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# Crawler Crane Failure Cause Analysis Using Fishbone Diagram, Pareto Principle, and Failure Mode Effect Analysis: A Comprehensive Approach to Minimize Downtime and Improve Operational Reliability

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## Abstract

Crawler cranes are critical heavy equipment in the construction industry, but they often experience failures that cause downtime and increased costs. This article comprehensively analyses crawler crane failures using three main methods: Fishbone Diagram, Pareto Principle, and Failure Mode and Effect Analysis (FMEA). Failure data for the past two years (January 2022 – September 2024) is analyzed to identify root causes and determine repair priorities. A Fishbone Diagram is used to identify the main causes of failure, which are grouped into four categories: Mechanical, Electrical, Environmental, and Human Error. From this analysis, it is found that mechanical failure is the most dominant cause. This analysis found that mechanical failure is the most dominant cause, mechanical failures account for most failures (60%), followed by electrical failures (33%), with failures in the gearbox and engine overheating being the most significant causes. Furthermore, FMEA evaluates potential failure modes, determines their impacts, and sets mitigation priorities based on the Risk Priority Number (RPN). The results of this study provide a strategic approach to minimize downtime by focusing maintenance efforts on the root causes of failure. This article also offers a new contribution by combining three comprehensive analysis methods not systematically applied to crawler crane maintenance. This research is expected to help improve operational reliability and reduce repair costs in the construction industry.

## Keywords

Crawler crane, Fishbone Diagram, Prinsip Pareto, FMEA, Preventive maintenance

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## Introduction

In the construction and infrastructure industry, cranes, especially crawler cranes, are essential in heavy operations such as lifting and moving materials on construction sites. The reliability of this equipment is crucial because operational failures can cause significant downtime, increase repair costs, and reduce productivity. Addressing this problem requires a comprehensive approach to minimize the risk of failure and optimize equipment maintenance issues. Some common approaches, such as Fishbone Diagrams, help identify root causes, Pareto Principle is used to prioritize the main causes of failure, and Failure Mode and Effect Analysis (FMEA) determines practical corrective actions. Recent studies have used Fishbone Diagrams for internal audit processes (Ardha et al., 2023) and corporate economics (Fatmaria Tantri et al., 2024). Then Fishbone Diagrams are also used in the healthcare sector to assess medical infections (Hovanec et al., 2023) and environmental industries (Kumah et al., 2024). In addition, fishbone diagrams are also used for Natural-Technological (Natech) risk assessments in crude oil storage tanks (Mandal & Agarwal, 2024).

Recent research on the Pareto Principle discusses multi-objective optimization based on the Pareto Principle (P. Gao et al., 2023; Wang et al., 2023; Xu et al., 2023; Yang & Xia, 2024). Other researchers base the Pareto Principle on evolutionary optimization and neural networks (Ma et al., 2024), sustainable supply chain management, and optimization (Goodarzian et al., 2023). Various studies on the Pareto Principle are used for virtual learning communities to determine the factors that most affect learning outcomes (Serradell-Lopez et al., 2023). In addition, the Pareto Principle is also used for statistical analysis of the frequency of natural disasters such as floods (Anghel & Ilinca, 2023). Meanwhile, related to mechanical design and engineering, discussing structural engineering and design (Hu et al., 2023) and identifying significant factors in the machining process of superalloy metals (O et al., 2023).

Furthermore, research on FMEA is used to identify and reduce risks in the manufacturing environment (Salah et al., 2023). In the maritime sector, FMEA has been used to manage various types of risks, including environmental (Ceylan et al., 2023) and cybersecurity (Park et al., 2023), maritime transportation to evaluate transportation risk management (Jin et al., 2023; P. Liu et al., 2024). FMEA is also used in the energy sector to manage the risk of failure at hydrogen transfer stations (Li et al., 2024) and in oil and gas drilling operations for a more comprehensive risk analysis (Hatefi & Balilehvand, 2023). In healthcare technology, FMEA is used to assess risks and improve the reliability of technology and to assess risks in robot-assisted rehabilitation applications, focusing on the reliability of healthcare technology (J. Liu et al., 2023). In addition, FMEA is also used in other fields, such as the aviation industry, focusing on improving safety and quality (Resende et al., 2024) and testing and calibration laboratories, helping to improve the quality and reliability of laboratory processes (Testik & Unlu, 2023). Meanwhile, research related to crawler cranes has been carried out, such as Solazzi (2024) exploring material innovation in crane construction (Solazzi, 2024), primarily using composite materials to reduce overall weight. Zhu et al. (2024) developed an automation system for crawler crane assembly (Zhu; et al., 2024). Then, Gao et al. (2024) focused on the flexible braking process during hook-free lowering on a crawler crane (W. Gao et al., 2024). Lu et al. (2023) used UAV and Swin Transformer technology to detect dangerous zones for crawler cranes (Lu et al., 2023). Cui et al. (2023) focused on cooperative lifting operations with two crawler cranes under rope speed constraints (Cui et al., 2023). It can be seen that previous studies related to crawler cranes have focused more on specific technical aspects (such as materials, assembly, and operation, including braking, safe working zones, and lifting).

