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Regular Research Article

A Comprehensive Risk Control Analysis of Shorebase Loading and Unloading Processes Using HIRARC, HAZOP, and Delphi Methodologies

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Abstract: Shorebase loading and unloading operations in the offshore oil and gas supply chain involve intensive interactions among heavy equipment, workers, dock conditions, and hazardous materials. Although standard safety procedures are commonly implemented, previous assessments have often applied HIRARC, HAZOP, or expert judgment separately, leaving a methodological gap in how field-based hazards, process deviations, and expert validation can be integrated into a single risk-control framework. This study addresses that gap by combining Hazard Identification, Risk Assessment, and Risk Control (HIRARC), Hazard and Operability Study (HAZOP), and the Delphi method to analyze loading and unloading risks at PT. X, East Kalimantan. HIRARC identified 14 work-activity hazards, of which 57.14% were categorized as moderate risk and 42.86% as insignificant risk. HAZOP identified 14 operational deviations, consisting of 71% low-risk and 29% moderate-risk deviations. Expert validation through two Delphi iterations confirmed key risk priorities related to working at heights, hazardous-material handling, heavy-equipment operation, night work, and adverse weather. The integrated approach demonstrates that HIRARC is effective for capturing direct field hazards, HAZOP strengthens deviation-based process analysis, and Delphi reduces subjectivity by validating mitigation priorities through expert consensus. The results provide practical recommendations for improving shorebase safety governance through routine inspections, competency-based training, lighting improvement, traffic control, early warning systems, and stricter supervision.

Keywords: HIRARC; HAZOP; Delphi Method

1. Introduction

Occupational health and safety (OHS) regulations are crucial components of worker protection, particularly in high-risk industries such as oil and gas. In Indonesia, Law No. 13 of 2003 on Manpower and Law No. 14 of 2004 on the National Labour Protection emphasize the rights of workers to a safe and healthy work environment, with specific provisions targeting industries characterized by significant hazards [1]. The oil and gas sector, particularly its operational stages in exploration, drilling, and transportation, exposes workers to numerous risks. Among these, the processes of loading and unloading goods at shorebases represent critical points in the oil and gas supply chain, where safety issues can lead to severe accidents or even fatalities. This paper focuses on the operational risks present at Tanjung Batu Shorebase, a key logistics hub supporting offshore oil and gas operations.

Tanjung Batu Shorebase, located in East Kalimantan, Indonesia, plays an essential role in the offshore oil and gas supply chain, facilitating the safe transport of goods to and from offshore platforms. However, as a vital point for offshore activities, it is exposed to significant risks. Among the various risks, those associated with loading and unloading processes such as handling heavy equipment, variable environmental conditions,

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and pressure to meet tight operational timelines are some of the most critical. Despite the implementation of standard operating procedures (SOPs) for Kesehatan dan Keselamatan Kerja (K3) (occupational health and safety), many hazards remain unaddressed or inadequately mitigated due to insufficient hazard identification and risk analysis.

Loading and unloading operations at shorebases are inherently dangerous due to the dynamic nature of the work environment. Large cranes, forklifts, trucks, and other heavy equipment are used to move materials, which poses a risk to workers both directly involved and nearby. The combination of heavy machinery with human workers creates potential hazards that can lead to serious accidents if not properly managed [2, 3]. Additionally, extreme weather conditions and the constant movement of goods increase the complexity of these operations. For instance, shifting weather patterns, high winds, and strong tides can directly affect the safety of these activities, making them more prone to accidents [4, 5].

Furthermore, despite the implementation of comprehensive K3 SOPs at the shorebase, there remain potential risks that have not been optimally identified or analyzed. The challenge lies in the fact that traditional safety protocols, while effective to some extent, may fail to comprehensively identify and address all the risks associated with loading and unloading activities [6]. As a result, the safety measures may not be fully tailored to the specific operational context of Tanjung Batu Shorebase. To fill this gap, a more systematic and comprehensive risk analysis approach is necessary to identify hazards, assess risks, and implement the most effective mitigation strategies.

