Department of Digital Business
Journal of Artificial Intelligence and Digital Business (RIGGS)
Homepage: https://journal.ilmudata.co.id/index.php/RIGGS
Vol. 5 No. 2 (2026) pp: 492-503
P-ISSN: 2963-9298, e-ISSN: 2963-914X

Hydraulic Valve Failure Analysis at MT. Beyond Using the FMEA Method

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Abstract

Hydraulic valve failure on a tanker can significantly impact operational performance and shipping safety. This study aims to analyze the causes, impacts, and solutions to hydraulic valve failure on the MT. Beyond. The method used was a qualitative descriptive approach, with data collection techniques through observation, interviews, and documentation studies. Data analysis was performed using the Fishbone Diagram method to identify root causes and Failure Mode and Effects Analysis (FMEA) to evaluate the level of failure risk based on severity, occurrence, and detection parameters. The results showed that hydraulic valve failure was influenced by human, machine, material, method, and environmental factors, with the dominant causes being operational errors, low component quality, fluid contamination, and lack of maintenance. The FMEA analysis showed that the key components with high risk were the disc and seat, which had the highest Risk Priority Number (RPN) values of 162 and 132, respectively. Failure of these components can cause uncontrolled flow, potentially reducing overall system performance due to corrosion, leakage, and wear,thus becoming the main priority for repair. The conclusion of this study confirms that improving component quality, regular maintenance, operator training, and implementing an effective monitoring system can reduce the risk of failure and increase the reliability of the ship's hydraulic system.

Keywords: *Hydraulic Valve, FMEA, Fishbone Diagram, Tanker, Hydraulic System.*

1. Introduction

The maritime transportation industry plays a strategic role in supporting the distribution of goods and services, both domestically and internationally. In the context of globalization, competition among shipping companies is increasingly fierce, demanding improved service quality, not only in terms of fleet quantity but also in ensuring the operational condition of vessels, which must always be in prime condition and ready for use [1]. Along with the development of the shipping industry, attention to safety, operational efficiency, and environmental protection is increasing, particularly in the operation of tankers, which have the potential to pose a risk of marine pollution [2].

However, various incidents in the maritime sector demonstrate that ship accidents and system failures remain significant problems [3]. One critical issue is the failure of components in hydraulic systems, particularly hydraulic valves, which play a role in regulating fluid flow and maintaining system stability [4]. Previous studies have revealed that valve failure can be caused by various factors such as material quality, extreme operational conditions, contamination, corrosion, and errors in maintenance and installation [5]. However, research specifically analyzing hydraulic valve failures on tankers using a systematic approach, such as Failure Mode and Effects Analysis (FMEA), is still limited.

This research gap is increasingly important given the impact of hydraulic system failure, particularly in a ship's steering system, which can result in impaired maneuvering, increased risk of accidents, and potential economic and environmental losses [6]. Several studies have shown that steering system failure caused by valve malfunction can reduce a ship's operational reliability and increase the likelihood of incidents in confined waters and ports [7]. Therefore, a comprehensive analysis of the causes and impacts of valve failure is crucial, both scientifically and practically.

Based on these issues, this study aims to analyze the factors causing hydraulic valve failure on the MT vessel. Furthermore, it aims to identify the impact on steering system performance and formulate effective solutions to address and prevent similar failures in the future. The approach used in this study is the Failure Mode and Effects Analysis (FMEA) method, which has proven effective in identifying potential failures and prioritizing risk management in engineering systems [8].

This research is expected to provide added value to the development of scientific knowledge in the field of marine engineering, particularly related to the reliability analysis of ship hydraulic systems. In addition, the results of this study are also expected to be a practical reference for the shipping industry in improving maintenance and risk management systems, so as to minimize the potential for operational failure and increase the safety and efficiency of tankers.

2. Literature Review

A ship is a means of maritime transportation that transports goods and passengers from one region to another through waters [9]. Based on Law of the Republic of Indonesia No. 21 of 1992, a ship is defined as a watercraft of various shapes and types propelled by mechanical power, wind, or towing, including floating structures. In practice, tankers are one type of vessel that plays a vital role in the distribution of crude oil and its derivatives [9]. Tankers can be classified into crude carriers, black oil product carriers, and light-oil product carriers, depending on the type of cargo they carry [10]. The operational reliability of a ship depends heavily on its support systems, including the hydraulic system, which serves as the power source for various ship mechanisms [11].