Based on recent research conducted by several previous researchers reviewing various methods such as the Fishbone Diagram, Pareto Principle, and FMEA applied in various industrial and technology sectors, including health, energy, transportation, and manufacturing. In addition, research on crawler cranes focuses more on technical aspects, such as material innovation, automation systems, flexible braking, danger zone detection, and cooperative lifting operations. In this article, researchers will do something different from previous research; namely, the research will focus specifically on the causes of crawler crane failure and use the Fishbone Diagram method, Pareto Principle, and FMEA to identify root causes of failure, prioritize the main causes, and determine corrective actions. This approach aims to reduce downtime and improve operational reliability, with more emphasis on maintenance issues and operational failure risk management.

## Methodology

The approach used in this article involves three main steps:

- Fishbone Diagram (Ishikawa Diagram) (Ardha et al., 2023):

  This method is used to identify the root cause of failure. In the context of crawler cranes, the root causes are identified based on data from the last two years and grouped into mechanical, electrical, environmental, and human error categories. This diagram helps to correlate the various factors that contribute to failure.
- Pareto Principle (Anghel & Ilinca, 2023):

  The Pareto Principle or 80/20 rule is applied to identify 20% of the causes contributing to 80% of the problems. In this article, mechanical failure is the dominant cause that requires more attention to reduce downtime. The maintenance focus can be directed to the most critical problems by applying the Pareto principle.
- Failure Mode and Effect Analysis (FMEA) (Ceylan et al., 2023):

  FMEA evaluates potential failure modes, determines the impact of each failure, and prioritizes mitigation based on the Risk Priority Number (RPN). Thus, this approach helps determine the corrective actions that can be taken to prevent the recurrence of failure.

The following is an explanation of the Severity, Occurrence, Detection, and Risk Priority Number (RPN) criteria values in the context of Failure Mode and Effect Analysis (FMEA):

- Severity (S)
  a. Definition: Severity measures the level of impact or consequence of a failure mode if it occurs. This value ranges from 1 to 10, where 1 indicates a shallow impact, and 10 indicates a very high or critical impact.
  b. Example: In the context of a crawler crane, a hydraulic system failure that results in a load falling has a high severity (e.g., 9 or 10) because it can result in a serious accident or material damage.
- Occurrence (O)
  a. Definition: Occurrence measures how often a particular failure mode is expected to occur. This value also ranges from 1 to 10, where 1 indicates rare and 10 indicates frequent.

b. Example: If data shows that gearbox failures occur regularly, it might be given a high occurrence score (e.g., 7 or 8), while a less frequent component failure might only receive a score of 2 or 3.

- Detection (D)
  a. Definition: Detection measures the ability to detect a failure mode before it causes a negative impact. It ranges from 1 to 10, with 1 indicating a very high probability of detection and 10 indicating a very low probability.
  b. Example: If a monitoring and alarm system is in place to detect hydraulic leaks, then the detection score might be low (e.g., 2). However, if there is no detection system and failures are only discovered when they occur, the detection score might be high (e.g., 8 or 9).
- Risk Priority Number (RPN.)
  a. Definition: The RPN is calculated by multiplying the severity, occurrence, and detection scores (RPN = S × O × D). The RPN identifies and prioritizes failure modes that require further repair attention.
  b. Example: If a failure mode has a severity of 9, occurrence of 7, and detection of 2, then its RPN is 126 (RPN = 9 × 7 × 2). Failure modes with higher RPN indicate greater risk and should be prioritized for corrective action.

The severity, occurrence, detection, and RPN criteria values are critical in the FMEA process, as they help the management team identify critical risks and plan appropriate mitigation actions. Thus, this approach can improve the operational reliability and safety of equipment such as crawler cranes.