The research gap addressed in this study lies in the limited integration of activity-based hazard assessment, process-deviation analysis, and expert consensus validation in shorebase loading and unloading operations. Previous studies in port and oil-and-gas settings commonly emphasize either HIRARC for work-activity risk ranking, HAZOP for process deviation analysis, or Delphi-based expert judgment separately. Consequently, the relationship between direct field hazards, abnormal operational deviations, and expert-validated mitigation priorities remains insufficiently explained. The novelty of this study is the development of an integrated HIRARC-HAZOP-Delphi framework for shorebase operations, in which HIRARC captures practical work hazards, HAZOP identifies deviations from intended operational conditions, and Delphi validates the risk-control priorities through experienced practitioners. This integration provides a stronger basis for managerial decision-making than a single-method assessment.

This study utilizes a combination of three established risk management methodologies HIRARC (Hazard Identification, Risk Assessment, and Risk Control), HAZOP (Hazard and Operability Study), and Delphi to provide a more comprehensive and robust assessment of the risks involved in the loading and unloading operations at the shorebase. The HIRARC method is a well-known approach for conducting priority-based risk assessments. By systematically identifying hazards and evaluating the associated risks, HIRARC enables organizations to focus on the most critical risks and implement preventive measures accordingly [7-9]. The HAZOP method, on the other hand, is designed to identify deviations from normal operations that could lead to hazardous situations. This technique is particularly useful for analyzing operational processes in detail, ensuring that all potential safety issues are addressed [6, 10-12]. Finally, the Delphi method involves collecting expert opinions to achieve consensus on the likelihood and impact of identified hazards, ensuring that decisions are based on collective expertise rather than subjective judgment [13-15].

By integrating these three methods, this study aims to provide a more accurate risk mapping, offering a better understanding of the risks associated with shorebase operations. Unlike previous studies that often focus on using just one or two methods, this study adopts an integrated approach tailored specifically to the operational setting of Tanjung Batu Shorebase. The combination of these methods ensures that all aspects of the operation are covered, from hazard identification to risk assessment and expert validation. This approach is particularly beneficial in complex operational environments such as shorebases, where various risks may arise from different sources and processes.

The results of this study are expected to contribute significantly to improving the management of loading and unloading operational risks at the shorebase. By identifying critical hazards and recommending effective

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mitigation strategies, the study will help enhance safety practices at the shorebase and contribute to the overall safety culture in offshore oil and gas operations. Additionally, the findings will provide valuable insights into how risk management methodologies can be integrated to improve safety and operational efficiency in high-risk industries. This integrated risk assessment approach is not only applicable to shorebases but could also be adapted for use in other similar high-risk operations, further supporting the sustainability of the oil and gas industry while safeguarding workers' health and safety.

In conclusion, this study aims to improve the safety of shorebase operations by providing comprehensive risk analysis using a combination of well-established methodologies. The outcomes will contribute to the safety and sustainability of the oil and gas sector, ensuring that the industry continues to meet both operational and regulatory safety standards.

2. Materials and Methods

This case study was conducted at PT. X, East Kalimantan, from February 17 to March 13, 2025. The unit of analysis was the loading and unloading process at the shorebase, including crane and forklift operation, rigging, truck mobilization, container handling, pipe relocation, night work, work at height, hazardous-material handling, and inspection activities. Data were collected through field observation, work-activity mapping, review of operational procedures, and structured questionnaires for selected respondents. The analysis was designed in three sequential but connected stages: (1) HIRARC was used to identify activity-based hazards and classify their likelihood-severity scores; (2) HAZOP was used to examine operational deviations at selected process nodes; and (3) the Delphi method was used to validate risk priorities and mitigation measures through expert consensus.

Respondents were selected purposively because the study required personnel with direct exposure to loading and unloading tasks and sufficient operational knowledge to assess risk realistically. The HIRARC assessment involved 9 jetty workers because they directly performed and observed routine field activities; this group consisted of three operational teams, each led by one jetty master and supported by two tonnage checkers. The HAZOP assessment involved 27 workers representing the main loading and unloading activities so that each process node could be evaluated by personnel familiar with the relevant operational deviations. The Delphi process involved 10 informants with at least two years of experience in shorebase loading and unloading, ensuring that expert judgment came from respondents who understood equipment hazards, human-equipment interaction, dock conditions, and hazardous materials. This respondent structure was considered adequate for a focused case study because each method required role-based expertise rather than statistical population representation.

