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Safety Risk Analysis of LCT Type RoRo Vessel Berthing Process Using FMEA and Fuzzy FMEA Methods

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Abstract

The berthing process of Roll-on/Roll-off (RoRo) vessels of the Landing Craft Tank (LCT) type at Company X presents significant operational risks. This study analyzes safety risks using the Failure Mode and Effects Analysis (FMEA) and fuzzy FMEA methods. The method has been used because it helps to provide a structure for potential failure and assess various hazards. On the other hand, the research aims to prioritise risk based on severity, occurrence, and detectability, which can be calculated using FMEA.The highest RPN values from FMEA were found in ramp door placement (RPN = 50), safety cone installation (RPN = 48), and vehicle access (RPN = 45). Fuzzy FMEA identified ramp door risk (D20) as the top priority with FPRN = 134. Risk controls were proposed using the hierarchy of controls. Data were gathered from observations, interviews, and questionnaires with nine respondents. The integrated approach provided a more objective and practical risk analysis.

Keywords: Risk Analysis, Failure Mode, Effect Analysis, Risk Control

1. INTRODUCTION

Indonesia is a maritime country, most of whose territory consist of waters with a sea area reaching approximately 5.8 million km^2. This geographical condition makes the maritime transportation sector a vital component in economic activities, particularly in the distribution of goods and trade between regions. The existence of ports has a strategic role as transportation hubs that support logistics mobility and connectivity between islands in Indonesia [1]. In maritime transportation operations, one type of ship widely used to support the distribution of goods in the Roll On/Roll Off (RoRo) ship, particularly the Landing Craft Tank (LCT) type. This type of ship is designed to transport wheeled land vehicles and other cargo loads directly through a ramp door system, so that the loading and unloading process can be carried out more quickly and efficiently [2].

The main advantage of RoRo ships is their ability to integrate with land transportation systems and their relatively short loading and unloading times. This makes RoRo ships, especially the LCT type, the primary choice for short-distance shipping and inter-island logistics distribution [3]. One shipping company that operates RoRo ships is Company X, which plays a role in supporting transportation and logistics distribution activities through maritime services.

Despite its operational advantages, the process of berthing RoRo vessels at ports is highly complex due to the involvement of various technical factors, coordination between vessels, and the readiness of port facilities. Based on observations at Company X, the process of berthing RoRo vessels for loading and unloading activities has significant potential risks. These risks can impact personnel safety, damage vessels, and disrupt port infrastructure. Therefore, risk management at every stage of the berthing process is a very important aspect to improve operational safety and efficiency in maritime service companies [4].

Risk in ship breathing activities are generally caused by several main factors, including human error, limited port infrastructure, and environmental conditions such as weather and sea waves [5]. In addition to occupational safety aspects, shipping companies also have responsibilities in managing environmental impacts as regulated in international conventions on the prevention of marine pollution. One relevant regulation is

MARPOL 73/78 Annex III which regulates the prevention of pollution from hazardous materials transported by sea in packaged form [6]. The implementation of this regulation aims to ensure that port operations are not only safe, but also sustainable and environmentally friendly.

In the context of operational risk management, Company X currently uses the Job Safety Analysis (JSA) method to identify potential hazards in work processes. JSA is a systematic method used to analyze risks at each stage of work. However, based on field observations, the JSA method still has several limitations in identifying all potential risks that occur during the RoRo ship berthing process [7]. These limitations include the analysis process requiring a relatively long time, the lack of comprehensive initial hazard list, and low worker involvement in the hazard identification process. In addition, the JSA method often does not optimally consider the risk control hierarchy and potential hazards that arise from dynamic work activities [8].

To overcome these limitations, the Failure Mode and Effect Analysis (FMEA) method can be used as more systematic risk analysis tool. FMEA is a method used to identify potential failures in a system or process and evaluate their impact on operational performance. In FMEA, the risk level is determined based on three main parameters, namely severity (S), occurrence (O), and detection (D), which are then calculated in the form of a Risk Priority Number (RPN) to determine the priority of risk handling [9]. This method is widely used in various industrial sectors to improve the quality and reliability of operational processes.

However, the FMEA method also has several weaknesses, primarily related to subjectivity in assessing risk parameters. Assessments of severity, occurrence, and detection often depend on individual perceptions, which can result in inconsistent RPN values [10]. Furthermore, the RPN calculation method by multiplying there three parameters can produce the same value even though the actual risk importance level is different. To address these issues, a fuzzy logic approach can be integrated into the FMEA method. Fuzzy logic is an analytical method capable of handling uncertainty and ambiguity in decision-making systems. By using the fuzzy FMEA approach, the risk evaluation process can be carried out more flexibility and produce more representative risk priority values [11]. Several previous studies have shown that the integration between FMEA and fuzzy FMEA can improve the accuracy of risk analysis and help organizations in determining risk mitigation priorities more effectively [12].

