IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Operation failure of risk analysis on floating storage and offloading

To cite this article: Silvianita *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1298** 012031

Operation failure of risk analysis on floating storage and offloading

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Abstract. The need for petroleum in daily life is increasing. The oil comes from the seabed, so it is necessary to have adequate facilities during the exploration and exploitation of crude oil. The process of distributing crude oil to FSO is assisted by the Product Transfer System pipeline. In this process there is a possibility of failure that occurs form several factors, namely tools, weather and sea conditions, and human. In this study, the analysis of the risk of operational failure during loading-unloading of crude oil is discussed. The analysis was carried out using the HAZOP Analysis and Bow-Tie Analysis methods. HAZOP Analysis for hazard identification, and Bow-Tie Analysis for finding the appropriate mitigation. From this method, an overview of the risks than can occur can be obtained so that the risk control required by FSO can be implemented. From the results of this study, it was found that there are 41 potential hazards on the process of loading-unloading crude oil FSO, with the highest risk is inadequate quality of the transfer equipment components with the likelihood rank is 4 and severity rank is 4. The results of Bow-Tie visualization of dominant risk found five causes, namely corrosion, inadequate material quality, eroded material, service life, and material degradation, and five consequences, namely property damage, delayed operational activities, oil spills, environmental damage due to oil spill, and corrosion occurs on the product transfer equipment.

Keywords: Floating Storage and Offloading (FSO), crude oil, operation failure, HAZOP Analysis, Bow-Tie Analysis

1. Introduction

In daily life, the need for petroleum has many benefits in various fields, such as household needs, construction, vehicle fuel, and others. This makes the need for oil very profitable. Petroleum is a strategic natural resource, has high economic value, and is a non-renewable natural resource. Petroleum is found under land and the seabed. So, in the process of exploration and exploitation of oil off the coast, of course, it is necessary to have adequate facilities for the extraction process. Of course, the facilities needed are those that can survive the harsh marine environment. There are many types of offshore structures, this paper will discuss about Floating Storage and Offloading (FSO). Floating Storage and Offloading (FSO) is one of the most profitable structures in the petroleum industry [1]. FSO itself is a floating offshore platform designed for offshore hydrocarbon exploration activities, one of which is crude oil. FSO has several functions, which include loading-unloading crude oil. Loading-unloading is an activity where the FSO receives the processed oil, stores it, and distributes it to a carrier or shuttle tanker. While offshore, the FSO is moored with a floating structure, namely Single Point Mooring (SPM), so that its balance is not disturbed due to environmental loads during the loading-unloading process of crude oil [2]. Due to its large size, the FSO significantly influences wave, wind, and current loads. SPM is connected to the product transfer system pipe, which transfers products from the seabed to the ship. At this time, the author conducted research on Y Floating Storage and Offloading System (FSO).

In distributing oil to FSO, it is undeniable that there are possibilities of failure. Operational failure during loading-unloading of crude oil can result in losses from small to large scale for several parties involved. Failure, in this case, can occur from 2 factors, namely internal and external factors, both from tools and weather and sea conditions. This can be detrimental to many parties and also harms many aspects, such as the environment, people, assets and companies, and others.

Failure can occur anytime and anywhere, so within the company, it is necessary to carry out risk management to avoid or minimize the occurrence of the risk. Risk management needs to be managed qualitatively and quantitatively to predict or control risks in a project [3]. Thus, risk management can make it easier for companies to determine the actions taken when these risks occur. The objectives of this paper is to determine the most potential hazard failure of loading-unloading crude oil operation of FSO and also their threats and consequences using HAZOP and Bow Tie Analysis.

There are several cases regarding failures in offshore structures, which then cause several major impacts, be it on reputation, assets, environmental pollution, or fatalities in the form of fatalities [4]. Cases that have occurred are like the Oil Rig owned by Transocean, which exploded, caught fire, and sank and then caused environmental pollution due to oil leaks and also fatality in the form of fatalities of as many as 11 workers [5]. This results from missed warning signals and failures in monitoring and disseminating information. Another case is the FPSO Cidade do Rio de Janeiro, which experienced an oil leak due to a cracked hull on the FPSO [6]. There have been several risk analyses regarding FPSOs and other offshore structures. The author carried out research at North West Java East, especially research on operation failures on loading-unloading crude oil at the FSO. Thus, early prevention can be done for each potential hazard and appropriate mitigation if the hazard occurs.