The loading and unloading flow shown in Figure 1 was used to define the operational boundaries of the assessment. Each activity was decomposed into work steps, associated equipment, potential hazard sources, possible deviation scenarios, and existing controls. This applied workflow was prioritized to ensure that the risk assessment reflected actual shorebase operations rather than only general theoretical definitions.

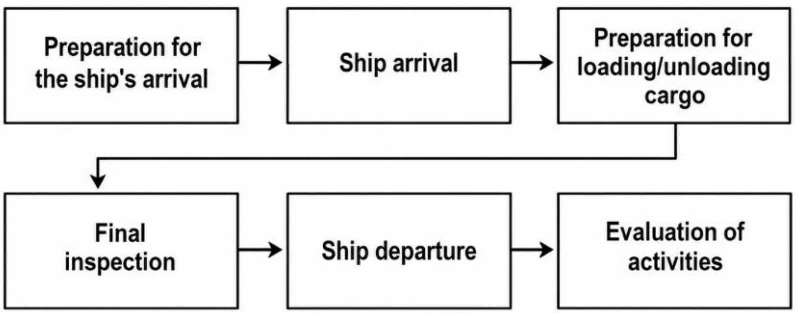

Figure 1. Loading and unloading operational flow at PT. X shorebase.

In this study, risk was operationally defined as the combination of the likelihood of an unwanted

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event and the severity or consequence of its impact on workers, equipment, materials, and operational continuity. Hazard identification therefore focused on observable sources of harm during shorebase activities, including heavy equipment movement, lifting failure, work at height, inadequate lighting, weather disturbance, and hazardous-material release.

HIRARC was applied by listing each loading and unloading activity, identifying its hazard source, assigning likelihood and severity scores, calculating the risk value using Equation (1), and classifying the result into low, moderate, high, or extreme risk categories according to the risk matrix. Existing controls and recommended additional controls were then linked to the assessed risk level so that the results could be directly translated into preventive actions.

$$\text{Risk (R)} = \text{Likelihood (L)} \times \text{Severity (S)} \qquad (1)$$

A risk assessment matrix is a combination of the likelihood (L) and the severity (S) of an event, resulting in an estimated risk level. This matrix is designed to determine the magnitude of potential risks. In risk assessment using HIRARC, risk levels are grouped into four categories: extreme risk, high risk, moderate risk, and low risk.

Likelihood	Severity					Risk Level (S X L)
	1	2	3	4	5	
A	H	H	E	E	E	*E = Extreme*
B	M	H	H	E	E	*H = High*
C	L	M	H	E	E	*M = Moderate*
D	L	L	M	H	E	*L = Low*
E	L	L	M	H	H	

Figure 2. HIRARC risk matrix scale used for likelihood-severity classification [19].

Table 1. Likelihood and Severity Measuring Scale

LIKELIHOOD (L)	SEVERITY (S)
E = Very High	5 = Multiple Fatal Injuries
D = High	4 = Fatal Injury
C = Moderate	3 = Serious Injury
B = Low	2 = Moderate Injury
A = Very Low	1 = Minor Injury

HAZOP was applied to examine deviations from normal operating conditions in the loading and unloading process. The nodes were determined from the main work processes and risk sources identified during field observation, namely heavy-equipment operation, unsafe binding or lifting, container movement, chemical or hazardous-material handling, truck mobilization, bad weather exposure, night work, equipment inspection, overload conditions, PPE use, training, and communication. For each node, possible deviations were identified, their causes and consequences were described, likelihood and consequence scores were assigned, and the final risk level was calculated using Equation (2). This procedure allowed the study to capture system failures and procedural deviations that may not be fully visible in activity-based HIRARC assessment.

$$\text{Risk} = \text{Level of likelihood of occurrence} \times \text{Level of consequence} \qquad (2)$$

Likelihood refers to the level that reflects the chance of an impact caused by a risk source at each stage of the work process. Consequence refers to a value that describes the extent of the impact caused by the risk source at each stage of the work process. This impact analysis is crucial for obtaining information that can be used to prevent and reduce potential accidents that may occur in the

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workplace.

