zulna, 2022). By using an FBD, the structure and function of each component can be represented simply in the form of functional blocks, making it easier to understand how the system operates as an integrated unit.

The preparation of the FBD is carried out after the main functions and interactions among components in the system have been identified. Therefore, this diagram can be used as a basis for determining preventive maintenance activities (Moubray, 2001). Through the FBD, the relationships between subsystems and major components can be clearly described, helping technicians or analysts identify critical points that have the potential to cause system failure. In addition, the FBD plays an important role as a source of technical information in developing a more effective maintenance strategy. If the previous maintenance system is proven to be less efficient, the FBD can be used as a reference to improve maintenance planning because it provides a logical representation of the interaction and sequence of operation among components (Suwignjo et al., 2022) . Thus, the implementation of the Functional Block Diagram not only helps in understanding the functions and interactions of the system, but also supports the process of identifying the causes of failure and planning more appropriate and targeted maintenance actions.

2.4 Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) was applied to identify, evaluate, and prioritize the failure modes of each subsystem of the reach stacker. The FMEA worksheet was developed based on the information obtained from the FBD, historical maintenance data, and expert judgement.

Each row in the FMEA worksheet (Moubray, 2001) contained the following elements:

- Component or subsystem
- Function of the component
- Functional failure
- Failure mode
- Failure effect
- Severity (S)
- Occurrence (O)
- Detection (D)
- Risk Priority Number (RPN)

The Severity (S) score represents the seriousness of the consequences caused by the failure. A higher severity score indicates that the failure has a significant impact on operational continuity, productivity, or safety. The Occurrence (O) score reflects the frequency of failure based on the historical breakdown data. Components that failed more frequently received higher occurrence scores. The Detection (D) score indicates the likelihood that the maintenance system can detect the failure before it occurs. A high detection score means that the failure is difficult to detect and is usually identified only after the machine experiences operational problems.

The Risk Priority Number (RPN) was calculated using the following equation:

$$RPN = S \times O \times D$$

where:

- (S) = Severity
- (O) = Occurrence
- (D) = Detection

The RPN value was used to determine the maintenance priority of each failure mode. Failure modes with high RPN values were considered more critical and therefore required immediate corrective action.

The assessment of the S, O, and D values was carried out through expert judgement involving senior mechanics and maintenance personnel. Each expert independently evaluated the failure modes based on their practical experience, technical knowledge, and historical records. The final score used in the analysis was determined from the average of the experts' evaluations.

2.5 Risk Categorization

After the RPN values had been calculated, the risk level of each failure mode was classified into low, medium, and high categories. This classification was intended to simplify the prioritization of maintenance actions and to focus the analysis on the most critical failures.

The average RPN value was obtained by dividing the total RPN value of 9,176 by the total number of failure modes, which was 62. Based on this calculation, the following risk categories were established (McElroy et al., 2016; Obeng et al., 2025; Reddy, 2015; Uyi et al., 2022):

- Low risk: ($RPN < 74$)
- Medium risk: ($74 < RPN < 222$)
- High risk: ($RPN > 222$)

Failure modes classified as high risk were selected for further discussion because they have the greatest potential to affect the reliability and safety of reach stacker operation.

2.6 Development of Maintenance Recommendations

The final stage of the study was the development of maintenance recommendations based on the identified critical components. The recommendations were formulated by considering the RPN values, the characteristics of the failures, and the operational importance of each component.

Components with the highest RPN values, such as the spreader, wiring system, chassis, hydraulic system, and braking system, were prioritized for corrective and preventive actions. The recommended maintenance strategies included:

- Increasing the frequency of inspection for critical components
- Replacing worn components based on operating hours and historical failure trends
- Applying predictive maintenance methods, such as hydraulic pressure monitoring and thermal inspection of electrical systems
- Improving operator training to reduce failures caused by operational errors
- Developing a maintenance database to record and monitor recurring failures

By implementing these recommendations, the company can shift its maintenance strategy from reactive maintenance toward a more proactive and risk-based maintenance system. This approach is expected to reduce downtime, improve operational efficiency, and increase the reliability of reach stacker unit number 73.

