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Application of Failure Mode and Effect Analysis (FMEA) and Fishbone Diagram in the Analysis of Engine Component Failure on Harbour Mobile Crane

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***Abstract* – Container loading and unloading port is a port that uses Harbour Mobile Cranes (HMCs) as its main tool in the container loading and unloading process and operates 24 hours. The high work intensity causes the HMC engine components to be susceptible to failure, thus disrupting the smooth operation of operational activities. This study aims to analyze failures of Harbour Mobile Crane (HMC) engine components at a container loading and unloading service company using Failure Modes and Effects Analysis (FMEA) and Fishbone Diagram methods. The FMEA method is used to identify engine component failures and determine the Risk Priority Number (RPN) value, while the fishbone diagram is used to identify the root cause of failure and determine recommendations. The results of the FMEA analysis on 7 engine components show that the highest RPN value is found in the fuel filter component with an RPN value of 105. Furthermore, the component with the highest RPN value is analysed using a fishbone diagram to determine the root cause in terms of people, method, machines, material, measurements, management, environment, and maintenance factors. The results of the fishbone diagram analysis are used as a reference for providing recommendations using the risk control hierarchy, namely elimination, substitution, engineering, administrative control, and personal protective equipment.**

***Keywords :* Failure Mode and Effect Analysis, Fishbone Diagram, Harbour Mobile Crane, Risk Priority Number**

I. INTRODUCTION

Ports play a crucial role in economic activity, particularly in the distribution of goods, services, and information. Ports also serve as logistics hubs, integrating various modes of transportation, including sea, land, and air. Consequently, loading and unloading activities are one of the largest drivers of a country's economy. (Ardiansyah et al., 2024).

Container loading and unloading ports play a vital role in driving the economy through the distribution of goods and are an example of a service industry representative of the service industry, with a focus on maritime freight forwarding. As a crucial sector of the national economy, container loading and unloading ports play a significant role in providing satisfactory service and operating professionally and efficiently. To support the effectiveness and efficiency of container loading and unloading operations, ports focus on container loading and unloading services that require the assistance of heavy equipment. Harbour Mobile Crane (HMC) is one such tool that can support loading and unloading activities.

Harbour Mobile Crane (HMC) is heavy equipment, a type of lifting and transporting equipment used in container loading and unloading activities, operating 24/7. HMC plays a crucial role in ensuring the smooth flow of goods, accelerating ship docking times at ports, and improving the overall efficiency and productivity of port operations [2].

Data on Harbour Mobile Crane (HMC) component failures or damage at a container loading and unloading service company from January to December 2024 shows that the highest number of component failures occurred on the Konecranes Gottwald 5506 HMC. There were 137 component failures on the Konecranes Gottwald 5506 HMC. In expert judgment interviews with engineering supervisors, one of the HMC components that frequently failed was the engine. Maintenance and upkeep of the equipment is carried out by the company's engineering division by implementing a maintenance system in the

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form of corrective maintenance and preventive maintenance to prevent failures; however, based on data and field observations, failure or damage to engine components on HMC equipment still occurs frequently. Equipment failure can occur at any time without warning and cause disruption to the production process, posing a risk to workers around it (Fimansyah, 2018).

Based on the above issues, a risk analysis is necessary to prevent and mitigate HMC component failures. This risk analysis aims to mitigate and minimise existing risks, thereby streamlining the production process. [4]. According to Pibisono et al., (2020) Failure Mode and Effect Analysis (FMEA) is a tool that systematically identifies the effects or consequences of system or process failures and reduces or eliminates the likelihood of failure occurring. A method for finding the root cause of a component failure is necessary to identify the root cause of the problem. Fishbone diagrams are one of the root cause analysis methods that have advantages over other methods, namely identifying and organising the causes that arise from a specific effect, and separating the root causes. (Putri et al., 2023).

This study uses a combination of the Failure Mode and Effect Analysis (FMEA) and fishbone diagram methods to analyse the failure risk of Harbour Mobile Crane (HMC) engine components. This combination of the two methods has been applied in a previous study by Cintya Putri et al., (2023) which discussed the failure risk analysis of wet sandblasting machine components using the Failure Mode and Effect Analysis (FMEA) and fishbone diagram methods in the manufacturing industry. In a study by Sufriyani Tanuwijaya dan Sukania (2021)This combination of the two methods was also used to analyse the failure of steel production machines and maintenance management systems in the steel manufacturing industry.

This research focuses on Harbour Mobile Crane (HMC), which is used as an operational aid for loading and unloading containers. Different research locations and objects naturally have different factors that cause problems. These factors include management, work methods and processes, and labour, which can contribute to component failures. It is hoped that the analysis of Harbour Mobile Crane (HMC) engine component failures will reduce the number of HMC failures.

