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A New Approach to Risk Assessment Model and Management for Jetty Fuel Terminal Industrywide Using Risk Priority Number

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Abstract: Jetty is an essential part of a fuel terminal and oil distribution process in terms of loading and unloading oil from and to tanker. Jetty has been widely used in fuel supply point facilities in archipelago countries like Indonesia. The increase in the importance given to maritime transportation has not only resulted in the development of the structure of safety issues but has also led to new investigations into the design of ships, the configuration of ports, and the operations conducted, all of which are essential components. However, it is not possible to ignore the risk inherent in jetty fuel terminal operations. Most of the research have pre-dominantly focused on the operation and impact of ship maneuvers and ship operations. But focusing on the jetty fuel risk itself is also very important as a whole part of reliability of a fuel receiving facility. FMEA is frequently used as a risk analysis method in determining risks arising from oil and gas sector. Each category of Severity, Occurance, and Detection from each risk factor can be rated to obtained the Risk Priority Number value. Mooring facilities assessment furthermore provides the implementation of assessment (grading) of operational suitability of jetties, based on the results of a visual assessment and special inspections. This paper aims to identify the risk associated with and to analyze these risk using Risk Priority Number ranking.

Keywords: Jetty; Fuel Terminal; Risk Analysis; Jetty Assessment; Risk Priority Number

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1. Introduction

Jetty is an essential part of a fuel terminal and oil distribution process in terms of loading and unloading oil from and to tanker. Jetty has been widely used in fuel supply point facilities in archipelago countries like Indonesia. In 2023, a total of 42.7 million kiloliter of Public Service Obligation (PSO) fuel, 13.3 million kiloliter of non-PSO fuel, 14.2 million kiloliter of PSO LPG, and 1.2 million kiloliter of non-PSO LPG have been distributed in Indonesia.

As a national energy company focused on distributing energy products, PT. X owns 129 marine loading and unloading port facilities supporting the refined oil distribution, 111 of them are Jetties [1]. As a type of conventional mooring facility, jetty is usually used in waters with sufficient depth and calm sea conditions. Jetty generally consists of jetty head (as a place for cargo transfer equipment), breasting dolphin (as a berthing/mooring load receiving structure), mooring dolphin (as a mooring load receiving structure), trestle & catwalk (access). Main consideration of the jetty type lies in the simplicity of its operations and maintenance. With the exception of the Island Berth, all cargo transfer equipment is positioned above sea level. Jetty in general is built with deep foundation by piling structure. Jetty structure has various types as shown in Fig. 1, each of its types adjust the diversity of oil tanker and Liquefied Petroleum Gas (LPG) carrier visiting a particular port in view of their size, dead weight tonnage and type of cargo they carry, an appropriate berthing facility is essential to mitigate the significant range of lateral forces exerted by these vessels.

Figure 1. Types of Jetty Fuel Port Profile

Figure 2. Examples of observed damage condition and failure of jetty terminals: a) weld joints damage at jetty steel pile, b) marine growth, c) catwalk collapsed, d) concrete spalling at the deck slab, e) mooring post rope protector railing pile damaged from heavy corrosion

The heightened emphasis on marine operation has contributed to the development of safety frameworks and has spurred the initiation of novel study into many essential components. However, The risks associated with a jetty fuel terminal operations also cannot be overlooked. Jetties are often exposed to many damage threats that can disturb the overall operability, from the misconfiguration of the equipment, severe corrosion of the jetty steel piling, to the scenarios involving fatality, injury, or equipment unavailibility. Some examples of the damage occurred is shown in Fig 2. A jetty assessment is a thorough engineering examination of a jetty's structure to determine its condition and identify any signs of damage, corrosion, or wear. By assess the suitability of mooring facilities in the form of grading, mitigation plan can be made to repair or enchance the mooring facilities. The periodic assessments to determine the level of suitability of mooring facilities is regulated in the SIGTTO's Jetty Maintenance and Inspection Guide, ASCE Waterfront Facilities Inspection and Assessment, and ABS Rules for Building and Classing Single Point Moorings.