3. Results and Discussion

3.1 Functional Block Diagram Analysis

The Functional Block Diagram shows in Figure 3 that the reach stacker consists of several interrelated subsystems. Failure in one component directly affects the performance of the other components and may cause the entire machine to stop operating. Figure 3 presents the functional architecture of the reach stacker and highlights the relationship between the main subsystems and the critical failure modes identified through the FMEA analysis. The figure shows that the reach stacker is composed of several interconnected subsystems, namely the power and control system, hydraulic power conversion system, mechanical lifting structure, spreader system, and electrical wiring system. These subsystems operate in an integrated manner to support container lifting, transportation, and stacking operations.

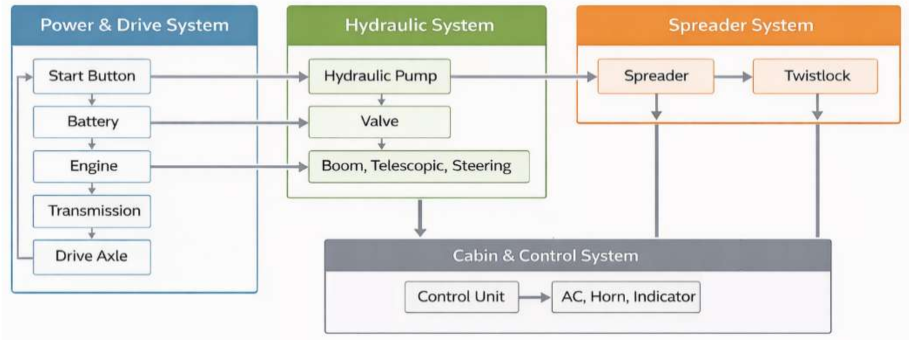

Figure 3. Functional Block Diagram (FBD) of Reach Stacker

3.2 FMEA Results

The FMEA analysis identified several failure modes with high RPN values as depitch in Table 2. The highest RPN value was obtained by the spreader subsystem, specifically the twist-lock mechanism, with an RPN of 360. This failure prevents the container from being locked or released and therefore directly interrupts loading and unloading operations.

Tabel 2. FMEA Worksheet Reach Stcker Number 73 with RPN Value in the High-Risk Category

System: *RS73 REACH STACKER KONECRANES SMV 4531 TCE5*				***Date:*** *23-24 Juni*					
Sub-system: *Reach Stacker components*				***Year:*** *2025*					
No	***Equipment***	***Functional***	***Functional Failure***	***Failure Mode***	***Failure Effect***	**S**	**O**	**D**	**RPN**
3	*Spreader*	As a container lifter	The locking system does not work (*lock/unlock*) part of *twist-lock*	The *twist-lock* mechanism is stuck or unresponsive when the *lock/unlock command*	Containers cannot be locked or removed	8	5	9	360
5	*Brakes*	Functions to stop or slow down the movement of *the reach stacker*	Brakes can't grip	Canvas break wear	Difficult to stop	8	3	10	240
8	*Chassis*	As the main framework that supports all the components of the *reach stacker*	Vehicle load imbalance/stability	Broken counter *weight* pin bolt	The unit becomes unstable when lifting/moving loads	7	4	10	280
9	*Hydraulic System*	As a power source for the lifting of a mechanism by utilizing fluid pressure	Can't set the cylinder *spreader* for 20/40 ft containers	Hydraulic oil leak and 20-40 hydraulic cylinders are damaged	Can't adjust container size	7	4	8	224
			Hydraulic pressure is not channeled	Hydraulic hose wears/leaks	Reduced hydraulic performance	7	5	7	245
			Unable to withstand hydraulic pressure	*seal* or *O-ring* leakage	Hydraulic pressure decreases	7	4	8	224
11	AC	Cabin air conditioning	The air is not cold	Blower motor *is* faulty (AC fan does not rotate)	Hot cabin temperature	8	4	10	320
14	*Horn*	Provides a warning sound signal / signal	The horn cannot sound	The horn *unit* is broken	Operator can't provide voice alerts	7	4	10	280
17	*Wiring*	Transmitting electrical current and signals between electrical and electronic components	Can't go forward/backward	Electrical Faults Due to *Faulty Wiring*	Reach Stacker is immobile	9	4	8	288

Other critical components were the AC system (RPN = 320), wiring system (RPN = 288), chassis and horn (RPN = 280), hydraulic system (RPN = 245), and brake system (RPN = 240). Most of these failures are related to low detectability and high operational importance.