Likelihood	Consequence				
	Insignificant (Very Low)	Minor (Low)	Moderate (Medium)	Major (High)	Catastrophic (Very High)
Almost certain (Very High)	S(5)	S(10)	T(15)	T(20)	T(25)
Likely (High)	R(4)	S(8)	S(12)	T(16)	T(20)
Possible (Moderate)	R(3)	S(6)	S(9)	T(12)	T(15)
Unlikely (Low)	R(2)	R(4)	S(6)	S(8)	T(10)
Rare (Very Low)	R(1)	R(2)	R(3)	R(4)	S(5)

Figure 3. HAZOP risk matrix scale used for likelihood-consequence classification [19].

The Delphi method was used as an expert-validation stage. In the first round, experienced informants identified and confirmed potential risks based on their operational knowledge. In the second round, the same risks were rated using a five-point Likert scale to measure the level of agreement. Consensus was evaluated using the mean, median, standard deviation, and interquartile range (IQR). A risk item was considered to have achieved consensus when the standard deviation was below 1.5 and the IQR was below 2.5, indicating that respondents had sufficiently consistent judgments.

The consensus indicators were calculated for each risk item. The mean and median were used to describe central tendency, while standard deviation and IQR were used to evaluate the dispersion of expert responses. This approach was selected to reduce the influence of individual subjectivity and to determine whether additional Delphi rounds were required.

$$\text{Mean} = \frac{\Sigma xi}{n} \quad (3)$$

Where, xi is value of each respondent and n is number of respondents. Standard Deviation is how far the values are spread from the average with the formula:

$$\text{Std Dev} = \sqrt{\frac{\Sigma(xi - \bar{x}^{\,2})}{n}} \quad (4)$$

After obtaining the standard deviation value, continue to find the IQR value which is the difference between the third quartile (Q3) and the first quartile (Q1), describing the distribution of data in the middle 50% of the population. The work steps begin by sorting the data, determine Q1 (first quartile, 25% value), Determine Q3 (third quartile, 75% value), Calculate IQR = Q3 – Q1.

3. Results

3.1 Shorebase Risk Identification of PT. X

From the results of the identification of high-risk activities in the work area of PT. X, it was found that there were risky activities and risk deviations. Risk identification in loading and unloading activities at the shorebase of PT. X was carried out by grouping each risk based on the main categories, namely Heavy Equipment Hazards, Human and Equipment Interaction, Dock Conditions, and Hazardous Materials.

Table 2. Main Identification

NO.	Primary Identification	Code
1	Dangers of Heavy Equipment	AB
2	Human and Equipment Interaction	MP
3	Pier Condition	KD
4	Material Dangerous	MB

3.2 HIRARC Method Risk Identification Results

The HIRARC assessment showed that

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occupational risk levels varied between low and moderate categories. No high or extreme risks were identified in the analyzed activities. The assessment was based on actual loading and unloading activities at the PT. X shorebase and classified using the likelihood-severity matrix. Table 3 presents the activity, hazard identification, score, and risk level for each work step.

Table 3. Risk identification

Risk Category	Risk Code	Activity	Hazard Identification	*Risk Assessment*		Score	*Risk Level*
				Likelihood	*Severity*		
	P1	Crane operation during loading and unloading	Load falls due to sling breaking	E	3	3	M
AB	P2	Use of forklift to move goods	Forklift overturned/rolled over	E	3	3	M
	P6	Pipe transfer using a crane	Pipe fell due to poor locking	E	3	3	M
	P7	Use of hydraulic tools for dismantling	Hydraulic tool failed to operate	E	2	2	L
AB	P12	Use of weight lifting slings	Sling rope broke due to overload	E	2	2	L
	P14	Routine inspection activities of lifting equipment	Injuries due to equipment failure	E	2	2	L
	P3	Lifting of loads by rigging team	Injuries due to incorrect binding	D	2	4	L
	P4	Operators working at height	Fall from a height	D	3	5	M
MP	P9	Unloading of containers from a ship	Container falls/falls on operator	E	3	3	M
	P10	Night shift work	Operator fatigue, lack of focus	D	3	5	M
	P8	Mobilization of transport trucks at shorebase	Collision between trucks	E	3	3	M
KD	P11	Truck driver activities at the dock	Operator fell from truck cabin	E	2	3	L
	P13	Moving goods during bad weather	Items fell due to strong winds	E	3	3	M
MB	P5	*(chemical)* material loading process	Hazardous chemical spills	E	2	2	L