A hydraulic system is a technology that utilizes liquid fluids, typically oil, to generate linear and rotational motion based on the principle of uniform fluid pressure distribution in all directions [12]. His system offers advantages in flexible power distribution, the ability to generate large forces, and ease of load control through pressure control valves [13]. One of the main components in a hydraulic system is the valve, a device that functions to regulate, direct, and control fluid flow in a piping system [14]. Valves can be operated manually or automatically, and come in various types, such as butterfly valves, check valves, gate valves, and bypass valves, each with different characteristics and functions [15]. In the case of a tanker's hydraulic system, valves play a crucial role in maintaining stable fluid flow and pressure, so failure of this component can significantly impact overall system performance [16].

The main functions of valves in a hydraulic system can be categorized into three: stop valves, opening or closing the flow [17], regulating valves to regulate fluid flow [18], d safety valves to maintain pressure within safe limits [19]. To maintain optimal valve performance, maintenance and care are required, considering the material, operating temperature, and regular use of lubricants [20]. The choice of materials, such as brass, iron, stainless steel, or steel, must be tailored to the operating conditions to prevent damage due to high temperatures or corrosive environments [21]. In addition, maritime safety aspects are also an important part of ship operations, which include the protection of humans, the environment, and assets through the implementation of international standards such as SOLAS and other safety procedures [22].

In analyzing engineering system failures, the Failure Modes and Effects Analysis (FMEA) method is used as a systematic approach to identify failure modes, causes, and impacts. FMEA evaluates risk levels through three main parameters: severity, occurrence, and detection, which are then calculated as a Risk Priority Number (RPN). This method has proven effective in improving system reliability, identifying repair priorities, and reducing the risk of failure in various industries [23]. Furthermore, the Fishbone Analysis method is also frequently used to identify root causes of problems through a cause-and-effect approach involving human, machine, method, material, environmental, and measurement factors [1].

Based on the literature review, there is a gap in both theoretical and empirical research, namely the lack of comprehensive studies integrating valve failure analysis, its impact on ship steering systems, and risk prioritization using the FMEA method in the operational context of tankers. Therefore, this study contributes to filling this gap by presenting a more focused analysis of the real-life case of MT Beyond. Thus, the results of this research are expected to enrich the development of science in the field of marine engineering as well as provide practical recommendations in improving the reliability of hydraulic systems and operational safety of ships.

DOI: https://doi.org/10.31004/riggs.v5i2.7915

3. Research Methods

This research uses a qualitative descriptive approach to provide an in-depth description of the hydraulic valve failure phenomenon on the MT. Beyond. This approach was chosen because it provides a comprehensive understanding of the problem characteristics, causal factors, and impacts in a real-life operational context. To support a systematic analysis, this research integrates the Failure Mode and Effects Analysis (FMEA) method as a tool to identify failure modes, causes, and their impacts on the system.

The research was conducted on the MT. Beyond, a charter tanker owned by Shell International Eastern Trading Company and operated by Hong Lam Marine Pte. Ltd., operating in Singapore, specifically at the Bukom Terminal. The research process was conducted over three months, from April to June 2024, covering data collection, data processing, and the compilation of research results.

The population in this study was the entire MT. Beyond the crew involved in the operation and maintenance of the hydraulic system, totaling 12 people. The sampling technique used was the census method, where all members of the population were sampled. This approach was chosen to obtain comprehensive and representative data, considering that each crew member plays a crucial role in the operation and maintenance of the hydraulic valve.

The research instruments used included observation guidelines and in-depth interviews to identify hydraulic system conditions, failure characteristics, and causal factors. The data collected consisted of primary and secondary data. Primary data was obtained through direct observation of hydraulic valve conditions and interviews with ship crew members regarding their experiences with system failures. Meanwhile, secondary data was obtained from technical documents, maintenance reports, and case studies from other vessels with similar problems. Data collection techniques included case studies, field observations, and interviews to obtain valid and contextual information.

Data analysis was conducted using two main methods: Fishbone Analysis and Failure Mode and Effects Analysis (FMEA). Fishbone analysis is used to identify root causes of failures based on categories such as human, machine, method, material, and environment. Furthermore, the FMEA method is used to evaluate the risk level of each failure mode using three main parameters: severity, occurrence, and detection. These three parameters are then calculated as a Risk Priority Number (RPN) using the equation $RPN = S \times O \times D$, allowing for systematic risk management priorities. This approach allows researchers to identify the root causes of failure and formulate effective improvement recommendations to improve the reliability of the ship's hydraulic system.