Hence, research specifically examining the integration of FMEA and fuzzy FMEA methods in the RoRo ship berthing process is still relatively limited, especially in the context of maritime service operations in Indonesia. Therefore, this study aims to analyze the risk level in the RoRo ship berthing process at Company X using FMEA and fuzzy FMEA methods. This study also aims to determined the value of the Fuzzy Risk Priority Number (FPRN) and formulate an appropriate risk control strategy to reduce the frequency and impact of failures in the ship berthing process. The research results are expected to contribute to improving operational safety, efficiency of ship berthing processes, and the effectiveness of risk management in the maritime transportation sector, particularly in RoRo ship operations at port.

2. METHODS

2.1. Data Collection

This research was conducted at Company X, located in East Kalimantan. Data were collected through observation, interviews, and questionnaires involving nine respondents from the HSE team, the medical unit, and RoRo officers. The Failure Mode and Effect Analysis (FMEA) method was first applied to identify risks and calculate the Risk Priority Number (RPN) based on three parameters: occurrence (O), severity (S), and detection (D). To minimise subjectivity in the assessment, the fuzzy FMEA approach was employed, utilising linguistic variables through the stages of fuzzification, inference, and defuzzification to obtain the Fuzzy Risk Priority Number (FPRN).

Table 1. Presents the Potential Failure Modes and Their Causes Identified During the RoRo Vessel Berthing Process.

No.	RoRo Vessel Berthing Process	Code	Potential Failure Mode	Cause of Failure
1.	Installation of safety cones on the RoRo ramp door (A)	A1	Delay in the berthing process	Delay in the installation of safety cones
		A2	Incorrect positioning of the RoRo vessel during berthing	Strong wind conditions in the dock area

Table 2 Presents the FMEA assessment of the RoRo vessel berthing process

Code	Occurrence	Severity	Detection
A1	4	2	3
A2	3	3	4

2.2. FMEA Procedure

Weights are assigned to the occurrence (O), severity (S), and detection (D) values based on potential risks, failure causes, and the resulting Risk Priority Number (RPN). The determination and definition of failure priorities were carried out through interviews with relevant stakeholders. The Risk Priority Number is calculated using the following formula:

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

Where RPN refers to the Risk Priority Number, with O representing occurrence, S representing severity, and D representing detection

2.3. Fuzzy FMEA Procedure

a. Fuzzification

In this stage, the crisp parameter values O, S, and D are converted to linguistic terms (low, medium, high) using fuzzy membership functions. The linguistic scale is classified in Table 3.

Table 3. Fuzzification

Category	Scale (1 - 5)
Low	1 - 2
Medium	3 - 4
High	5

b. Inference

In this stage, the fuzzy inputs are processed by a fuzzy rule-based system that combines the three parameters into an overall risk assessment. For example, an input combination of (medium, medium, low) results in a medium risk level.

c. Defuzzification

The fuzzy inference results (linguistic values) are then converted back into specific numerical values, known as the Fuzzy Risk Priority Number (Fuzzy RPN or FPRN), through the defuzzification process. The defuzzification formula used in this study is as follows:

$$FRPN = \frac{\mathrm{Min}(\mathrm{npS} \times \mathrm{npO} \times \mathrm{npD})}{nt} \quad (2)$$

Where Min denotes the minimum domain value, npS represents the value of the severity parameter, npO indicates the value of the occurrence parameter, npD refers to the value of the detection parameter, and nt is the highest parameter value used in the assessment scale. Accordingly, the FPRN yields a more representative numerical value of failure risk because it incorporates uncertainty and the variation in respondents' assessments, thus enabling a more realistic and reliable evaluation of risk levels in the failure analysis process.

2.4 Risk Control

Risks with the highest FPRN values are considered the most critical. Risk control measures are developed based on the hierarchy of controls approach, which consists of elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). These measures aim to reduce the severity and frequency of failures in the RoRo vessel berthing process.

3. RESULTS AND DISCUSSION

3.1. Risk Assessment Result Using FMEA

The initial risk assessment was carried out using the Failure Mode and Effects Analysis (FMEA) method. Based on the identification of 28 potential failure modes during the berthing process of an LCT-type RoRo vessel, each failure mode was evaluated using three main parameters, namely occurrence (O), severity (S), and detection (D). The values of these parameters were obtained from questionnaires distributed to respondents consisting of three RoRo officers, three safety personnel, and one HSE officer. Furthermore, the Risk Priority Number (RPN) was calculated to determine the priority level of each risk. The results showed that the three failure modes with the highest RPN values were the placement of the shore ramp door (RPN = 50), installation of safety cones (RPN = 48), and vehicle access (RPN = 45). These three failure modes were identified as the main priorities for control and mitigation because their high RPN values reflect a combination of relatively frequent occurrence, significant impact, and low detectability.

3.2. Risk Assessment Result Using Fuzzy FMEA

To overcome the subjectivity limitation of the conventional FMEA method, further analysis was performed using the fuzzy FMEA approach. In this method, the occurrence (O), severity (S), and detection (D) parameters were transformed into linguistic variables such as low, medium, and high, and then processed through fuzzification, fuzzy inference, and defuzzification to obtain the Fuzzy Risk Priority Number (FPRN). The results of the fuzzy FMEA analysis showed a shift in risk prioritisation compared with the conventional FMEA results. The failure mode with the highest FPRN value was code D20 (vehicle access), with an FPRN of 134, while codes A8 and C18 also demonstrated relatively high FPRN values. The rise in the ranking of code D20 indicates that the fuzzy approach is better able to capture uncertainty and subjective judgment, which are not proportionally represented in the conventional FMEA calculation.