2. Literature review

Table 1. Literature review summary

References	Scope/Topics	Methods	Objectives
[7]	Drilling platform	BOW TIE	to represent the potential accident scenarios, their causes, and the associated consequences
[8]	Anchor Handling Operation	BOW TIE	to reduce potential risks during AHO operations and increase maritime safety.
[9]	Port Berth Construction	Hazard Identification	To identify the hazards and risks associated with the construction of a dock at Visakhapatnam Port and to evaluate existing preventive controls to avoid incidents and accidents.
[10]	Board Ships	BOW TIE	to conduct a risk analysis for confined space accidents on board ships using fuzzy bow-tie methodology. And to identify the hazards and risks associated with confined spaces on board ships and to evaluate the effectiveness of existing preventive controls to avoid accidents and incidents
[11]	Small LNG-Fueled Fishing Ship	Hazard Identification	To conduct a preliminary risk assessment on the development of the fuel gas supply system of a small LNG-fueled fishing ship.

IOP Conf. Series: Earth and Environmental Science 1298 (2024) 012031 doi:10.1088/1755-1315/1298/1/012031

[12]	Structural and Marine Facilities	BOW TIE	Application of process safety bow-ties into failure risks for structural and marine offshore facilities
[13]	Lima-Compresor Platform	BOW TIE	To identify potential hazards and risks associated with the decommissioning process and to evaluate the effectiveness of existing preventive controls to avoid accidents and incidents.
[14]	Ship Grounding Accident	Hazard Identification	to identify the hazard of ship grounding; where a ship runs on a rock with a forward speed, and to select a set of credible scenarios with a limited number that can still represent all possible situations of the accidents
[15]	Mobile Mooring System	HAZOP	to explain the potential causes and the possible consequences of mooring system failures using HAZOP as preliminary analysis

3. Failure risk

In this research, the case study used in Northwest Java, one of the floating offshore platforms in Indonesia. Table 2 shows the likelihood ranking used in this paper.

Table 2. Likelihood Ranking [16]

Likelihood		
1	*Almost Impossible*	Almost never happens in the oil and gas industry
2	*Very low*	Ever happened in the oil and gas industry
3	*Low*	Has happened once in 100 years
4	*Medium*	Happens at least once per year
5	*High*	Happens more than once per year

The severity rank is on a scale of 1 to 6, divided into four aspects: health and safety, environmental, equipment damage and business value, and business reputation as shown in Table 3 [16]

Table 3. Severity Ranking

Severity					
No		Health and Safety	Environmental	Equipment Damage and Business Value	Business Reputation
1	Slight	Minor injury or health effects but no effect on performance	Slight damage (oil spill <1 bbls)	Cost USD 50.000 and partial shutdown < 1 day	No media attention
2	Minor	Impact on health, medical treatment is required and impact on limited activities	Damage can still be controlled and repaired on site, has minor impact on the environment (1-15 bbls oil spil)	Costs > USD 50.000 – 25.000 and total shutdown < 1 day	Local press and regulatory requests

Table 3. Severity Ranking

3	Moderate	Unable to work for > 3 days	Moderate damage requiring cleanup or removal from company (15-100 bbls oil spill)	Costs > USD 250.000 – 1 million and total shutdown > 1 day – 1 week	Local press and potential fines by regulators
4	Serious	Accidents that cause permanent disability and require hospitalization	Oil spill and severe environmental damage (100 – 250 bbls oil spill)	Costs > USD 1 million – 10 million and total shutdown > 1 – 2 weeks	National media and potential regional coverage and demands by regulators
5	Major	Causing 2 fatalities due to accidents or illness, substances that cause death	Oil spill is out of control and causes severe environmental damage beyond site limits (>250 – 500 bbls oil spill)	Costs that reach > USD 10 million – 50 million and total production shutdowns for > 2 – 4 weeks	Regional media and potential international coverage, demands by regulators
6	Catastrophic	More than 3 fatalities due to accidents or diseases or materials with the potential to cause death	Oil spill are not controlled and cause severe environmental damage that continues to exceed site limits (>500 bbls)	Costs reached > USD 50 million and total shutdown for more than 1 month	Major impact on business reputation internationally