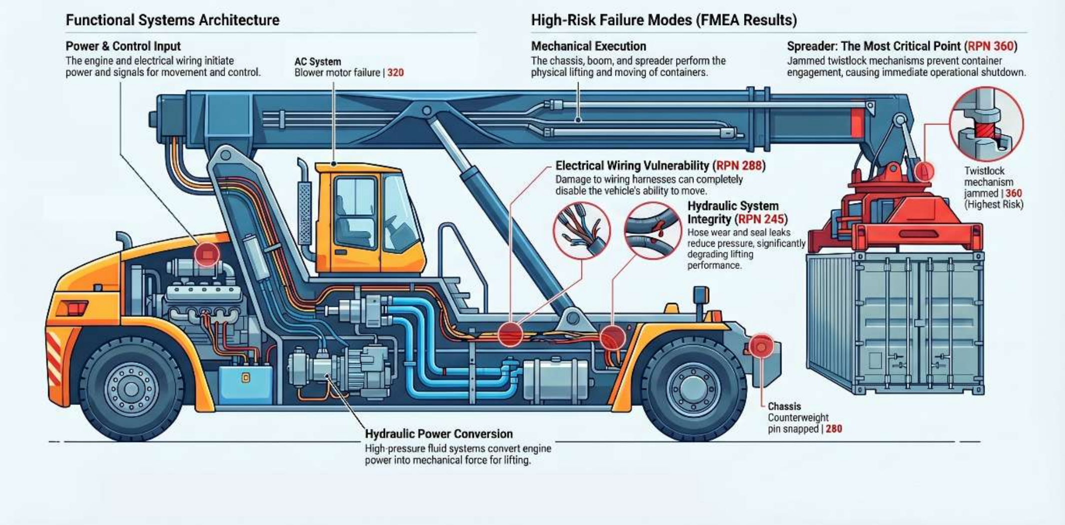

Figure 4. Reach stacker functional architectur and critical failure analysis

Figure 4 also shows that the critical failures are concentrated in subsystems directly associated with lifting, machine stability, movement, and operator safety. Therefore, the spreader, wiring, chassis, hydraulic, and brake systems should receive the highest maintenance priority.

3.3 Discussion of Critical Components

The twist-lock mechanism in the spreader received a severity score of 8 because the reach stacker cannot operate if the container cannot be locked or released. The spreader is the main subsystem responsible for securing the container during lifting, transferring, and unloading processes. Therefore, any malfunction in the twist-lock mechanism directly interrupts the primary function of the reach stacker. If the container cannot be locked properly, the machine is unable to lift the load safely. Conversely, if the container cannot be released, the unloading process is delayed and terminal operations must be stopped until the failure is repaired (Pekih & Sutawijaya, 2023). In addition to reducing productivity, this type of failure may also create a serious safety risk because an unsecured container may fall or shift position during handling. Similar findings were reported by (Pekih & Sutawijaya, 2023), who identified spreader-related failures as one of the most dominant causes of downtime in reach stacker operations.

The occurrence score was 5 because the failure occurred 25 times during 14,602 operating hours from 2021–2023. This relatively high frequency indicates that the twist-lock mechanism is repeatedly exposed to heavy working cycles and severe environmental conditions. During operation, the spreader experiences continuous loading and unloading cycles, vibration, dust, humidity, and exposure to sea air. Such conditions accelerate wear of the locking mechanism, actuator, and moving joints, thereby increasing the likelihood of failure (Aji et al., 2017). Previous studies on port handling equipment also reported that cyclic mechanical loading and corrosive environments are major factors contributing to the deterioration of spreader components (Suwignjo et al., 2022; Wibowo et al., 2023).