Note: L = Low risk; M = Moderate risk. Likelihood and severity follow the HIRARC matrix in Figure 2.

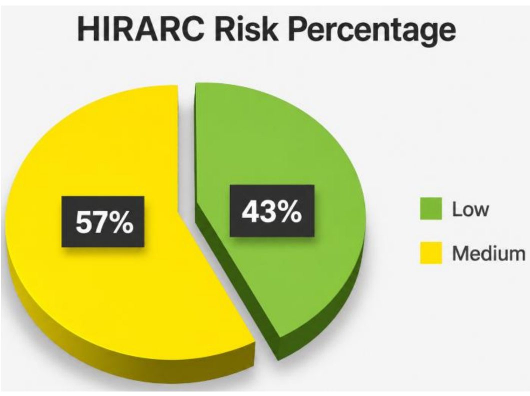

Figure 4. Percentage distribution of HIRARC risk levels.

3.3 HAZOP Method Risk Identification Results

The HAZOP assessment emphasized

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deviations from normal operating conditions. Compared with HIRARC, which focuses on work activities, HAZOP was used to detect possible system failures, procedural deviations, and abnormal operating conditions that could lead to accidents. Table 4 summarizes the HAZOP nodes, deviations, likelihood-consequence scores, and risk levels.

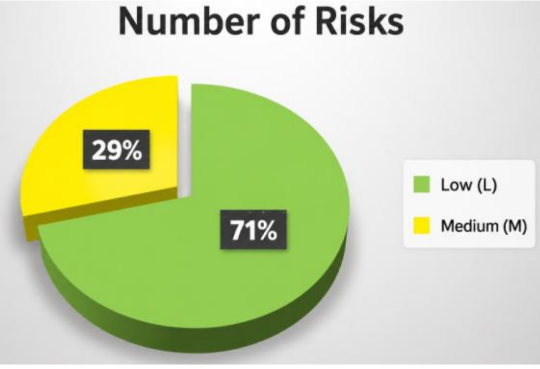

Figure 5. Percentage distribution of HAZOP risk levels.

Table 4. Hazard identification

Risk Category	Risk Code	Activity	Risk Deviation	L	C	Score	*Risk Level*
AB	D1	Use of heavy equipment	The use of heavy equipment (cranes/forklifts) causes the potential for work accidents.	1	1	1	R
	D2	Container fell during loading-unloading	Unstable load when lifted resulting in damage to material/cargo	2	3	6	S
	D6	Lack of PPE, training, or communication	Lack of heavy equipment operator training results in operational errors	1	2	2	R
	D7	Use of heavy equipment	Malfunction of heavy equipment such as cranes or forklifts	3	3	9	S
	D9	Non-routine equipment inspection	There is no routine inspection of heavy equipment before use.	1	1	1	R
	D11	Heavy Equipment Overload	Overload of heavy equipment capacity resulting in equipment damage or work accidents	1	4	4	R
	D8	Unsafe binding/lifting	Improper placement of items increases the risk of damage or accidents.	1	2	2	R
MP	D10	Unsafe binding/lifting	Materials/goods are not tied properly so they are at risk of falling	2	4	8	S
	D14	Lack of PPE, training, or communication	Lack of standard personal protective equipment (PPE) during the operation	1	3	3	R
KD	D3	Bad weather	Bad weather conditions (rain, wind) hamper the loading and unloading process	4	3	12	S
	D5	Chemical Spill	Leakage of hazardous materials during loading and unloading	2	2	4	S
	D12	Lack of PPE, training, or communication	Inadequate location access causes disruption to operational flow.	1	1	1	R

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Risk Category	Risk Code	Activity	Risk Deviation	L	C	Score	*Risk Level*
KD	D13	Night shift work	Loading and unloading process at night without adequate lighting	2	2	4	R
MB	D4	Lack of PPE, training, or communication	Communication disruption between equipment operator and site supervisor	2	2	4	S

Note: L = Insignificant risk; M = Moderate risk. L and C indicate likelihood and consequence in the HAZOP matrix.