So, from the questionnaire results, it can be calculated for the likelihood and severity rank of each potential hazard. Each variable has different likelihood and severity category values, so the likelihood and severity ranking is calculated using the formula below:

$$Severity\ Average = \frac{\sum_{i=1}^{6} a_i n_i}{5} \quad (1)$$

$$Likelihood\ Average = \frac{\sum_{i=1}^{5} a_i n_i}{5} \quad (2)$$

Description:
a_i = rating constant (1 until 5 for likelihood, and 1 until 6 for severity)
n_i = respondent probability
I = 0,1,2,3,4,… n
N = total numbers of respondent

4.Risk matrix

From the calculation results of the average likelihood rank and severity rank, the next step is to classify the level of risk. The risk matrix used follows ISO 31000:2009 [16], divided into three levels : low risk, medium risk, and high risk. To determine the level of the risk matrix, the likelihood ranking, and severity ranking is multiplied for each potential hazard. From the multiplication results, it can be determined the level of risk for each potential hazard variable.

After assessing the causes and impacts of each existing risk is carried out, the determination of risk control or what can be called operational controls is carried out. Determination of risk control is an action to reduce or prevent the risk that has been predicted in advance. Risk control is carried out by distributing questionnaires back to stakeholders. Next step can be continued by calculating the likelihood and severity again on operational controls. This calculation is carried out again to know whether the controls that have been made are effective enough to minimize the impact of the potential hazards that exist. From the questionnaires that have been distributed, the likelihood and severity results are obtained from the five respondents for operational controls for each potential hazard. The risk level classification table can be seen below in the Risk Matrix table 4.

Table 4. Risk Matrix

		Likelihood				
		1	2	3	4	5
Severity	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25
	6	6	12	18	24	30

High	High Risk – The activity should not be carried out until the risk has been reduced. The value for this high risk is from 15 to 30.
M	Moderate Risk – Action is needed to reduce the risk, but the cost of necessary prevention must be carefully calculated and limited. The value of this moderate risk is from 5 to 12.
L	Low Risk – Acceptable risk additional controls are not required. The value of this low risk is from 1 to 4.

The likelihood and severity rank can be calculated from the questionnaire results above. In the same way, as in the previous likelihood and severity calculations, the likelihood and severity ranking results are obtained using operational controls.

5. Risk matrix after operational controls

From the likelihood and severity ranking results above, the risk matrix can then be calculated again with the presence of operational controls. The calculation of the risk matrix is carried out the same as before, namely the multiplication between the likelihood ranking and the severity ranking. Thus, the results of the risk matrix are obtained as shown in the following table:

From the calculation of the risk matrix, it is found that the operational controls for each potential hazard are categorized in green, which is low risk. Thus, it can be concluded that the operational controls that have been made are efficient enough to be used to reduce the impact of the potential hazards that exist in the loading-unloading process of crude oil at the Y FSO.

6. HAZOP worksheet

Furthermore, the analysis results above can be entered into the HAZOP Worksheet table. HAZOP Worksheets are columns containing main activities, tasks, activity codes, activity descriptions, potential hazards, possible causes, possible impacts, ranking for likelihood and severity for each potential hazard, operational controls, and ranking for likelihood and severity for each operational control. Thus, a HAZOP Worksheet was formed on the crude oil transfer operation at FSO Y, as shown in the table 5 below.

Table 5. HAZOP Worksheet Result

Task 1: Floating and subsea hose loading crude oil from Platform to FSO										
Activity Description	Potential Hazard	Possible Causes	Hazard Effect	Likelihood	Severity	Risk	Operational Controls	Likelihood	Severity	Risk
Floating and subsea hose operation	1.1.1. Hose leaked	- Corrosion - Inadequate material quality - High pressure	-Crude oil transfer failure -Property damage -Environmental damage (oil spill)	3	4	12	- Perform fatigue life assessment - Periodic inspection and maintenance on each component	2	2	4
	1.1.2. Twisted hose	- Sea conditions - Human error	Property damage	3	4	12	Periodic inspection and maintenance	2	2	4
	1.1.3. Inadequate quality of the components on the hose	- Corrosion - Inadequate material quality - Eroded material	-Property damage -Potential hose leakage -Environmental damage (oil spill)	3	4	12	Determination of quality standards of the type of hose material	2	2	4
	1.1.4. Inadequate quality of the transfer equipment components	- Corrosion - Inadequate material quality - Eroded material	Property damage	4	3	12	Determination of quality standards of the type of transfer equipment materials	2	2	4

7. Bow-tie analysis

Bow-Tie Analysis can be continued after calculating the likelihood, severity, and risk matrix, which is then summarized in a HAZOP Worksheet table. Based on the HAZOP Analysis above, the critical risk during the loading-unloading process of crude oil at the Y FSO occurs in the floating and subsea hose operations during offloading of crude oil from the Y FSO to the Tanker, with the potential danger being that the quality of the transfer equipment components is inadequate.