## Results and Discussion

This study takes data from a company operating in Indonesia that uses crawler cranes as its main equipment for lifting materials and personnel (personnel transfer) activities. The following is a table of updated crawler crane failure data with failure duration from January 2022 to September 2024:

Figure 1. Crawler crane

Table 1. Crawler crane failure data ((January 2022 to September 2024)

| No | Failure Date | Failure Cause | Downtime Duration (hours) | Failure Type | Failure Description | Corrective Action |
|---|---|---|---|---|---|---|
| 1 | 12/01/2022 | Engine overheating | 5 | *Mechanical* | Engine overheats during heavy operation | Radiator and fan service |
| 2 | 28/02/2022 | Electrical short circuit | 8 | *Electrical* | Electrical cable burns, causing a total blackout | Replacing cables and fuses |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | 15/04/2022 | Hydraulic system failure | 12 | *Mechanical* | Hydraulic system leaks and cannot lift load | Repairing hydraulic pumps |
| 4 | 23/06/2022 | Track bolt broken | 2 | *Other* | Track bolts broken on rough terrain | Replacing track bolts |
| 5 | 05/09/2022 | Control system failure | 6 | *Electrical* | Control panel unresponsive | Repairing control panels |
| 6 | 17/12/2022 | Engine failure | 10 | *Mechanical* | The engine won't start | Repairing engine starters |
| 7 | 11/03/2023 | Brake failure | 4 | *Mechanical* | Crane brakes jammed | Repairing brake systems |
| 8 | 22/06/2023 | Gearbox problem | 7 | *Mechanical* | The gearbox is noisy and worn | Rebuilding gearboxes |
| 9 | 05/09/2023 | Oil leak | 3 | *Mechanical* | Oil seal leaks | Replacing seals |
| 10 | 18/10/2023 | Electronic system failure | 5 | *Electrical* | Temperature sensor fault | Calibrating temperature sensors |
| 11 | 21/12/2023 | Hydraulic system leak | 9 | *Mechanical* | Hydraulic hose leaks | Replacing hydraulic hoses |
| 12 | 10/02/2024 | Turbocharger failure | 8 | *Mechanical* | The turbocharger is not functioning optimally | Replacing turbochargers |
| 13 | 25/05/2024 | Cooling system failure | 6 | *Mechanical* | Cooling system failure | Replacing radiator components |
| 14 | 13/08/2024 | Control panel short circuit | 7 | *Electrical* | Control panel short circuit | Repairing electrical circuits |
| 15 | 05/09/2024 | Gearbox failure | 10 | *Mechanical* | Mechanical faults cause the crane to be unable to move | Repairing gearboxes |

The following are the steps for analyzing crawler crane failure data for the past two years using the Fishbone Diagram, Pareto Diagram, and Failure Mode and Effect Analysis (FMEA). In addition, analysis and discussion will be included for each method.

- Fishbone Diagram

A Fishbone Diagram is used to identify the root cause of a problem or failure based on the main category. In this case, the main categories of causes of failure in crawler cranes can be grouped as follows:

a. Mechanical
b. Electrical
c. Environmental
d. Human Error

Fishbone Diagram can describe each category in more detail according to existing failure data.

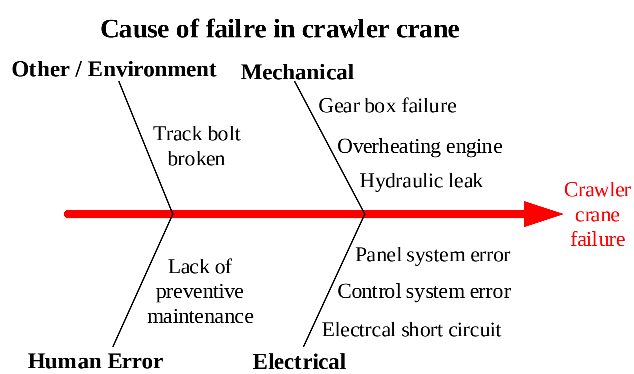

Figure 2. Causes of failure in crawler cranes

- Fishbone Diagram Analysis and Discussion:

a. Mechanical failures such as gearbox, engine overheating, and hydraulic leaks account for most downtime.
b. Electrical failures, such as short circuits and control system problems, are also significant, especially those related to short circuits in the control panel.
c. Environmental factors such as rough terrain cause track bolts to break, which, although not frequent, still affects operations.
d. Human error, involving a lack of preventive maintenance, can contribute to some problems, such as engine overheating.

- Pareto Diagram

The Pareto diagram will help us see the most frequent and impactful causes of failure. In the context of this failure, we will calculate the frequency of failures for each category (Mechanical, Electrical, etc.) and determine the most critical ones.