II. THEORY REVIEW

A. *Risk Management*

Risk management is a systematic process for identifying, assessing, and managing risks that can impact a company's objectives by minimising those that could hinder them. The goal of risk management is to help companies identify and mitigate risks, thereby preventing financial losses, reputational damage, and operational disruptions. (Siswanto, 2021). Risks inherent in the workplace must be controlled. Risk control aims to minimise hazards by implementing a risk control hierarchy: elimination, substitution, engineering, administrative controls, and personal protective equipment.

Table 1. Severity Scale

Rank	Impact	Severity Level
10	Failure not preceded by warnings	Dangerous without warning
9	Failure preceded by warnings	Dangerous with a warning
8	Product inoperable	Very High
7	Product operable with significantly reduced performance	High
6	Product operable, but some additional items (secondary functions) are inoperable.	Medium
5	Product operable with slightly reduced performance	Low
4	Customer-aware defect (>75%)	Very Low
3	Customer-aware defect (50%)	Minor
2	Customer-aware defect (<25%)	Very Minor
1	No impact	Nothing

Table 2. Occurrence Scale

Rank	Risk Probability	Description
10	Very High	More than one occurrence per day
9	High	One occurrence every three or four days
8	High	One occurrence per week
7	Quite High	Once a month
6	Medium	Once every 3 months
5	Low	Once every 6 months
4	Very Low	Once a year
3	Rare	Once every 1-3 years
2	Very Rare	Once every 3-6 years
1	Rarely	Once every 6-100 years

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B. *Failure Mode and Effect Analysis (FMEA)*

Failure Mode and Effect Analysis (FMEA) is a tool used to analyse the reliability of a system and the causes of its failure to meet system reliability and safety requirements, design, and process by providing basic information regarding system, design, and process reliability predictions. (Hendra, 2023). The goal is to evaluate the effects of failure modes to determine actions to reduce the risk of component failure. FMEA identifies information from each failure type, the impact of the failure, and the level of failure risk priority (Situngkir et al., 2019). The output of FMEA is the failure mode, the impact of the failure, and the Risk Priority Number (RPN) value of the analysed object. The Risk Priority Number (RPN) is obtained from the multiplication of severity, occurrence, and detection. The higher the RPN value, the more critical the problem is and requires further action.

Table 3. Detection Scale

Rank	Detection Probability	Detection Level
10	The controller cannot detect the failure	Almost Impossible
9	It is improbable that the controller will detect a potential failure	Very Rarely
8	The controller will rarely detect a potential failure	Rarely
7	The controller has a very low probability of detecting a failure	Very Low
6	The controller has a low probability of detecting a failure	Low
5	The controller's probability of detecting a failure is moderate	Medium
4	The controller's probability of detecting a failure is somewhat high	Quiet High
3	The controller's probability of detecting failure is high	High
2	The controller's probability of detecting failure is very high	Very High
1	Failure in the process cannot occur because it has been prevented through the Solution design.	Almost Certain

Table 1 explains the severity scale from 1 to 10, the higher the value is more dangerous. Table 2 explains the occurrence scale from 1 to 10, the higher the value has more frequent the occurrence. Table 3 explains the detection scale from 1 to 10, the higher the value has more detectable the failure.

C. *Fishbone Diagram*

A fishbone diagram is a visual tool used to graphically and structurally depict the causes or factors related to a particular problem or issue. This diagram was invented by Kaoru Ishikawa, a Japanese quality management expert, and is often used in various fields, including manufacturing, business, and other fields, as an analysis and improvement tool. [11]. The basic principle of a fishbone diagram is to illustrate the relationship between the problem that occurs and all its causal factors. The shape of the diagram resembles a fishbone, with a centre line depicting the problem or issue whose causes will be identified. In identifying using a fishbone diagram, there are several main factors involved in finding the cause of a problem. According to Pušnik et al., (2019these main factors are people or manpower, methods, machines, materials, measurements, environment, management, and maintenance.

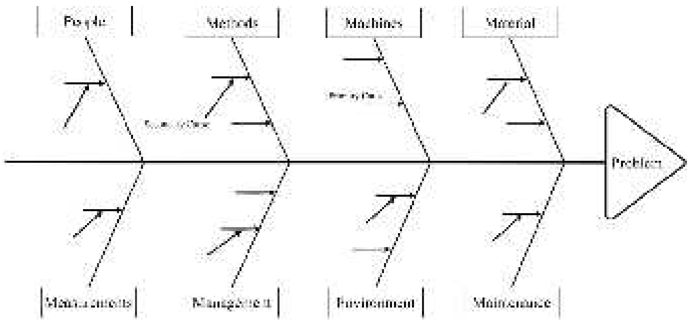

Figure 1. Fishbone Diagram.

