

Optimizing Reachtruck Reliability in Cold Storage Industry Using Reliability Centered Maintenance Based on Fuzzy FMEA

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Abstract—Reach trucks are critical equipment in cold storage operations due to their efficiency in lifting and transporting loads in narrow aisles and cold environments. However, high failure rates and extended downtimes significantly reduce their reliability, which directly affects operational performance and business revenue. This study aims to optimize the reliability of reach trucks by identifying critical components and determining the appropriate maintenance intervals using a combined method of Reliability Centered Maintenance (RCM) and Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA). The research employs qualitative and quantitative approaches through failure data analysis, expert judgment, and risk priority number (RPN) evaluation using fuzzy logic. The hydraulic system and driver unit were identified as the most failure-prone systems, with the hose and gearbox as the most critical components. The application of fuzzy logic provides a more accurate prioritization of failure risks compared to conventional FMEA. Furthermore, RCM II was used to develop a preventive maintenance framework to improve equipment reliability. The findings demonstrate that the integrated approach effectively reduces downtime and enhances the maintenance planning process. This study contributes to developing a more structured and risk-based maintenance strategy for reach trucks in the cold storage industry.

Keywords— Component prioritization, Downtime reduction, FMEA, Fuzzy logic, Hydraulic system, Maintenance strategy, Preventive maintenance, Reach truck, Reliability analysis, RCM II

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I. INTRODUCTION

The cold storage industry is a critical sector in modern logistics, especially in supporting supply chains for perishable goods. One of the essential components in this industry is the use of reach trucks—specialized forklifts designed to operate efficiently in narrow aisles and controlled cold environments. At PT. MGM Bosco Logistics, a leading cold storage operator in East Java, reach trucks play a vital role in daily operations involving inbound and outbound goods movement. However, operational efficiency is often compromised due to frequent breakdowns of reach trucks, which lead to increased downtime, higher maintenance costs, and interruptions in the overall logistics process. These disruptions not only reduce equipment reliability but also have a direct impact on the company's revenue due to delayed order fulfillment and the need for third-party equipment rentals.

Maintaining the reliability of reach trucks in extreme cold conditions presents unique challenges. Unlike standard forklifts, reach trucks operating in low-temperature environments require specific components, skilled technicians, and well-designed maintenance strategies. In practice, many companies, including PT. MGM Bosco Logistics, still apply reactive or minimal

preventive maintenance approaches. This is further exacerbated by the limited availability of spare parts many of which are imported and the absence of scheduled maintenance intervals. These gaps increase the likelihood of equipment failure and raise the overall risk level within the cold storage operation.

Several previous studies have attempted to address the maintenance challenges of forklifts and similar material handling equipment. Kastalani et al. (2023) conducted a reliability analysis to enhance forklift usage effectiveness [1]. Wibowo and Kurniati (2019) developed a maintenance strategy using Reliability Centered Maintenance (RCM II), while Suprianto (2011) explored failure rates to determine optimal maintenance intervals [2,3]. In parallel, research on risk analysis using Failure Mode and Effect Analysis (FMEA) and its advanced variant Fuzzy FMEA has gained traction. Ramadhan and Nurhidayat (2022) demonstrated how fuzzy logic can overcome the subjectivity and linear assumptions of traditional FMEA by providing a more precise risk prioritization model [3]. However, most existing literature applies either RCM or Fuzzy FMEA in isolation, with limited integration between the two methods.

This research addresses the above gap by integrating the structured preventive maintenance approach of RCM with the enhanced risk assessment capabilities of Fuzzy FMEA. The combination is expected to provide a more accurate identification of failure risks and support decision-making in maintenance planning. By applying this integrated method to reach trucks in a cold storage setting, the study aims to formulate a comprehensive maintenance framework that is both data-driven and practically implementable. Through expert-based evaluation, historical failure data, and fuzzy logic

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processing via MATLAB, this research identifies critical components and proposes optimal maintenance intervals.