Table 2. Data for Pareto Diagram

| Causes of Failure | Frequency | Cumulative Percentage |
|---|---|---|
| Mechanical | 9 | 60% |
| Electrical | 5 | 33% |
| Other (Environmental) | 1 | 7% |
| Human error | 0 | 0% |

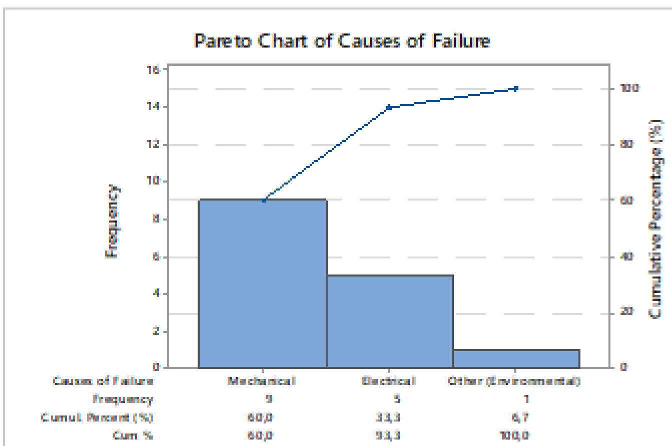


Figure 3. Pareto Diagram of crawler crane failure

Based on the Pareto diagram, mechanical failures account for most failures (60%), followed by electrical failures (33%). Therefore, the main focus should be improving the reliability of the mechanical system. Interventions such as preventive maintenance on the gearbox, hydraulic system, and engine and operator training to prevent overheating can significantly reduce downtime.

- Failure Mode and Effect Analysis (FMEA)

FMEA is used to identify potential failure modes, the effects of the failure, and mitigation measures to reduce the impact of the failure. The following is a customized FMEA table for crawler crane failure.

Table 3. FMEA results on crawler crane

| Failure Mode | Cause | Potential Effects | Severity (S) | Occurrence (O) | Detection (D) | Risk Priority Number (RPN) | Mitigation |
|---|---|---|---|---|---|---|---|
| Overheating engine | Cooling system damaged | Total engine failure | 8 | 6 | 5 | 240 | Regular inspection, repair, and replacement of cooling components |
| Electrical short circuit | Wires burnt | Total electrical failure | 7 | 4 | 6 | 168 | Regular cable replacement, electrical safety inspection |
| Gearbox failure | Worn out | Cannot move | 9 | 5 | 4 | 180 | Regular repair, component lubrication |
| Hydraulic leak | Seal leaks | Cannot lift the load | 8 | 4 | 5 | 160 | Regular inspection of seals and hydraulic pumps |

Based on the highest RPN, the main focus should be on preventing engine overheating and gearbox failure, as both are highly severe and frequent. Cooling system maintenance and gearbox lubrication and repair are critical steps to reduce the risk. Electrical short circuits are also a significant risk, but early detection through wiring inspections and electrical safety systems can reduce their impact.

The results of this research offer a more comprehensive and structured analytical approach than previous studies. Some of the main differences include:

a. The latest empirical data: this article uses actual failure data on crawler cranes over two years (January 2022 to September 2024), thus providing an up-to-date view of failure patterns and a more relevant and up-to-date context.
b. Integration of three-step methodologies: Previous studies often use only one method, such as a Fishbone Diagram to identify causes or an FMEA for failure mode analysis. This article combines all three methods to provide a more holistic and actionable analysis, which has not been fully applied in the context of crawler cranes.
c. Application of the Pareto Principle to maintenance optimization: By identifying the root causes of failures that cause the most significant downtime, this article focuses on preventive efforts by strengthening critical areas that contribute the most to failures, which has not been widely applied in other literature.
d. FMEA extended with RPN evaluation: This article identifies failure modes and evaluates their impact and likelihood to provide priority-based mitigation action recommendations.
e. Emphasis on preventive maintenance: This article provides practical recommendations for strengthening preventive maintenance strategies derived from the results of FMEA and Pareto analysis, which has not been discussed in much detail in previous literature.

## Conclusion

Based on crawler crane failure data for two years and an integrated analysis between the Fishbone Diagram, Pareto Diagram, and FMEA, the following conclusions can be drawn. The Fishbone Diagram shows that mechanical failure is dominant in crawler crane failure. Mechanical failures such as gearbox, engine overheating, and hydraulic leaks account for most downtime, followed by electrical and environmental problems. The Pareto Diagram confirms that mechanical failures account for the majority of failures (60%), followed by electrical failures (33%), so the main focus of improvement should be directed to this area. FMEA identifies critical failure modes, such as engine overheating and gearbox failure, and recommends mitigation measures to reduce risks. Implementing better preventive maintenance strategies, operator training, and continuous system monitoring can significantly reduce downtime duration and failure frequency. Optimization can be applied to reliability, availability, and maintainability (RAM) for further research. In addition, preventive maintenance and corrective maintenance optimization strategies can also be used.

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