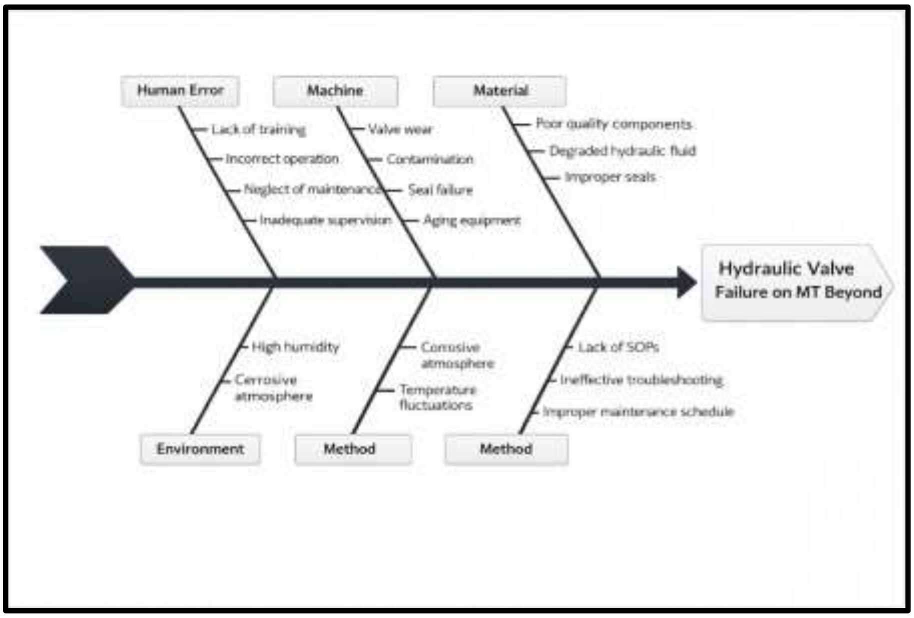
4. Results and Discussions

This research was conducted on the MT. Beyond tanker, an oil product carrier with a main specification of 110 meters in length, 5,153 MT gross tonnage, and operated under Hong Lam Marine Pte. Ltd.

Picture 1. MT Beyond
Source: Documentation (2024)

DOI: https://doi.org/10.31004/riggs.v5i2.7915

This ship is equipped with a hydraulic system that plays a crucial role in valve operation, particularly in the steering system and fluid flow control. Based on observations and interviews, data were obtained on the factors causing hydraulic valve failure, presented systematically in several main categories: human error, machine error, material error, method error, and environmental error.



Picture 2. Fishbone Diagram of Factors Causing Hydraulic Valve Failure on the MT Beyond
Source: Data Analysis Results (2024)

The identification results indicated that machine and material factors were the dominant causes of failure, with low valve quality and hydraulic fluid contamination being the highest contributors, respectively. Furthermore, method factors also contributed significantly, particularly inconsistent maintenance schedules and non-standard operating procedures. Environmental factors, such as corrosion due to sea conditions, were also significant causes. Fishbone diagram analysis confirmed that hydraulic valve failure resulted from a complex interaction of these factors, requiring a comprehensive repair approach.

Next, a Failure Mode and Effects Analysis (FMEA) was conducted to evaluate the risk level of each hydraulic gate valve component. The FMEA data processing stage includes severity, occurrence, and detection, all of which are used in the calculation formula to determine the RPN value. RPN = S x O x D [24].

4.1. Severity

Severity, with higher scores indicating greater severity. The scoring was conducted by the 12-member crew of the MT Beyond, consisting of the engineer, helmsman, and other technical team members. The severity scores for the Hydraulic Gate Valve component failure are shown in Table 1.

Table 1. Severity Scores

Components	Type of Functional Failure	Severity
Stem Nut	Worn threaded rod	5
Stem	Worn rod	4
	Bent rod	5
Disc	Corroded disc	7
	Leaking disc	7
	Eroded disc	6
	Corroded seat	6

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Components	Type of Functional Failure	Severity
Seat	Leaking seat	7
	Eroded seat	6
Hand Wheel	Loose handwheel	2
	Broken handwheel	4
Gland Packing	Leaking gland	5
	Loose gland	6
Packing	Leaking packing	5
	Worn packing	4
Gasket	Leaking gasket	6
	Broken gasket	5

4.2. Occurrence

Occurrence is an assessment of the frequency or likelihood of a component failing. This frequency is assessed based on historical data or estimates from inspection results. The higher the occurrence score, the more frequently the failure is expected to occur. A high score indicates a high probability of failure and requires serious attention. The following are the occurrence scores for functional failures in Hydraulic Gate Valve components, as shown in Table 2.