Risk analysis using the Bow-Tie Analysis method was performed using BowtieXP software. This method can then clearly describe the threats and consequences. In this Bow-Tie diagram, you can find the causal and preventive variables on the left side of the diagram, the consequences and mitigation variables on the right side of the diagram, the escalation factor, and the mitigation escalation. The following is Bow-Tie Analysis Modelling for activity code inadequate quality of transfer equipment components.

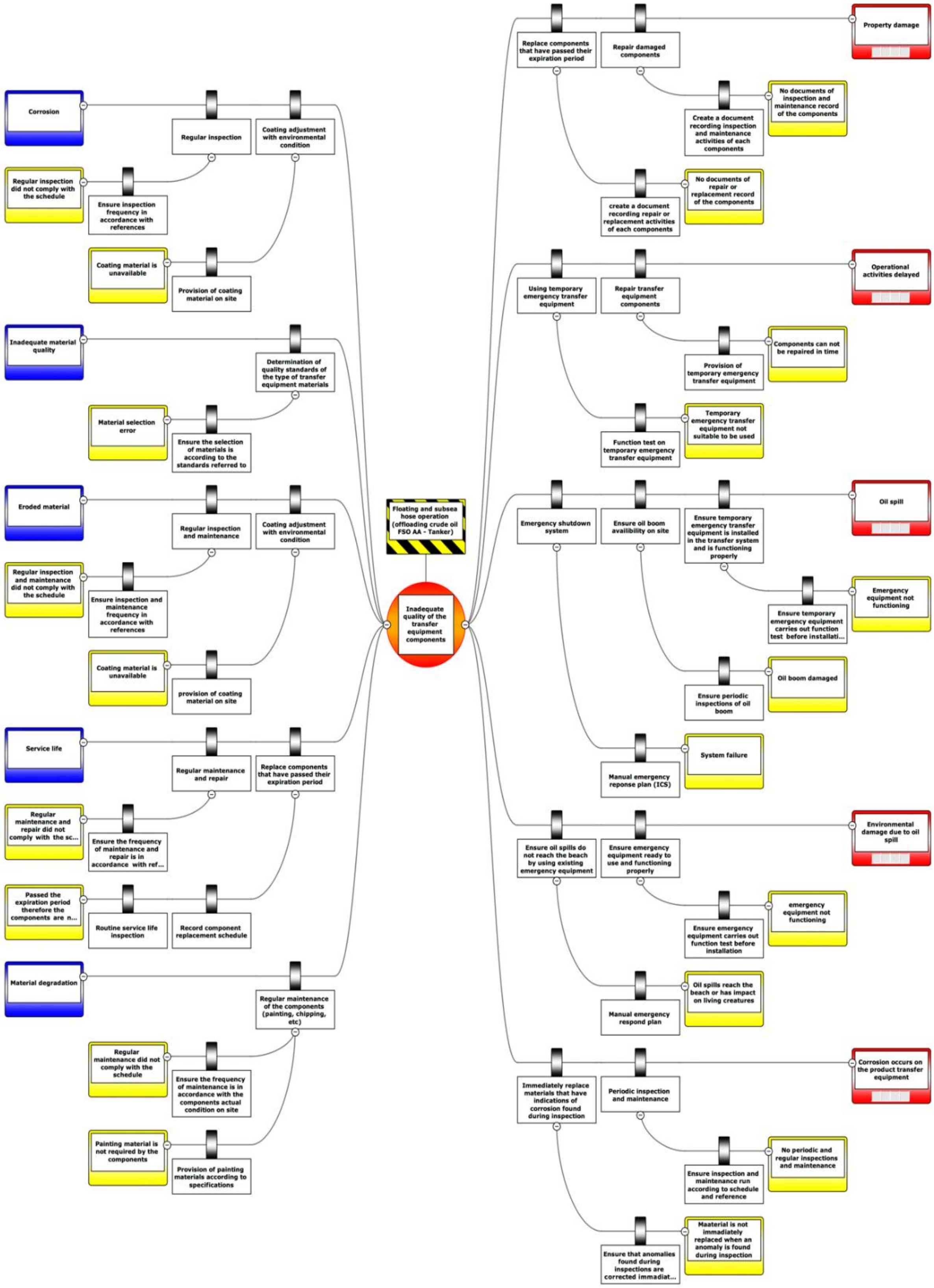

Figure 1. Bow-Tie Analysis Modeling for Indequate Quality of the Transfer Equipment Components