3.4 Comparison of HIRARC and HAZOP Risk Assessments

The comparison between HIRARC and HAZOP was conducted to identify convergence and divergence between field-based hazards and process-deviation risks. HIRARC captures direct hazards experienced by workers during activities, while HAZOP identifies deviations that may arise when equipment, procedures, communication, or environmental conditions do not operate as intended. The Delphi method was then used to validate whether these risks were considered important by experienced personnel.

Table 5. Comparison of HIRARC and HAZOP

No	Loading and Unloading Activities	HIRARC Code & Description	HAZOP Code & Description
1	Use of heavy equipment	P1: Load falls due to sling breaking. P2: Forklift overturned	D1: Heavy equipment causes work accidents. D7: Crane/forklift malfunction
2	Unsafe binding/lifting	P3: Injury due to incorrect binding	D10: Material is not properly bonded. D8: Placement of goods is not appropriate
3	Working at heights	P4: Fall from a height	–
4	Chemical spill	P5: Hazardous chemical spills	D5: Hazardous material leak
5	Pipe relocation	P6: Pipe fell due to poor locking	–
6	Hydraulic tool failure	P7: Hydraulic tool fails to operate	–
7	Truck mobilization	P8: Collision between trucks P2: Forklift Overturned	–
8	Container fell during loading-unloading	P9: Operators override container	D2: Unstable load causes damage
9	Night work	P10: Operator fatigue	D14: Night without adequate lighting
10	Truck driver falls	P11: Operator fell from the cabin	–
11	Overload of lifting equipment	P12: Sling rope broke due to overload	D11: Heavy equipment overload
12	Dangerous weather	P13: Items fell due to high winds	D3: Dangerous weather hampers the process
13	Non-routine equipment inspection	P14: Injury due to equipment failure	D9: No routine inspections
14	Lack of PPE, training, or communication	–	D4: Communication disorders D6: Lack of training

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No	Loading and Unloading Activities	HIRARC Code & Description	HAZOP Code & Description
			D12: Inadequate access to location D14: No standard PPE

Note: A dash indicates that the risk was not directly identified by the corresponding method.

The comparison indicates that nine risks overlap directly between HIRARC and HAZOP, including heavy-equipment operation, unsafe binding or lifting, chemical spill, container fall, night work, overload, dangerous weather, non-routine inspection, and PPE/training/communication issues. Several hazards, such as working at height, pipe relocation, hydraulic-tool failure, and truck-driver falls, were captured mainly by HIRARC because they are related to field activities. Conversely, communication disruption, inadequate access, and lack of standardized PPE appeared more clearly in HAZOP because they represent procedural or system deviations. This overlap analysis shows that the two methods are complementary rather than redundant.

3.5 Risk Control using the Delphi method

The Delphi method relies on experts through two rounds of questionnaires. Based on the questionnaire recap, the purpose of the first round of the Delphi questionnaire was to obtain information about the background of the selected respondents and map the possible risks that might occur in the port area. The Iteration 1 questionnaire in this study was compiled based on the Delphi method, which aims to systematically collect expert opinions through several rounds [15]. The selected respondents were experienced workers at PT. X, with work periods ranging from 6 to 8 years. Based on the Delphi approach, selecting participants with practical knowledge and direct experience in the field being studied is crucial to producing valid and relevant data [13, 14].