3.3. Risk Control

To overcome the limitation of subjectivity in the conventional FMEA method, a further analysis was conducted using the fuzzy approach. Based on the FPRN values, the risk control strategy was focused on the failure modes with the highest risk levels. The control measures were developed in accordance with the hierarchy of controls. The failure modes with the highest risk levels are presented in Table 4.

Table 4. Risk Control

Code	FRPN	Ranking	Risk Control				
			Elimination	Substitution	Engineering Control	Adminitrative control	PPE
D20	134	1	Stopping operations when the locking mechanism has not been inspected.	Replacing old locking components with corrosion-resistant and wear-resistant materials.	Adding a dual locking lever as a backup for the main system.	Training technicians on the locking system and early damage detection.	Providing high-impact safety helmets for all workers in the vehicle access area.

As presented in Table 4, the risk code D20 has the highest FPRN value (134) and ranks first, making it the top priority for mitigation. The control measures for this risk include elimination by stopping operations when the locking system has not been inspected, supported by substitution (component replacement), engineering control (addition of a dual locking lever), technician training, and provision of personal protective equipment (PPE). This indicates that the D20 risk is highly critical and requires a comprehensive and multilayered control approach.

4. CONCLUSION

The FMEA analysis indicates that the three main risks in the RoRo vessel berthing process at Company X are the placement of the land ramp door (RPN 50), the installation of safety cones (RPN 48), and vehicle access (RPN 45). These risks have significant impacts on operational safety because they occur frequently, are difficult to detect, and may disrupt the smooth loading and unloading process. The fuzzy FMEA results show a change in the risk-priority order. The ramp door placement risk (code D20) remains in the first position with an FPRN value of 134. This difference indicates that fuzzy FMEA provides a more accurate assessment by accounting for variations in respondents' perceptions of risk. In the context of safety measures for workers, the implementation of Personal Protective Equipment (PPE) is critical. Specifically, it is essential to provide high-impact safety helmets for all personnel operating or present within the vehicle access area. This initiative aims to mitigate the risk of head injuries in a potentially hazardous environment characterized by vehicle movements and other related activities.

REFERENCES

[1] R. O. Gurning and E. Budiyanto, *Manajemen Bisnis Pelabuhan*. Jakarta, Indonesia: APE Publishing, 2007.

[2] Masroeri, "Analisis operasional kapal Roll On/Roll Off (RoRo) dalam distribusi logistik antar pulau di Indonesia," *Jurnal Transportasi Laut*, vol. 12, no. 2, pp. 45–53, 2018.

[3] Sudra, "Evaluasi kinerja kapal Landing Craft Tank (LCT) pada pelayaran jarak pendek," *Jurnal Teknik Perkapalan*, vol. 4, no. 3, pp. 201–208, 2016.

[4] Suwandiyana, "Manajemen risiko operasional dalam kegiatan sandar kapal di pelabuhan," *Jurnal Manajemen Transportasi & Logistik*, vol. 8, no. 1, pp. 55–63, 2021.

[5] Pambayun, "Analisis faktor risiko kecelakaan kerja pada aktivitas pelabuhan dan transportasi laut," *Jurnal Keselamatan Transportasi*, vol. 6, no. 1, pp. 12–21, 2024.

[6] International Maritime Organization (IMO), *International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 Annex III: Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form*. London, U.K.: IMO, 2017.

[7] Z. Ikhsan, "Evaluasi penerapan Job Safety Analysis (JSA) dalam sistem keselamatan kerja di industri maritim," *Jurnal Keselamatan Kerja dan Lingkungan*, vol. 10, no. 2, pp. 89–97, 2022.

[8] A. Ghasemi, "Limitations of Job Safety Analysis in dynamic work environments and risk assessment improvement," *Safety Science*, vol. 159, pp. 1–9, 2023.

[9] Hartanti, D. A. Pratiwi, and S. Nugroho, "Implementation of Failure Mode and Effects Analysis (FMEA) for risk mitigation in industrial processes," *Journal of Industrial Engineering and Management*, vol. 15, no. 3, pp. 456–468, 2022.

[10] K. Balaraju, D. Raj, and V. Murthy, "Fuzzy FMEA for risk evaluation in engineering systems," *International Journal of Quality & Reliability Management*, vol. 29, no. 5, pp. 1–15, 2022.

[11] N. Nuchpho, "Application of fuzzy logic in risk assessment and decision-making processes," *Engineering Journal*, vol. 23, no. 4, pp. 125–134, 2019.

[12] F. Chandra, "Integration of FMEA and fuzzy logic approach for improving risk prioritization," *International Journal of Industrial Engineering*, vol. 28, no. 2, pp. 145–154, 2021.