Within the field of maritime industry, several studies that have been conducted previously reveals that numerous risk assesments have been performed concerning mooring facility operations. Murat Yorulmaz and Mert Susoy conducted research on the the application of the integration method of the VIKOR-ELECTRE methods and DEMATEL to mitigate the risk of a Ship to Ship (STS) operation conducted in marine environtments [2]. A STS operation involves the transfer of cargo, typically liquid bulk such as crude oil or LNG, between two ship tankers positioned alongside each other at sea. These operations require precise maneuvering and safety protocols to ensure efficient and secure transfer without environmental hazards. Stavrou and Ventikos contributed to the literature by conducting a risk analysis of the STS operation process using the Failure Mode and Effects Analysis method [3-4]. Ventikos and Stavrou conducted research on a general risk analysis of the developments in STS operations [5]. Another study led by Arici and colleagues examined the risk factors associated with accidents occurring during the ship berthing and unberthing operations [6]. Failure Mode and Effects Analysis (FMEA) is a widely recognized and utilized method for conducting comprehensive risk analysis arising from oil and gas sector. By using FMEA, each category of Severity, Occurance, and Detection from each risk factor can be rated to obtained the Risk Priority Number value. As can be seen from the literature review above, most of the research have pre-dominantly focused on the operability and significant of ship maneuvers and ship operations. But focusing on the jetty fuel risk itself is also very important as a whole part of reliability of a fuel receiving facility. The weakness of current feasibility assessment of the jetty is that its application of equal scoring variable to all risk values, without weighting them according to the varying vulnerabilities of each jetty component. Therefore, this paper aims to identify every risk associated with and to analyze these risks using Risk Priority Number ranking, which will allow for a more nuanced and accurate prioritization of risks based on component vulnerabilities.

2. Methods

In this paper, the above-posed issues and emerging threat will be considered as "risk factor" in the aggregated risk assessment process, as described by the workflow chart (See Figure 3).

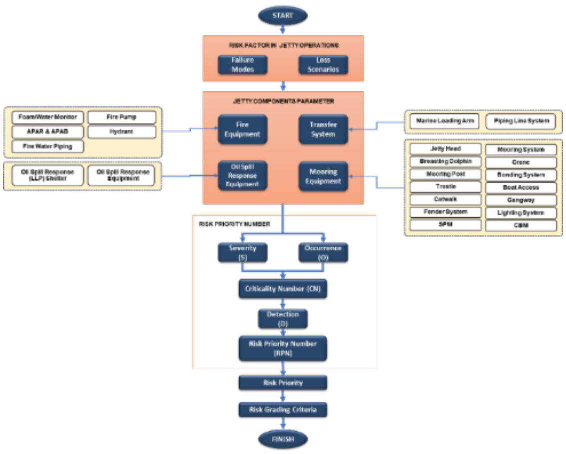

Figure 3. Jetty Risk Assesment Model and Management Workflow Chart

2.1. Risk Factor

The risk factors indicated in have been categorized based on the main jetty assets and parameters: mooring equipment, fire equipment, transfer system, and oil spill response equipment. Risk identification is structurally and mechanically developed from its components and type or size of the potential defects or anomalies and loss scenarios in common jetty facilities in Indonesia and industrywide. Some international regulations are conducted to mitigate these risks, such as International Safety Guide for Oil Tankers and Terminals, Tanker Safety Guide, OCIMF's Mooring Equipment Guidelines, and OCIMF's Jetty Inspection and Maintenance Guide [7-9]. Although some factors have less likelihood of accidents than others, each factor is capable of creating environmental catastrophies even resulting in human fatalities. Therefore, it is important to identify each asset and register every risks to take necessary precautions. In this study, 17 risks inherent in conventional jetty fuel terminal risk asessment were used in the study. The identified risks are presented in Table 1.

Table 1. Risk Factors in Jetty Fuel Terminal

Code	Risk Factor	Code	Risk Factor
F1	Jetty Platform Failure and Collapse	F10	Grounding and Bonding Failure
F2	Mooring Post Failure	F11	Access Ladder Failure
F3	Trestle Failure and Collapse	F12	Lighting
F4	Catwalk Failure	F13	Piping Line System
F5	Gangway Failure	F14	MLA / Cargo Hose
F6	Fender System Failure	F15	Fire Fighting System Failure
F7	Mooring System Failure	F16	Oil Spill Response System Failure
F8	Crane Failure	F17	Lightning Rod Failure
F9	Cathodic Protection Failure		

2.2. Risk Priority Number

The application of Failure Modes and Effects Analysis (FMEA) method is used to identify the efectiveness of risks model and assesments. In the FMEA application section of the research, each factor will be rated based on the characteristics of its Severity (S), Occurrence (O), and Detection (D) on a specific scale based on ASCE Waterfront Facilities Inspection and Assessment [2]. The result is Risk Priority Number (RPN). The factors generates D on a scale of 1–10 is based on the table provided in Table 2. The assessment of Parameter D is based on statistical data regarding the ease of inspection access from facilities over the past 10 years to minimize the effect of subjective variability.