Table 6. Identification of Delphi survey

No	Risk Identification Classification	Risk	Category	Frequency of mention
1	AB	Operation of heavy equipment (crane, forklift)	Equipment	2 times
2		Hit, crushed, hit by falling load from heavy equipment	Equipment	1 time
3		Heavy equipment mechanical failure (sling breaks, forklift brakes fail, crane collapses)	Equipment	1 time
4	MP	Work in high altitude areas	Work environment	2 times
5		Human error: ineffective communication, SOP violations, PPE not used	Man	1 time
6	KD	*Man over boat* (fell into the sea during loading and unloading activities)	Work environment	1 time
7		Extreme weather (high winds, heavy rain, high waves)	Natural Environment	1 time
8		Imbalance of ship or dock load (ship tilting, crane losing stability)	Work environment	1 time
9	MB	Handling of hazardous materials (bulk *transfer)*	Material/ Material	2 times
10		Chemical/oil spills/leaks (environmental pollution, potential fire/explosion)	Material/ Material	1 time

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No	Risk Identification Classification	Risk	Category	Frequency of mention
11		Fire/explosion due to flammable materials (gas, fuel)	Material/ Material	1 time

The first round of the Delphi survey identified 11 potential risks, compiled from all respondents' input. These risks were then grouped into four main categories: Heavy Equipment Hazards, Human-Equipment Interaction, Dock Conditions, and Hazardous Materials. A second round was then conducted, where respondents' responses were also examined to determine whether they agreed or disagreed with the eleven potential risks identified in the first round of the Delphi questionnaire. A Likert scale ranging from 1 to 5 was used for assessment. The data were then analyzed using descriptive statistics to gain a comprehensive understanding of respondents' perceptions of potential risks in loading and unloading activities at the shorebase. This analysis included calculating the mean, median, standard deviation, and interquartile range (IQR). This approach aligns with the Delphi method, which emphasizes not only consensus building but also analyzes the level of perception and diversity of respondents' opinions through quantitative data [15]. The general middle value of all responses was obtained.

Next, find the median, or middle value, of the sorted data. If the data is even, the median is the average of the two middle values. Next, calculate the standard deviation. The smaller the standard deviation value, the more consistent (homogeneous) the respondents' answers. After obtaining the standard deviation value, continue to find the IQR value which is the difference between the third quartile (Q3) and the first quartile (Q1), describing the distribution of data in the middle 50% of the population. The work steps begin by sorting the data, determine Q1 (first quartile, 25% value), Determine Q3 (third quartile, 75% value), Calculate IQR = Q3 – Q1.

Table 7. Results of Data Processing of the Delphi Questionnaire Round II

No	Instrument	Source person										Mean	Median	Std	IQR
		1	2	3	4	5	6	7	8	9	10				
1	Work in high altitude areas	5	5	4	4	5	4	4	4	5	5	4.5	4.5	0.53	1
2	Handling of hazardous materials (bulk *transfer)*	5	5	4	5	4	4	5	5	4	5	4.6	5	0.52	1
3	Operation of heavy equipment (crane, forklift)	4	5	4	5	5	5	4	4	5	4	4.5	4.5	0.53	1
4	*Man over boat* (fell into the sea during loading and unloading activities)	4	4	5	5	5	4	4	4	5	4	4.4	4	0.52	1
5	Hit, crushed, hit by falling load from heavy equipment	5	4	5	4	5	5	5	5	5	5	4.8	5	0.42	0
6	Heavy equipment mechanical failure (sling breaks, forklift brakes fail, crane collapses)	4	4	5	4	5	4	4	4	5	5	4.4	4	0.52	1

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No	Instrument	Source person										Mean	Median	Std	IQR
		1	2	3	4	5	6	7	8	9	10				
7	Chemical/oil spills/leaks (environmental pollution, potential fire/explosion)	5	5	4	4	4	5	4	5	4	4	4.4	4	0.52	1
8	Extreme weather (high winds, heavy rain, high waves)	4	5	5	4	4	4	5	5	4	4	4.4	4	0.52	1
9	Imbalance of ship or dock load (ship tilting, crane losing stability)	4	4	4	5	4	4	4	4	5	5	4.3	4	0.48	0.75
10	Human error: ineffective communication, SOP violations, PPE not used	4	4	5	5	4	5	5	4	4	5	4.5	4.5	0.53	1
11	Fire/explosion due to flammable materials (gas, fuel)	4	4	4	5	4	4	4	5	5	4	4.3	4	0.48	0.75

Based on the literature, consensus is considered achieved if standard deviation value < 1.5 and IQR value < 2.5. The calculation results show that all instruments (11 risks) have a standard deviation value below 1.5 and an IQR value below 2.5. This indicates that all respondents have reached a consensus on the risk assessments provided.