The description of the threat of inadequate quality of the transfer equipment components is shown in Table 6.

Table 6. Threat of Inadequate Quality of The Transfer Equipment

Threat				
Risk	Causes	Preventive barrier	Escalation factor	Mitigation escalation
Inadequate quality of the transfer equipment components	- Corrosion	- Regular inspection - Coating adjustment with environmental condition	- Regular inspection did not comply with the schedule - Coating material is unavailable	- Ensure inspection frequency in accordance with references - Provision of coating material on site
	Inadequate material quality	Determination of quality standards of the type of transfer equipment materials	Material selection error	Ensure the selection of materials according to the standards
	Eroded material	- Regular inspection and maintenance - Coating adjustment with environmental condition	- Regular inspection and maintenance did not comply with the schedule - Coating material is unavailable	- Ensure inspection and maintenance frequency in accordance with references - Provision of coating material on site
	Service life	- Regular maintenance and repair - Replace components that have passed their expiration period.	- *Regular* maintenance and repair did not comply with the schedule - Passed the expiration period therefore the components are not adequate	- Ensure the frequency of maintenance and repair is in accordance with reference - Routine inspection on service life inspections - Record component replacement schedule
	Material degradation	Regular maintenance of the components (painting, chipping, etc)	- *Regular* maintenance did not comply with the schedule - Painting material is not as required by the components	- Ensure the frequency of maintenance is in accordance with the components actual condition on site - Provision of paint materials according to specifications

The description of the consequences of inadequate quality of the transfer equipment components is shown in Table 7.

Table 7. Consequences of Inadequate Quality of The Transfer Equipment

Risk	Consequences		Escalation Factor	Mitigation Escalation
	Consequences	Mitigation		
Inadequate quality of the transfer equipment components	Property damage	- Repair damaged components - Replace components that have passed the expiration period	- No documents of inspection and maintenance record of the components - No documents of repair or replacement record of the components	- Create a document recording inspection and maintenance activities of each components - Create a document recording repair or replacement activities of each components
	Operational activities delayed	- Repair transfer equipment components - Using temporary emergency transfer equipment	- Components cannot be repaired in time - Temporary emergency transfer equipment not suitable to be used	- Provision of temporary emergency transfer equipment - Function test on temporary emergency transfer equipment
	Oil spill	- Ensure temporary emergency equipment is installed in the transfer equipment system and is functioning properly - Ensure oil boom availability on site - Emergency shutdown system	- Emergency equipment not functioning - Oil boom damaged - System failure	- Ensure temporary emergency equipment carries out function test before installation - Ensure periodic inspections of oil boom - Manual emergency response plan (ICS)
	Environmental damage due to oil spill	- Ensure emergency equipment ready to use and functioning properly - Ensure oil spills do not reach the beach by using existing emergency equipment	- Emergency equipment not functioning - Oil spill reach the beach or has impact on living creatures	- Ensure emergency equipment carries out function test before installation - Manual emergency respond plan
	Corrosion occurs on the product transfer equipment	- Periodic inspection and maintenance - Immediately replace materials that have indications of corrosion found during inspections	- No periodic and regular inspections and maintenance - Material is not immediately replaced when an anomaly is found during inspection	- Ensure inspection and maintenance run according to schedule and reference - Ensure that anomalies found during inspections

8. Conclusion
Based on the analysis, it can be concluded that:
1. There are five tasks in the product transfer process and the most potential hazard failure of loading-unloading crude oil operations at FSO Y is inadequate quality of transfer equipment components.
2. Bow-Tie Analysis shows the threats of Inadequate quality of the transfer equipment components, namely corrosion, inadequate material quality, eroded material, service life, and material degradation. (material degradation). Meanwhile the Consequences shows five consequences: property damage, operational activities delayed, oil spill, environmental damage due to oil spill, and corrosion occurs on the product transfer equipment.