Table 2. Detection Parameter [10]

Degree	Detection
10	Like it's not possible
9	Unlikely
8	Slightly Unlikely
7	Slightly Possible
6	Possible
5	Somewhat Possible
4	Likely
3	Highly Likely
2	Very Likely
1	Almost Certain

Whilst S and O is two variables that can multiplied to obtain a maximum value, D here acts as a critical value because regardless of the severity and/or the occurance, a risk factor may be eliminated from the analysis due to its ease of detection. Risk Priority Number is calculated using formula adapted from Yorulmaz [2] below.

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

To better analyze such factors, the the concept Criticality Number (CN) was introduced by using only parameter S and O without consider the Detection Parameter. As a result, the CN is obtained. Criticality Number is calculated using formula below.

$$CN = S \times O \quad (2)$$

In the next step of the research, the S, O and D values constitute the RPN in the FMEA method. Then, Risk Priority can be ranked from the highest value to the lowest value.

2.3. Occurance

Occurance parameter of jetty fuel terminal will be represented by the frequency of its damage category occurs wether in a specific location, in different location in the same company, or in the same industry. Occurance considers 5 ranking levels of the possibility of 17 Critical Item criteria occurring. This parameter will be scored ranging from 1 to 5.

The minimum score 1 means that the risk factor will have low probability of occurrence. The maximum score 5 means that that the risk factor will have high probability of occurrence.

Table 3. Occurance Ranking

Occurance	Description
5	Happened more than once a year in the same location
4	Happened more than once a year at the company
3	Happened within the company
2	Happened several times in the same industry
1	Happened in the same industry

2.4. Severity

Severity parameter of jetty fuel terminal involves the potential impact or harm that could result from a risk event. In this study, this could include injuries to personnel, damage to equipment, or adverse effects on experimental results. Severity level considers scoring from 1 to 5 based on the aspects of the consequence to the jetty standby availability, environtment (oil spill), safety consequence, and financial loss.

Table 4. Severity Ranking

No	Severity Aspect	1	2	3	4	5
1	Standby Availability	< 1 week	1-4 weeks	1-3 month(s)	3-6 months	> 6 months
2	Environtment (oil spill)	Small scale, can be handled with Oil Spill Dispersant (OSD)	-	medium scale, countermeasures deploy all LLP equipment	-	Large scale, countermeasures involve external parties
3	Safety Consequence	Minor impact (first aid treatment)	Medical treatment (treatment by doctor)	Minor loss of body part	Serious injury/permane nt disability	Fatality
4	Financial Loss	< IDR10 million	IDR 10 - 500 million	IDR 500 million to 1B	IDR 1 - 5B	> IDR 5 B

2.5. Grading Criteria

Mooring facilities assessment provides the implementation of assessment (grading) of operational suitability of jetties, based on the results of a visual assessment and special inspections. Grading implementation in risk assesment is a simple and conventional way to periodically identify the condition of mooring facilities. Guidelines for rating criteria for grading mooring facilities will be prepared based on ASCE-2015 with 5 rating categories can be observed in Table 5.

Table 5. Grading Criteria

Rating		Parameter Description			
		Mooring Equipments	Cargo Transfer Equipments	Fire Fighting Equipment	Oil Spill Response Equipment
1	Good	There is minor damage, but no structural damage/failure looks.	No visible damage, or only visible minor damage to cargo transfer equipments.	No visible damage, or only visible minor damage to fire equipment.	No visible damage, or only visible minor damage regarding oil spill response equipment.
2	Fair	The condition of the primary structure is good, but with the possibility of minor to moderate damage happen. Damage does not affect the strength of the structure to withstand operational loads	There is moderate to advanced local damage.	There is moderate to advanced local damage.	There is moderate to advanced local damage.
3	Poor	There was further structural damage, but this did not reduce operational capacity mooring facilities significantly.	There is further damage, but it is not disturbing operational function.	There is further damage, but it is not disturbing operational function.	There is further damage, but it is not disturbing operational function.

4	Serious	Further structural damage occurs which can affect operational capacity primary structure of mooring facilities significantly. Local structural failure possible occurs, and a reduction in operational expenses can be recommended	There is further damage to mooring elements, and a reduction in operational capacity is recommended.	There is further damage to mooring elements, and a reduction in operational capacity is recommended.	There is further damage to mooring elements, and a reduction in operational capacity is recommended.
5	Critical	Further structural damage occurred which had a very significant impact on the local structural failure of the primary structural elements. There is a high possibility of widespread damage to the structure, so operational loads must be reduced.	There is major damage to the mooring facility elements, and operational capacity reduction/de-activation must be carried out.	There is major damage to the mooring facility elements, and operational capacity reduction/de-activation must be carried out.	There is major damage to the mooring facility elements, and operational capacity reduction/de-activation must be carried out.