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III. METHODS

This research uses a qualitative descriptive approach with the aim of systematically, factually, and accurately describing the data in the field. The initial step in this research is to conduct initial observations, including literature studies related to the object being studied, field studies, and problem identification. Furthermore, to support future research, data collection is carried out. The data collected are primary data in the form of interviews with expert judgment and field observations. Meanwhile, secondary data includes data on HMC Type 5506 engine components, failure data, organisational data, and tool manuals. After the data is collected, the next stage is data processing and analysis. Data processing and analysis in this study include determining expert judgment, identifying objects using the Failure Mode and Effect Analysis (FMEA) method, identifying root causes using Fishbone Diagrams, and providing recommendations using the risk control hierarchy.

III. RESULTS AND DISCUSSION

A. *Failure Mode and Effect Analysis (FMEA)*

Failure Mode and Effect Analysis (FMEA) is an analytical method used to analyse failure modes, effects, and causes of failure in Harbour Mobile Crane (HMC) engine components. Table 4, the FMEA worksheet, presents an analysis of failures, impacts, causes, and control measures based on failure prevention based on the severity, occurrence, and detection criteria in Tables 1, 2, and 3. The FMEA was conducted using expert judgment, conducted by an HMC equipment supervisor familiar with each HMC component, as well as by an HSSE supervisor and HSSE manager familiar with hazard identification and risk management techniques within the company.

Table 4 shows the results of the FMEA analysis on seven HMC 5506 engine components: the auxiliary power supply, battery, fuel injector pump, fuel filter, radiator, temperature sensor, and water separator, with a total of 10 failure modes. From the results of the FMEA analysis, the Risk Priority Number (RPN) value can be determined for each component of the HMC type 5506 engine, which is obtained from calculations in the form of multiplying the severity value, the frequency value of a failure mode (occurrence), and the value of how effectively the existing system or control can detect the failure mode (detection).

The FMEA analysis of the HMC 5506 engine component showed the highest RPN value for the fuel filter component, with a clogged fuel filter failure mode. The Risk Priority Number (RPN) calculation is based on the multiplication of severity x occurrence x detection. Severity is scored as 5 (low) because a dirty/clogged fuel filter can slightly reduce HMC performance; occurrence is scored as 7 (moderately high) because the incident occurs once a month; and detection is scored as 3 (high) because a clogged fuel filter is highly detectable by controllers and mechanics. Based on the multiplication of severity × occurrence × detection, the total RPN for the fuel filter subcomponent with a dirty/clogged fuel filter failure mode is 105.

The component with the highest RPN value will be further identified for its root cause using a fishbone diagram, with the failure mode as the effect or head of the fish. The analysis using a fishbone diagram aims to identify the root cause of subcomponent failure from the perspective of people, methods, machines, materials, management, maintenance, measurement, and the environment, and facilitates the determination of recommendations for future implementation.

B. *Fishbone Diagram*

Figure 2 below shows a fishbone diagram of a fuel filter component failure, with the failure mode being a clogged fuel filter. The root cause analysis of the fuel filter component failure is reviewed from the perspectives of people, method, machine, material, measurements, management, environment, and maintenance.

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Table 4. Failure Mode and Effect Analysis of HMC Engine Components
Failure Mode and Effect Analysis Worksheet