References
[1] H. Meng, L. Kloul, and A. Rauzy, "Production availability analysis of Floating Production Storage and Offloading (FPSO) systems," *Applied Ocean Research*, vol. 74, pp. 117–126, May 2018, doi: 10.1016/j.apor.2018.02.026.
[2] J. Yu, H. Ding, Y. Yu, S. Wu, Q. Zeng, and W. Ma, "A novel risk analysis approach for FPSO single point mooring system using Bayesian Network and interval type-2 fuzzy sets," *Ocean Engineering*, vol. 266, Dec. 2022, doi: 10.1016/j.oceaneng.2022.113144.
[3] M. H. Haghighi and M. Ashrafi, "A new qualitative and quantitative analytical approach for risk management in energy project time-cost trade-off problem under interval type-2 fuzzy uncertainty: A case study in the gas industry," *Energy Reports*, vol. 8, pp. 12668–12685, Nov. 2022, doi: 10.1016/j.egyr.2022.09.064.
[4] A. Gokce Cicek Ceyhun, "THE IMPACT OF SHIPPING ACCIDENTS ON MARINE ENVIRONMENT: A STUDY OF TURKISH SEAS," 2014.
[5] L. Averill, B. Durkin, M. Chu, U. Ougradar, and A. Reeves, "Deepwater Horizon disaster." [Online]. Available: www.deepwaterhorizon.co.uk
[6] J. E. Vinnem, "FPSO Cidade de São Mateus gas explosion – Lessons learned," *Saf Sci*, vol. 101, pp. 295–304, Jan. 2018, doi: 10.1016/j.ssci.2017.09.021.
[7] M. Abimbola, F. Khan, and N. Khakzad, "Dynamic safety risk analysis of offshore drilling," *J Loss Prev Process Ind*, vol. 30, no. 1, 2014, doi: 10.1016/j.jlp.2014.05.002.
[8] M. Kaptan, "Risk assessment of ship anchorage handling operations using the fuzzy bow-tie method," *Ocean Engineering*, vol. 236, 2021, doi: 10.1016/j.oceaneng.2021.109500.
[9] R. Mahapatra, N. Kushwaha, S. K. Singh, R. Gandhi, and P. Vishwavidyalaya, "Hazards Identifications and Risk Assessment in Port Berth Construction-A Case Study." [Online]. Available: www.ijert.org
[10] C. Sakar, M. Buber, B. Koseoglu, and A. C. Toz, "Risk analysis for confined space accidents onboard ship using fuzzy bow-tie methodology," *Ocean Engineering*, vol. 263, Nov. 2022, doi: 10.1016/j.oceaneng.2022.112386.
[11] Y. Shao, H. K. Kang, Y. H. Lee, G. Królczyk, P. Gardoni, and Z. X. Li, "A preliminary risk assessment on development the fuel gas supply system of a small LNG fueled fishing ship," *Ocean Engineering*, vol. 258, Aug. 2022, doi: 10.1016/j.oceaneng.2022.111645.
[12] S. Slatnick *et al.*, "Bow-ties use for high-consequence marine risks of offshore structures," *Process Safety and Environmental Protection*, vol. 165, pp. 396–407, Sep. 2022, doi: 10.1016/j.psep.2022.07.026.
[13] A. Windiargo and D. M. Rosyid, "Risk Analysis of Decommissioning Process: Case Studies of Lima-Compresor Platform," *International Journal of Offshore and Coastal Engineering*, vol. 4, no. 1, pp. 27–34, 2020.
[14] S. A. M. Youssef and J. K. Paik, "Hazard identification and scenario selection of ship grounding accidents," *Ocean Engineering*, vol. 153, pp. 242–255, Apr. 2018, doi: 10.1016/j.oceaneng.2018.01.110.
[15] Silvianita, M. F. Khamidi, I. Rochani, and D. M. Chamelia, "Hazard and Operability Analysis (HAZOP) of Mobile Mooring System," *Procedia Earth and Planetary Science*, vol. 14, 2015, doi: 10.1016/j.proeps.2015.07.103.

[16] "Risk management-Principles and guidelines Management du risque-Principes et lignes directrices," 2009. [Online]. Available: www.iso.org