The novelty of this study lies in its focus on a high-impact yet under-researched operational setting: reach trucks in cold storage environments. While reach trucks are widely used, studies combining RCM and Fuzzy FMEA tailored to their use in cold storage logistics are rare. This research thus contributes to the discourse by providing both theoretical and practical insights for improving reliability and operational efficiency.

The objective of this research is to optimize the reliability of reach trucks by (1) identifying critical subsystems with high failure frequency, (2) calculating accurate Risk Priority Numbers (RPN) using fuzzy logic, and (3) developing preventive maintenance strategies through the RCM II framework. The ultimate goal is to reduce downtime, minimize operational risks, and improve the effectiveness of maintenance planning in cold storage industries.

II. METHOD

A. Description

This research was conducted by *Aji Andri Adi* through a case study approach at PT. MGM Bosco Logistics, a company operating in cold storage services that heavily utilizes reach trucks for warehouse operations. The purpose of the study was to optimize reach truck reliability using an integrated method of Reliability Centered Maintenance (RCM) and Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA). The research method combines qualitative and quantitative approaches, including expert judgment, data analysis, risk evaluation, and simulation using MATLAB.

1) Types and Sources of Data

The primary data used in this study consist of:

- a) Failure records of reach trucks from January 2022 to May 2024.
- b) Maintenance logs and component replacement history.
- c) Expert assessments from internal technicians and certified operators.

Data collection was conducted through:

- a) Field observations of operational processes and maintenance activities.
- b) Structured interviews with maintenance personnel.
- c) Review of technical manuals and manufacturer specifications.

This study focused on three reach truck units (RD Crown-1, RD Crown-4, RD Crown-5) with the highest failure rates. Components with the highest frequency of failure were identified to be hoses (hydraulic system) and gearboxes (driver unit).

2) Data Analysis Methods

The analysis process involved the following stages:

- a) **Failure Mode and Effect Analysis (FMEA):** Each subsystem was analyzed to identify potential failure modes, causes, effects, and the Risk Priority Number (RPN), calculated as:

$$RPN = S \times O \times D \quad (1)$$

where S is the severity score, O is the occurrence score, and D is the detection score. All values range from 1 to 10 based on expert judgment.

- b) **Fuzzy FMEA:** The RPN values obtained from classical FMEA were processed using fuzzy logic to improve accuracy. Membership functions for S , O , and D were defined with triangular and trapezoidal shapes. The fuzzy rule base consisted of IF-THEN rules, and defuzzification was performed using the Center of Gravity (COG) method to obtain the fuzzy-RPN (FRPN).

- c) **RCM II Framework:** A functional block diagram (FBD) was developed for the selected reach truck system. Functional failures and their consequences were classified into hidden, operational, safety, and non-operational categories. Based on the failure consequence analysis, proactive maintenance tasks were proposed and scheduled.

- d) **Maintenance Interval Determination:** The Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) were calculated from historical data to determine reliability and expected maintenance cycles. These were used to define optimal maintenance intervals:

$$Reliability (R) = e^{-\lambda t} \quad (2)$$

where λ is the failure rate, and t is the operational time.

$$Failure\ rate\ \lambda = 1/MTTF \quad (3)$$

- e) **Risk Matrix Mapping:** The FRPN results were mapped into a 3x3 risk matrix to prioritize components and determine critical parts requiring immediate preventive measures.

Framework of Reasearch

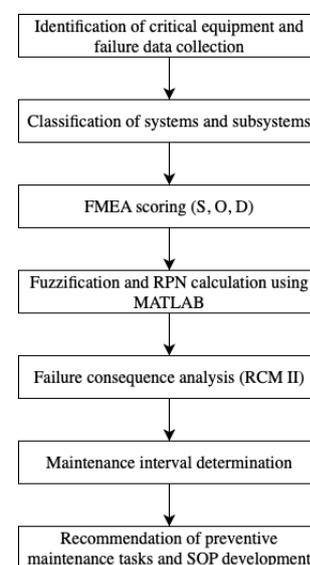


Figure 1. Flowchart of Research Methodology.