3. Finding

In this study, evaluations underwent an assessment through FMEA assessment resulting the main 17 risk factors and therefore the CN and RPN values were calculated. The CN value, taking into account the interconnections among the criteria, serves as an important benchmark for a more precise comprehension of the risk.

Figure 4 depicts the significant of CN and RPN values in relation to the various risk factors. The CN and RPN values are sorted in Vulnerability Order to denote the hierarchical precedence of its risk values. By evaluating the CN and RPN values, it is evident that F1 represents the foremost risk factor in the context of the Criticality Number (CN) metrics whilst F13 on the other hand stands out as the highest risk priority by Risk Priority Number. More in-depth examination of the risk rankings uncovers inconsistencies. Take F12 for instance, which rank only fourteenth in RPN, not aligned with its seventh rank in CN. The lowest priority of CN which is F16, comes as second last from the F11 in RPN due to F11 have a highly likely detection score. The overall risk priority number result are shown in Table 6.

Table 6. Risk Priority Number Result

Risk	O	Severity Aspects				$\bar{S}$	CN	D	RPN	Vulnerability Order		
		SA	E	SC	F					CN	RPN	CN-RPN
F1	3	5	5	5	5	5	15	2	30	1	5	-4
F2	2	5	1	3	5	3.5	7	3	21	5	6	-1
F3	3	5	5	2	3	3.75	11.25	3	33.75	2	4	-2
F4	1	5	0	2	2	2.25	2.25	3	6.75	12	15	-3
F5	1	5	0	5	0	2.5	2.5	5	12.5	7	11	-4
F6	3	4	5	0	3	3	9	4	36	3	2	1
F7	1	3	1	4	2	2.5	2.5	6	15	7	8	-1
F8	1	4	0	2	1	1.75	1.75	8	14	13	9	4
F9	1	4	0	0	2	1.5	1.5	9	13.5	14	10	4
F10	1	3	0	5	2	2.5	2.5	5	12.5	7	11	-4
F11	1	3	0	2	1	1.5	1.5	3	4.5	14	17	-3
F12	1	3	0	5	2	2.5	2.5	4	10	7	14	-7
F13	3	2	5	0	4	2.75	8.25	7	57.75	4	1	3
F14	3	2	0	4	0	1.5	4.5	8	36	6	2	4
F15	1	1	0	4	5	2.5	2.5	8	20	7	7	0
F16	1	1	0	0	4	1.25	1.25	5	6.25	17	16	1
F17	1	1	0	4	1	1.5	1.5	8	12	14	13	1

Note: O – Occurrence, SA – Standby Availability, E – Environment, S – Safety Consequences, F – Financial Loss, $\bar{S}$ – Severity

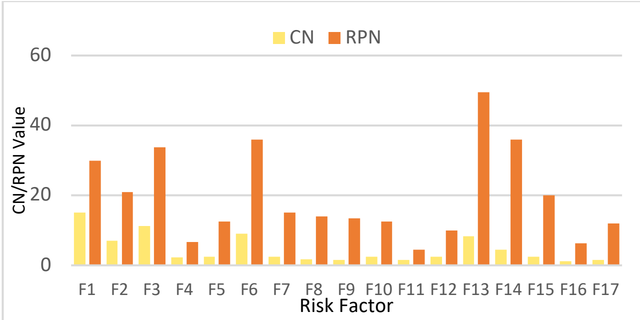

Figure 4. Distribution of CN and RPN Values

The discrepancies between CN and RPN rankings highlight the importance of considering both metrics in risk assessment. While CN provides a measure of the severity and potential impact of a risk, RPN incorporates the probability of detection, adding another layer of analysis. Therefore, Risk Priority Number (RPN) is selected to significantly enhance conventional risk assessment approaches for jetties. The traditional methodology typically does not employ numerical values for assessing jetty risks, often relying on qualitative assessments. These findings highlight the need for a more quantitative approach to enhance the accuracy and reliability of risk evaluations.