Table 2. Occurrence Scores

Components	Type of Functional Failure	Occurence
Stem Nut	Worn threaded rod	2
Stem	Worn rod	3
	Bent rod	3
Disc	Corroded disc	3
	Leaking disc	3
	Eroded disc	2
Seat	Corroded seat	3
	Leaking seat	3
	Eroded seat	2
Hand Wheel	Loose hand wheel	2
	Broken hand wheel	2
Gland Packing	Leaking gland	3
	Loose gland	3
Packing	Leaking packing	3
	Worn packing	2
Gasket	Leaking gasket	3

Source: Data Analysis Results (2024)

4.3 Detection

The detection score assesses the effectiveness of the detection or monitoring method used. A low detection score indicates that failures are difficult to detect before they occur, increasing the risk. A high detection score indicates that failures are easily detected, allowing for preventative or mitigating action. The following are the detection scores for functional failures in Hydraulic Gate Valve components, as shown in Table 3.

Table 3. Detection Scores

Components	Type of Functional Failure	Detection
Stem Nut	Worn threaded rod	3
Stem	Worn rod	3
	Bent rod	3

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Components	Type of Functional Failure	Detection
Disc	Corroded disc	3
	Leaking disc	3
	Eroded disc	3
Seat	Corroded seat	3
	Leaking seat	2
	Eroded seat	3
Hand Wheel	Loose handwheel	2
	Broken handwheel	2
Gland Packing	Leaking gland	3
	Loose gland	2
Packing	Leaking packing	3
	Worn packing	3
Gasket	Leaking gasket	3
	Broken gasket	2

Source: Data Analysis Results (2024)

In an FMEA analysis for a gate valve, each failure mode will have a different RPN. A high RPN indicates that the failure has a high impact, occurs frequently, and is difficult to detect, thus requiring greater attention than a failure mode with a lower RPN.

RPN = *Severity* x *Occurrence* x *Detection*

RPN for *Stem Nut*:

RPN = 5 x 2 x 3 = 30

The following are the components, failure types, and their respective RPN values, which can be seen in Table 4.

Table 4. Respective RPN Values

Component	Functions	Type of Functional Failure	*Severity* (S)	*Occurrence* (O)	*Detection* (D)	RPN
Stem Nut	The stem rotates along its groove.	Worn threaded rod	5	2	3	30
Stem	Moves the valve to open and close.	Worn rod	4	3	3	36
		Bent rod	5	2	3	30
Disc	Primary pressure to open and close the flow. Disc seat opening.	Corroded disc	7	3	3	63
		Leaking disc	7	3	3	63
		Eroded	6	2	3	36
Seat	Valve opening and closing.	Corroded seat	6	3	3	54
		Leaking seat	7	3	2	42
		Eroded seat	6	2	3	36
Hand Wheel	Packing position fastener.	Loose hand wheel	2	2	2	8
		Broken hand wheel	4	2	2	16
Gland Packing	Maintains tightness in the gap.	Leaking gland	5	3	3	45
		Loose gland	6	2	2	24

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Component	Functions	Type of Functional Failure	*Severity* (S)	*Occurrence* (O)	*Detection* (D)	RPN
Packing	Connects the valve body and bonnet. The stem rotates along its groove.	Leaking packing	5	3	3	45
		Worn packing	4	3	3	36
Gasket	Moves the valve to open and close.	Leaking gasket	6	3	3	54
		Broken gasket	5	3	2	30

Source: Data Analysis Results (2024)

Table 4 shows the risks of component failures on the ship, including severity, occurrence, detection, and RPN values. The disc has the highest risk with an RPN of 63 for corrosion and leakage, indicating the need for special attention. The seat and gasket are also at high risk with an RPN of 54 for corrosion and leakage. The handwheel has the lowest risk with an RPN of 8-16. Other component failure risks, such as the stem nut, stem, gland packing, and packing, have RPNs between 24 and 45, indicating a moderate risk level.

The FMEA calculation table is shown in Table 5 below.