B. Numerals

All numerical values are presented using the appropriate grouping format. For example:

1. Total component replacements = 1,234
2. Downtime duration = 3 days
3. MTTF = 245.67 hours

C. Units

All units used in this study follow the International System of Units (SI), such as hours (h), days (d), newtons (N), and degrees Celsius (°C).

D. Mathematics

To analyze the reliability of each change in redundant and single components, the first step is to determine the failure time distribution model and then use an availability comparison approach.

Reliability at time t: $R(t) = e^{-t/MTTF}$

III. RESULT AND DISCUSSION

This study aimed to optimize the reliability of reach trucks in the cold storage industry by integrating Reliability Centered Maintenance (RCM) and Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA). The research objectives were: (1) to identify critical components with the highest risk of failure, (2) to prioritize those components using Fuzzy RPN calculations, and (3) to develop preventive maintenance strategies based on RCM II framework. The following sections present and discuss the findings based on these objectives.

A. Identification of Critical Components

Based on historical data from 2022 to 2024 at PT. MGM Bosco Logistics, the most frequently reported failures occurred in the hydraulic and driver systems. Among the subsystems, hoses (hydraulic system) and gearboxes (driver unit) showed the highest number of replacements and repairs. For example, Hose components in the RD Crown-4 unit experienced 32 breakdown events over the period. This aligns with prior studies by Ramadhan and Nurhidayat (2022), which identified hydraulic systems as high-risk areas in forklift operations due to temperature sensitivity and operational pressure.

Analysis and sensitivity testing were carried out on the critical components of the three Reactruck units, namely (Hose, Bearing, Contactor, Wheel Castel) based on the MTTF/MTTR values of each component. For bearings / contactors / wheels, elasticity is very small (~0.01–0.02), meaning that availability is not sensitive to small changes in MTTF/MTTR.

Based on the analysis results, the critical components identified in the Reachtruck include the hose, bearing, contactor, and wheel castel. To create redundant variations of these critical components, we can design several strategic options, including active, standby, hybrid, and functional redundancy.

B. FMEA and Fuzzy RPN Results

Using conventional FMEA, each failure mode was scored with severity (S), occurrence (O), and detection (D) values, all on a scale of 1–10. The Risk Priority Number (RPN) was calculated as:

$$RPN = S \times O \times D \quad (1)$$

However, as discussed by Hartanti et al. (2022), traditional RPN lacks granularity in differentiating risk levels. To address this, fuzzy logic was applied using MATLAB's Fuzzy Toolbox, producing defuzzified RPN scores (FRPN) based on triangular membership functions and inference rules.

Figure 2 illustrates the comparison between manual RPN and fuzzy-RPN scores across the three reach truck units. The fuzzy scores provided more consistent risk categorization, avoiding ties or arbitrary rankings that often occur in conventional RPN.

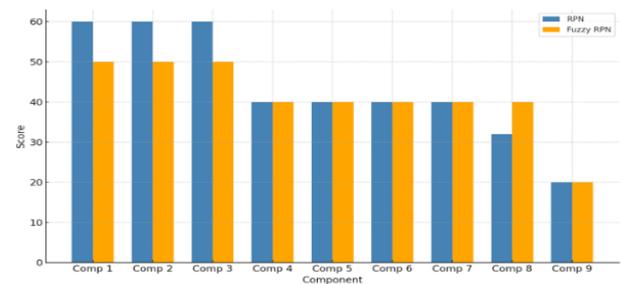


Figure 2. Comparison of RPN vs Fuzzy-RPN across Three

The results revealed that all three units shared the same top-priority critical components:

1. **Hose:** High frequency and severe impact on lifting function.
2. **Gearbox:** Directly affects mobility and operator safety.
3. **Contactor and Oil:** Moderate impact, but still significant based on fuzzy scores.

These findings confirm earlier conclusions by Wibowo and Kurniati (2019) that failure frequency combined with detection difficulty must be emphasized in forklift maintenance planning.