The detection score was 9 because the failure is difficult to detect before it happens. In most cases, operators become aware of the problem only when the spreader fails to lock or unlock the container during operation. This indicates that the current maintenance system still relies heavily on corrective maintenance rather than early detection methods. According to (Jardine & Tsang, 2013; Prabowo et al., 2018; Suwignjo et al., 2022), components with high severity and low detectability should receive the highest maintenance priority because they have the greatest potential to cause sudden operational disruption. Therefore, the spreader subsystem should become the primary target for preventive and predictive maintenance activities.

Most components with high RPN values have the following characteristics:

1. They are directly related to operational safety, such as brakes, chassis, horn, and wiring. The brake system, for example, is essential to control and stop the reach stacker, particularly when carrying heavy containers

(Arabian-Hoseynabadi et al., 2010). Worn brake pads may reduce braking performance and increase the risk of collision. Similarly, failure of the chassis or counterweight pin can reduce the stability of the machine and increase the possibility of overturning during lifting operations. The horn and wiring system are also critical because they support safe communication and machine movement in busy terminal areas.

2. They operate under high loads and harsh environmental conditions, such as the hydraulic system. The hydraulic subsystem continuously supplies pressure to the boom, spreader, steering, and lifting mechanisms. Hydraulic hoses, seals, and O-rings are exposed to fluctuating pressure, high temperature, vibration, and contamination. As a result, leakage and pressure loss frequently occur, reducing the performance of the reach stacker. Similar conditions were reported in previous maintenance studies of heavy equipment and cargo handling machinery (Aji et al., 2017).
3. They have poor detectability, meaning that failures are usually identified only after the damage has occurred. This condition is particularly evident in the spreader, wiring, and hydraulic systems. Damage in these components is often not visible during routine inspection and may only become apparent after the reach stacker experiences malfunction. Consequently, the current maintenance system should be improved by introducing predictive maintenance methods, such as hydraulic pressure monitoring, thermal inspection, and vibration analysis, in order to detect failures earlier and reduce unexpected downtime (Nelson, 2003).

3.4 Failure Pattern Based on Historical Data

The analysis of historical data in Figure 5 indicates that the failures were mainly caused by Component wear, Environmental stressors, and Human error

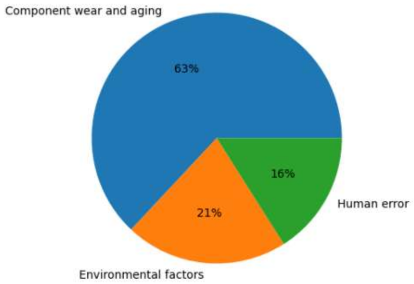

Figure 5. Main causes of Reach stacker failure (2021-2023)

The large contribution of wear-related failures indicates that maintenance should not only rely on corrective actions but also include periodic replacement and condition-based monitoring.

3.5 Maintenance Strategy Recommendation

Based on the FMEA results, maintenance priorities should be determined according to the RPN value and the operational importance of each component.

1. **Spreader subsystem as the first priority.**
   The spreader, particularly the twist-lock mechanism, should receive the highest maintenance priority because it has the highest RPN value of 360. Failure of this component directly stops the loading and unloading process because the container cannot be locked or released. Therefore, regular inspection, cleaning, lubrication, and replacement of worn parts should be performed to reduce the possibility of sudden failure (Rahmani et al., 2023).
2. **Wiring, chassis, and horn as the second priority.**
   These components are closely related to operational safety. Wiring failure can prevent the reach stacker from moving, while chassis and horn failures may increase the risk of accidents. Regular inspection of cables, connectors, horn units, and structural components is necessary to maintain safe operation (Aji et al., 2017).

3. **Hydraulic system and brake system as the third priority.**
   The hydraulic and brake systems should also be maintained regularly because their failure can reduce machine performance and safety. Hydraulic hose leakage, damaged seals, and worn brake pads should be checked and replaced periodically (Aji et al., 2017).