Table 5. FMEA RPN

Component	**Functions**	**Type of Functional Failure**	**Effects**	**S**	**Causes of Failure**	**O**	**Controls Implemented**	**D**	**RPN**
Stem Nut	The stem rotates according to its threaded groove.	The threaded stem is worn.	Its operation is impaired.	5	Its operation is incorrect.	2	Controlling the cleanliness of the stem.	3	30
RPN Total									30
Stem	To open and close the valve.	Worn stem	Leaking	4	*Stem ages*	3	Stem control	3	36
		Bent Stem	Outflow	5	*Stem ages*	2	Controls and provides lubrication	3	30
RPN Total									66
Disc	The most important primary pressure limit is the opening and closing of the flow.	Disc Corrosion	Uncontrolled Flow	7	Leakage	3	Controls *Disc*	3	63
		Disc Leaking	Uncontrolled Flow	7	*Disc wear*	3	Controls *Disc*	3	63
		Disc Eroded	Weak Flow	6	Friction	2	Controls *Disc*	3	36
RPN Total									162
Seat	As an opening for the Disc holder	Seat Corrosion	Uncontrolled Flow	6	Leakage	3	Controlling Seat Conditions	3	54
		Seat Leaking	Uncontrolled Flow	7	*Disc wear*	3	Controlling Seat Conditions	2	42

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Component	**Functions**	**Type of Functional Failure**	**Effects**	**S**	**Causes of Failure**	**O**	**Controls Implemented**	**D**	**RPN**
		Seat Eroded	Weak Flow	6	Friction	2	Controlling Seat Conditions	3	36
RPN Total									132
Hand Wheel	To move the valve to open and close	Hand Wheel Kendur	Imperfect opening and closing	2	Lack of lubrication	2	Controlling and lubricating	2	8
		Hand Wheel broken	Cannot open or close the valve	4	Lack of operation	2	Controlling the hand wheel	2	16
RPN Total									24
Gland Packing	As a gasket tightener	Leaking gland	Untightened bolts	5	Gland Packing Age	3	Controlling bolt tightness	3	45
		Untightened bolts	*Loose gland*	6	Looseness Occurs	2	Controlling grease addition	2	24
RPN Total									69
Packing	As a guard against defects	*Leaking Packing*	Outflow	5	Packing Age	3	Controlling bolt tightness	3	45
		Worn Packing	Leaking	4	Packing Age	3	Controlling packing	3	36
RPN Total									81
Gasket	Acts as a connector between the valve body and the bonnet	Gasket leak	Outflow	6	Gasket Age	3	Controlling bolt tightness	3	54
		Gasket rupture	Outflow	5	Gasket Age	3	Controlling gasket components	2	30
RPN Total									84
TOTAL									650

Source: Data Analysis Results (2024)

Table 5 shows that the highest RPN values are for the Disc component with an RPN of 162, the Seat component with an RPN of 132, and the Gasket component with an RPN of 84. The FMEA analysis indicates that the hydraulic gate valve on the MT Beyond still performs well, as the RPN of each instrument component is still below the standard RPN of 200.

The Failure Mode and Effects Analysis (FMEA) analysis of the hydraulic gate valve in Table 5 reveals the highest RPN values for each component. The higher the RPN, the lower the reliability of the component. The average RPN values are shown in Table 6 below.

Table 6. RPN Values for Each Component

No	**Component**	**RPN**
1	*Stem Nut*	30
2	*Stem*	68
3	*Disc*	162
4	*Seat*	132
5	*Hand Wheel*	24

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No	Component	RPN
6	*Gland Packing*	69
7	*Packing*	81
8	*Gasket*	84
RPN Total		650

Source: Data Analysis Results (2024)

Table 6 shows that the disc component has the highest Risk Priority Number (RPN) value of 162, followed by the seat at 132, and the gasket at 84. Components with high RPN values indicate a greater level of failure risk, both in terms of impact, frequency of occurrence, and difficulty of detection. Conversely, the hand wheel component has the lowest RPN value of 24, which indicates a relatively small risk level. Overall, the total system RPN value of 650 is still below the critical limit of 200 for each component, which indicates that the system is still in a reliable operational condition, although it still requires attention to high-risk components.