System: Harbour Mobile Crane 5506 Date: May
Subsystem: Engine Years: 2025

NO	Component	Potential Failure Mode	Potential Effect of Failure	Severity (S)	Potential Cause of Failure	Occurrence(O)	Current Control Detection	Detection (D)	RPN
1	Aux Power Supply	Aux power supply drop	HMC cannot start	7	The Auxiliary Power Supply cable is broken or corroded	2	Perform an inspection on the cable and plug connections	3	42
2	Accu	Accu drop	The engine cannot start	6	Battery usage period is up (age factor)	5	Replace the battery unit according to the validity period	3	90
		Clamp broken	The battery cannot supply electricity to the engine	4	Broken or corroded battery clamp	5	Perform clamp replacement and physical visual inspection of the battery	2	40
		Out of water	The battery cannot store the maximum amount of electricity	4	The battery water check was not carried out	5	Conduct regular inspections and filling	2	40
3	Fuel Injector Pump	Weak pump pressure	Fuel supply to the engine is not optimal	5	The fuel injector pump is broken	4	Replace the fuel pump according to specifications	3	60
4	Fuel Filter	Fuel filter clogged	The engine stalls and has no power	5	Dirty fuel and filter checks were not performed	7	Perform corrective maintenance on the fuel filter	3	105
5	Radiator	Out of water	Engine is overheated	5	The radiator water check was not carried out	6	Carry out routine filling periodically	2	60
		Leaking	Engine cooling is not optimal	4	The radiator is hit by an impact or iron particles	3	Visual check and engine temperature indicator	2	24
6	Sensor Temperature	Abnormal	The engine overheats due to a temperature indicator failure	4	The age factor of the temperature sensor is outdated	5	Replacing the temperature sensor unit and checking the sensor cable	3	60
7	Water Separator	Water is fresh to low	Water filtration from fuel is disrupted	5	Frequency too low	6	Replacing the water separator unit according to specifications	3	90

The following is a description of the causes that contribute to clogged fuel filters, reviewed from the aspects of people, method, machine, material, management, measurements, maintenance, and environment in Figure 3.

1. People
   Negligence in routine maintenance can easily lead to fuel filter clogging. Failure to maintain this component regularly can have serious consequences and disrupt the fuel supply to the engine.
2. Methods
   Incorrect fuel filter replacement can reduce the filter's capacity and hinder engine performance. These errors can include using a fuel filter that doesn't meet specifications and failing to maintain cleanliness during replacement. This occurs due to a lack of understanding of standard operating procedures (SOPs) by mechanics.
3. Machines
   Fuel filter blockages can be caused by other supporting components failing to function optimally, such as a damaged fuel pump, a

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suboptimal injection system, or a rusty fuel tank. If other supporting components aren't working optimally, the fuel filter is more likely to become clogged, as it has to work harder.