The following strategies are recommended to improve the reliability of the reach stacker and reduce the possibility of recurring failures:

- **Increase inspection frequency for spreader and hydraulic components.**
  Components with the highest failure rate should be inspected more frequently than other components. The spreader, hydraulic hose, seal, and twist-lock mechanism should be checked weekly or after a certain number of operating hours. This approach is expected to reduce the probability of sudden failure and improve the availability of the reach stacker.
- **Apply predictive maintenance using pressure sensors and thermal inspection.**
  The current maintenance system still relies mainly on corrective maintenance. Therefore, predictive maintenance should be introduced to detect potential failures before they occur. Hydraulic pressure sensors can be installed to monitor the performance of the hydraulic system in real time. Thermal inspection can also be used to identify overheating in the wiring system, electrical components, and hydraulic pumps. In addition, vibration analysis may be applied to detect abnormal conditions in the spreader and other rotating components. According to (Suwignjo et al., 2022), predictive maintenance is more effective than corrective maintenance because it reduces downtime and maintenance costs.
- **Improve operator training to reduce human error.**
  Historical data show that a significant portion of failures was related to operational errors. Therefore, operators should receive regular training regarding the correct use of the reach stacker, especially in operating the spreader, braking system, and steering system. Training should also include procedures for daily inspection, identification of early warning signs, and proper response to abnormal conditions. Better operator awareness can reduce the frequency of misuse and prolong the service life of the equipment.
- **Develop a historical maintenance database to monitor recurring failures.**
  A computerized maintenance database should be developed to record all failures, maintenance actions, component replacements, and operating hours. By analyzing this database, the company can identify recurring failures, determine the most problematic components, and improve the maintenance schedule based on actual operating conditions. Historical maintenance records also support future analysis using methods such as Mean Time Between Failure (MTBF) and reliability analysis (Fernanda, 2020; Suwignjo et al., 2022).

Overall, the proposed maintenance strategy shifts the company’s approach from reactive maintenance toward preventive and predictive maintenance. By focusing on the most critical components and implementing systematic monitoring, the company can reduce downtime, improve operational safety, and increase the reliability of reach stacker unit number 73 (Aslam et al., 2025; Opeyemi, 2018; Werbinska-Wojciechowska & Rogowski, 2025).

4. Conclusion

The FMEA analysis successfully identified the most critical failure modes in reach stacker unit number 73 based on 153 recorded failure incidents during the 2021–2023 period. The spreader subsystem, particularly the jammed or unresponsive twist-lock mechanism, was identified as the highest-risk component with an RPN value of 360. Other components with high risk were the AC system (RPN = 320), wiring system (RPN = 288), chassis and horn (RPN = 280), hydraulic system (RPN = 245), and brake system (RPN = 240). These components were classified as high priority because they are directly related to operational continuity and safety.

The analysis also showed that 63% of failures were caused by component wear, 21% by environmental stressors, and 16% by human error. This indicates that the current maintenance practice still relies excessively on corrective action and has limited capability to detect failures before they occur.

Through the integration of Functional Block Diagram (FBD) and FMEA, this study was able to identify the relationships among subsystems and determine the components that require the highest maintenance priority. The results suggest that the spreader subsystem should become the first maintenance priority, followed by the wiring, chassis, horn, hydraulic, and brake systems. Therefore, the company is recommended to implement a risk-based maintenance strategy through more frequent inspections, predictive monitoring, and periodic component replacement in order to reduce downtime and improve the reliability of reach stacker operations.

Unlike previous studies, this research combines FBD, FMEA, and historical operational data from 153 failure cases to establish a practical maintenance priority framework for reach stacker unit number 73. However, the findings are limited to one unit and one operating environment. Further studies involving additional reach stacker units and longer observation periods are necessary to validate the proposed maintenance strategy.

Credit authorship contribution statement

Muhamad Ari : Conceptualization
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Ucok Joko Suryanto : Data collection
Khoirul Amin : Writing
Muhammad Hisyam Fauzi : Writing

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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