4.4 Pareto Diagram

The Pareto diagram is used to state each component that is the main priority in contributing to failure, and also as a comparison between each instrument component [25]. To obtain the total percentage value, calculations are carried out, for example:

RPN *Stem Nut* = 30

RPN Total = 650

Thus:

$$Percentage\ of\ Overall\ Total = \frac{Average\ RPN}{RPN\ Total} \times 100$$

$$Percentage\ of\ Overall\ Total = \frac{30}{650} = 5\%$$

Table 7. Cumulative Percentage of Hydraulic Gate Valve

No	Component	RPN	Cumulative Total	Overall Percentage (%)	Cumulative Percentage (%)
1	*Stem Nut*	30	30	5	5
2	*Stem*	68	98	10	15
3	*Disc*	162	260	25	40
4	*Seat*	132	392	20	61
5	*Hand Wheel*	24	416	4	64
6	*Gland Packing*	69	485	11	75
7	*Packing*	81	566	12	87
8	*Gasket*	84	650	13	100
Total		650		100	

Source: Data Analysis Results (2024)

Table 7 shows the components of the Hydraulic Gate Valve along with their respective RPN values, cumulative total, and percentage risk of failure. The Disc has the highest RPN (162) and contributes 25% of the total risk, for a cumulative total of 40%. Meanwhile, the Gasket and Packing contributed 13% and 12%, respectively, bringing the cumulative percentage to 100%. On the other hand, the Hand Wheel has the lowest RPN (24) and contributes 4% to the total risk. The cumulative percentage starts at 5% for the Stem Nut and reaches 100% after all components are included.

DOI: https://doi.org/10.31004/riggs.v5i2.7915

The cumulative total RPN of the Hydraulic Gate Valve on the MT Beyond is shown in Table 8 below.

Table 8. Cumulative Total RPN of the Hydraulic Gate Valve

No	**Component**	**Cumulative Total**	**Cumulative Percentage (%)**
1	*Stem Nut*	30	5
2	*Stem*	98	15
3	*Disc*	260	40
4	*Seat*	392	61
5	*Hand Wheel*	416	64
6	*Gland Packing*	485	75
7	*Packing*	566	87
8	*Gasket*	650	100

Source: Data Analysis Results (2024)

Figure 3. Hydraulic Gate Valve Pareto Diagram Graph
Source: Data Analysis Results (2024)

Figure 3 shows the Pareto diagram, which demonstrates the failure risk analysis based on the Risk Priority Number (RPN) for the components of a Hydraulic Gate Valve. The disc component has the highest RPN (162), contributing approximately 25% of the total risk. This is followed by the seat (20%), gasket (13%), and packing (12%). These components contribute the largest share of the system's failure risk.

The red line. The diagram indicates that approximately 40% of the total failure risk comes from the disc component, while approximately 87% of the cumulative risk comes from the five main components: the disc, seat, gasket, packing, and gland packing. The component with the lowest RPN, such as the handwheel, accounts for only 4% of the total risk. These findings align with FMEA theory, which states that a small number of components often contribute significantly to the risk in a system. Therefore, improvement priorities are focused on components with the highest RPN values through improving material quality, regular maintenance, and controlling fluid contamination. These results are also consistent with previous research emphasizing the importance of preventive maintenance and operational condition control in improving hydraulic system reliability.

From a discussion perspective, the results of this study indicate that hydraulic valve failure is not only caused by technical factors, but also by human and procedural factors. This reinforces the concept that the reliability of engineering systems is the result of the interaction between humans, machines, and the environment. The implementation of the FMEA method in this study proved effective in identifying risk priorities and providing a basis for decision-making in system maintenance. Practically, these findings provide implications for shipping companies to improve maintenance standards, operator training, and component selection according to specifications to minimize the risk of failure.

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5. Conclusion

The research results indicate that the hydraulic valve failure occurred on the MT. Beyond was caused by various interrelated factors, including human, machine, material, method, and environmental factors. Fishbone diagram analysis identified operational errors, poor component quality, hydraulic fluid contamination, and lack of maintenance as the dominant factors contributing to the system failure. Meanwhile, a Failure Mode and Effects Analysis (FMEA) showed that the disc and seat components had the highest risk levels, with Risk Priority Numbers (RPN) of 162 and 132, respectively. Failure in these components has the potential to cause significant fluid flow disruption and degrade overall hydraulic system performance. Other components, such as the stem, gland packing, and gasket, also contributed to the failure risk with moderate levels of risk, while the handwheel had the lowest risk. Based on these analysis results, this study confirms that repair priorities should be focused on critical components, particularly the disc and seat, through routine inspections, the use of quality materials, and the application of anti-corrosion coatings. Furthermore, improving the lubrication system, replacing worn components, and strengthening operational and maintenance procedures are important steps in improving system reliability. Thus, the research objective is to comprehensively identify the causes, impacts, and solutions to hydraulic valve failures on MT. Beyond has been achieved.

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DOI: https://doi.org/10.31004/riggs.v5i2.7915