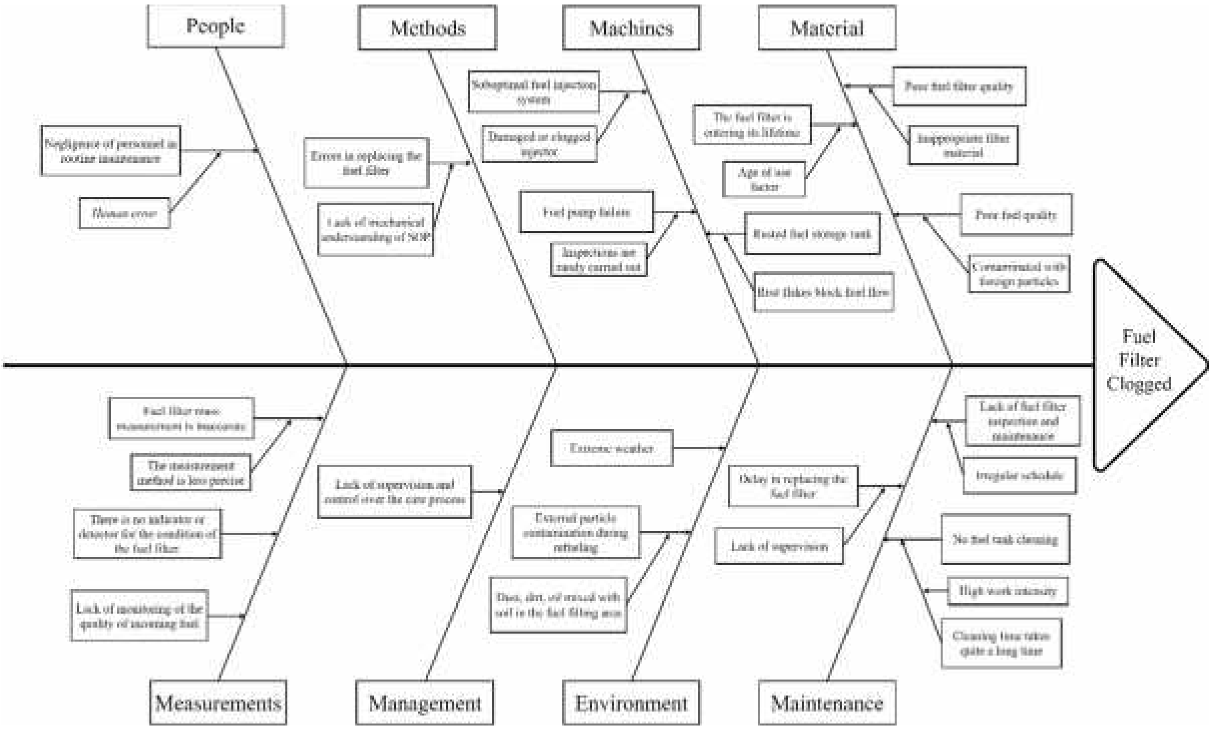

Figure 2. Fishbone Diagram of a Clogged Fuel Filter

4. Material
   A fuel filter that's reaching its lifespan is of poor quality and uses poor fuel quality will accelerate fuel filter clogging. The presence of clogging particles from poor fuel and the fuel filter's inability to filter properly contribute to this.
5. Management
   Lack of oversight and control over the maintenance process. Component maintenance is crucial to prevent future problems. However, sometimes this maintenance process is not carried out properly or even infrequently. A lack of oversight and control by management is one of the causes of this.
6. Measurements
   The lack of a fuel filter condition indicator and minimal fuel quality monitoring can lead to clogged filters. Fuel filter condition can only be detected visually. Therefore, measuring the service life must be determined from the time the component is installed.
7. Maintenance
   Delayed replacement, lack of inspection and maintenance, and failure to clean the tank can all lead to clogged fuel filters. This is because the fuel filter's performance has deteriorated due to numerous blockages and not being replaced promptly.
8. Environment
   A clogged fuel filter can be caused by extreme weather conditions and external particle contamination during refueling. These particles become airborne and enter the fuel tank, clogging the filter.

C. Recommendation

Recommendations for controlling clogged fuel filter failures are based on the underlying cause of the failure. Recommendations are based on a risk control hierarchy: elimination, substitution, engineering, administrative controls, and personal protective equipment.

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The following are recommendations for handling clogged fuel filters.

1. Elimination – This control cannot be done because the fuel filter is an important component for filtering fuel before it is distributed to the HMC engine.
2. Substitution – Replace the dirty fuel filter with a new one that meets the specifications of the diesel engine used, replace the damaged injector and fuel pump with a new one that meets the tool standards.
3. Engineering Control – Provides filter material in the fuel tank filler hole that can filter dirt mixed with the fuel that is entered, provides fuel filter protection to prevent foreign particles from entering, protects against extreme weather that causes dirt deposits on the fuel filter, and provides an anti-rust coating on the fuel tank.
4. Administration – Conducting toolbox meetings regularly, creating routine inspection schedules and adjusting the number of inspection officers, filling fuel by paying attention to the cleanliness of the surrounding environment, marking the fuel filter and recording the replacement time to estimate its service life, paying attention to the quality of the fuel before filling it into the tank, cleaning the fuel tank to prevent rust debris from entering the fuel flow, storing fuel stocks in a clean place and avoiding oil and dirt, maintaining the cleanliness of the fuel filling and storage area, and conducting daily supervision at the HMC equipment maintenance location.
5. Personal Protective Equipment (PPE) – In the existing basic failure causes, the use of PPE is not necessary because it does not cause injury to humans.

IV. CONCLUSION

Based on the results of the analysis and discussion carried out in this study, the following conclusions can be drawn:

1. The results of the calculation of the RPN value on 7 engine components of the Harbour Mobile Crane (HMC) type 5506 using the Failure Mode and Effect Analysis (FMEA) method showed that the highest RPN value was found in the fuel filter component with a value of 105, and the failure mode of the fuel filter was clogged.
2. The results identifying the causes of risk for components with the highest RPN values for the Harbour Mobile Crane (HMC) type 5506 using the Fishbone Diagram method revealed eight factors that influence fuel filter clogging. These factors include:
   a. People – Negligence of officers in routine maintenance.
   b. Methods – Fuel filter replacement error.
   c. Machines – Suboptimal injection system, fuel pump damage, and rusty fuel tank.
   d. Material – The fuel filter is entering its lifetime, and the quality of the fuel filter and fuel is poor.
   e. Management – Lack of supervision and control over the care process.
   f. Measurements – Inaccurate service life measurements, no indicators, and minimal monitoring of fuel quality.
   g. Maintenance – Delay in replacing the fuel filter, lack of inspection and maintenance, and failure to clean the fuel tank.
   h. Environment – Extreme weather and external particle contaminants.
3. Controls to reduce the occurrence of Harbour Mobile Crane (HMC) engine component failures were obtained from the results of the analysis using a fishbone diagram. The basic causes that influence the occurrence of failures were controlled based on the hierarchy of risk control, namely elimination, substitution, engineering, administrative control, and personal protective equipment. Recommendations that can be given to clogged fuel filters include conducting regular toolbox meetings to ensure understanding and compliance with SOPs, replacing damaged or expired component units, and conducting supervision in the equipment maintenance area.

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