3.1. Case Study of The Implementation of Fuel Jetty Terminal Grading Criteria

The result of Risk Factor RPN is used to develop a grading assesment of operational suitability of jetties. A jetty grading Assessment is carried out to identify weaknesses or deficiencies that may occur in the port facilities and the possibility of reducing or mitigating the weaknesses/deficiencies in question. Port Facility Security Assessments must meet the requirements set by IMO as required in ISPS Code Part A.15. In the case study, each of the mooring facilities and cargo transfer components will furthermore be divided into into the main subcomponents and rated equally. The grading weight and adjusted jetty grading assesment form are presented in Table 7 and Table 8.

Table 7. Jetty Grading Weight Based on Risk Priority Number

Code	Risk Factor	RPN	Percentage	Rounded
F1	Jetty Platform Failure and Collapse	30	9.00%	9%
F2	Mooring Post Failure	21	6.30%	6%
F3	Trestle Failure and Collapse	33.75	10.13%	10%
F4	Catwalk Failure	6.75	2.03%	2%
F5	Gangway Failure	12.5	3.75%	4%
F6	Fender System Failure	36	10.80%	11%
F7	Mooring System Failure	15	4.50%	5%
F8	Crane Failure	14	4.20%	4%
F9	Cathodic Protection Failure	13.5	4.05%	4%
F10	Grounding and Bonding Failure	12.5	3.75%	4%
F11	Access Ladder Failure	4.5	1.35%	1%
F12	Lighting	10	3.00%	3%
F13	Piping Line System	49.5	14.85%	15%
F14	MLA / Cargo Hose	36	10.80%	11%
F15	Fire Fighting System Failure	20	6.00%	6%
F16	Oil Spill Response System Failure	6.25	1.88%	2%
F17	Lightning Rod Failure	12	3.60%	4%
			Total	100%

Table 6. Case Study of Adjusted Jetty Grading Form Based on Risk Priority Number

No	Jetty Components		Maximum Grade
I	**Mooring Facilities**		
1	**Jetty Head (F1)**		**9.00%**
		1. Pile	3.00%
		2. Pile Cap	3.00%
		3. Beam and Slab	3.00%
2	**Mooring Post (F2)**		**6.40%**
		1. Pile	2.13%
		2. Pile Cap	2.13%
		3. Corner Protection	2.13%
3	**Trestle (F3)**		**10.13%**
		1. Pile	3.37%
		2. Concrete Structure	3.37%
		3. Railing	3.37%
4	**Mooring System (F7)**		**4.50%**
		1. Quick Release Hook	1.50%
		2. Capstan	1.50%
		3. Bollard	1.50%
5	**Fender System (F6)**		**10.80%**
		1. Frame	3.60%
		2. Rubber	3.60%
		3. Chain and Nut	3.60%
II	**Cargo Transfer**		
7	**Manifold System (F14)**		**10.80%**
		1. Tower	3.60%
		2. Counterweight	3.60%
		3. Motor, Flange, Hydraulic	3.60%

No	Jetty Components		Maximum Grade
8	**Piping Line System (F13)**		**14.85%**
		1. Piping Line	4.95%
		2. Flange	4.95%
		3. Valve, Bolt, Nut, Pipe Support	4.95%
III	**Safety Equipment**		
9	**Gangway (F5)**		**3.8%**
10	**Crane (F8)**		**4.2%**
11	**Cathodic Protection (F9)**		**4.1%**
12	**Catwalk (F4)**		**2.0%**
13	**Boat Access (F11)**		**1.4%**
14	**Grounding and Bonding (F10)**		**3.8%**
15	**Lighting (F12)**		**3.0%**
16	**Lighting Protection System (F17)**		**3.6%**
IV	**Fire Equipment (F15)**		**6.0%**
V	**Oil Spill Response Equipment (F16)**		**1.9%**

4. Conclusions

This paper conducted a risk assesment model and management for jetty fuel terminal using risk priority number method. The results are 17 risks inherent in jetty fuel terminal were identified in the study and evaluated. In-depth analysis from the CN and RPN values, risk factor F1 identified as the primary risk factor in terms of Criticality Number (CN) whilst F13 on the other hand emerges as the most significant risk factor by Risk Priority Number. The overall result of Risk Factor RPN is used to develop a grading assesment of operational suitability of jetties. Mooring facilities assessment provides the implementation of assessment (grading) of operational suitability of jetties, based on the results of a visual assessment and special inspections. Grading implementation in risk assesment is a simple and conventional way to periodically identify the condition of mooring facilities, Risk Priority Number proves to be an effective and reliable approach to give risk assesment of a jetty fuel terminal in the form of grading, and to optimize maintenance strategies.

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