C. Preventive Maintenance Planning using RCM II

Following RCM II methodology, the failure consequences were classified as operational and safety-critical. For example, a failed hydraulic hose could result in sudden loss of lifting power, halting cold storage operations and posing hazards to operators. Using the failure consequence analysis, proactive maintenance tasks were proposed. These included scheduled component inspections, hose replacements after 200 operating hours, and driver unit recalibrations.

The Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) values were also calculated. The average MTTF for critical components such as hoses was **215 hours**, while the MTTR reached **22.5 hours**. Based on the exponential reliability function:

$$R(t) = e^{-\lambda t}, \quad \lambda = \frac{1}{MTTF} \quad (2)$$

It was determined that the reliability significantly dropped after 180 hours of operation, supporting the proposed maintenance intervals.

Figure 3 presents the maintenance schedule matrix developed as part of the standard operating procedure (SOP) recommendation.

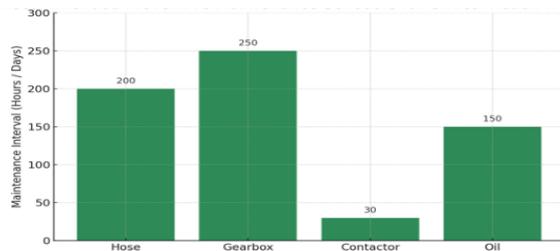


Figure 3. Recommended Preventive Maintenance Schedule for Critical Reach Truck Components

D. The Difference Between Fuzzy Method and Others

Fuzzy method involves establishing membership functions for each parameter S, O, and D. In the evaluation rules, this method uses IF-THEN logic which is compiled based on a combination of expert knowledge and the experience of field practitioners. These rules are used to map fuzzy inputs into relevant fuzzy outputs. In addition, this method can describe the actual risk level, so it can be used in making repair priority decisions.

E. Comparison with Previous Studies

While earlier studies by Supriyanto (2011) and Gustama et al. (2021) also used failure history for interval planning, this research contributes by applying fuzzy logic to better differentiate component risks. Moreover, unlike traditional RCM which relies on subjective maintenance priorities, the integration with fuzzy logic ensures more accurate data interpretation and decision-making.

F. Managerial Implications

The integration of RCM and Fuzzy FMEA offers significant value to cold storage businesses. First, it provides a structured and quantitative basis for maintenance planning, reducing reliance on reactive repairs. Second, the approach minimizes downtime, which in turn improves warehouse throughput and customer satisfaction. Third, the use of fuzzy logic reduces ambiguity in prioritizing components, allowing managers to allocate maintenance resources more efficiently.

The proposed framework can be standardized into company-wide SOPs, ensuring consistent preventive actions across all operational units. This contributes to improved asset longevity, reduced spare part costs, and enhanced safety for operators working in cold environments.

IV. CONCLUSION

This study was conducted to optimize the reliability of reach trucks operating in cold storage environments by integrating Reliability Centered Maintenance (RCM) and Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA). In response to the research objectives, the results confirmed that frequent equipment failures—

particularly in the hydraulic and driver units—contribute significantly to operational downtime and financial losses. Critical components such as hoses and gearboxes were identified based on failure records and expert evaluations.

The implementation of Fuzzy FMEA successfully improved the accuracy in prioritizing high-risk components, addressing the limitations of conventional FMEA. Furthermore, the application of RCM II enabled the classification of failure consequences and formulation of proactive maintenance actions, including optimal intervals for component inspection and replacement. This integrated approach has proven effective in minimizing unplanned downtime and provides a structured basis for preventive maintenance planning.

Based on these findings, it is recommended that cold storage companies adopt a combined RCM-Fuzzy FMEA framework to improve the reliability of their material handling systems. Standard Operating Procedures (SOPs) for maintenance should be developed or revised accordingly to include fuzzy-based risk assessment and maintenance scheduling. In the long term, this strategy not only enhances equipment performance but also supports business continuity and cost efficiency. Future studies may explore the integration of real-time sensor data to further refine predictive maintenance in cold storage operations.

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