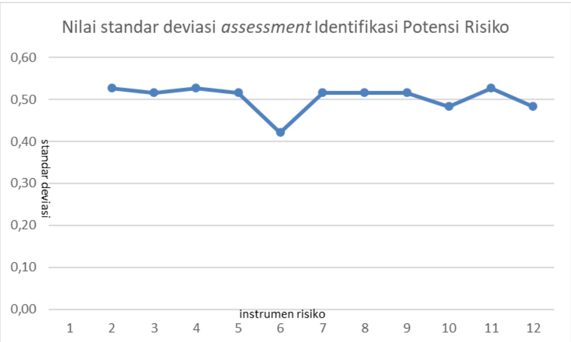

Figure 6. Standard deviation of Delphi Round II risk ratings.

The standard deviation values ranged from 0.42 to 0.53, while the IQR ranged from 0 to 1. Thus, the results of the first round of the Delphi survey met the consensus requirement, indicating that the respondents' risk assessments were consistent and dependable. Therefore, no additional Delphi rounds were required, and these results can be used as a basis for determining further mitigation measures.

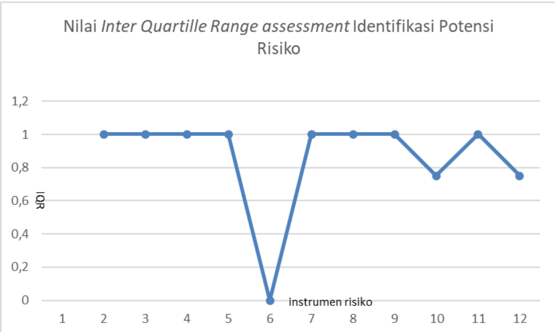

Figure 7. Interquartile range (IQR) of Delphi Round II risk ratings.

The following table presents a summary of the answers and findings from 10 expert respondents in the second Delphi iteration for each of the 14 risks. As a further stage, through the Second Delphi Iteration, the main risks that have been analyzed using the HIRARC and HAZOP methods will be compared and mapped.

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Table 8. HIRARC and HAZOP Risk Mitigation using the Delphi Method

No.	Main Risks	Risk Mitigation
1	Use of heavy equipment	The risk of work accidents can be reduced through more frequent equipment inspections and close supervision by supervisors in the work area.
2	Unsafe binding/lifting	Improved safety equipment and strict inspection checklists are needed to prevent accidents due to improper lifting procedures.
3	Working at heights	Safety at height is improved through more reliable protective equipment and standardized training.
4	Chemical spill	Leak risk mitigation is enhanced through the installation of leak sensors and increased frequency of equipment inspections.
5	Pipe relocation	Safety is improved through load balance monitoring and the use of better protective equipment.
6	Hydraulic tool failure	Technical risks can be reduced through regular inspections and the implementation of additional safety systems on hydraulic equipment.
7	Truck mobilization	Accidents during mobilization can be minimized through strict direct supervision and internal traffic management.
8	Container fell during loading and unloading	Implementation of load sensors and evaluation of worker competency can prevent accidents due to overloading.
9	Night work	The risks of night work are reduced through structured shift rotation and evaluation of operator workload.
10	Truck driver falls	Driver safety is enhanced through intensive training and regular evaluations of physical condition and workability.
11	Overload of lifting equipment	Load sensors and strict checklists are required to ensure the equipment does not operate beyond lifting capacity.
12	Bad weather	The use of early warning systems and operational coordination before activities can minimize the impact of extreme weather.
13	Non-routine equipment inspection	Implementing regular inspection discipline and increasing awareness of SOPs are key to preventing equipment damage.
14	Lack of PPE, training, or communication	Occupational safety is enhanced through risk awareness campaigns, intensive training, and effective cross-team communication.

The results of the second iteration of the Delphi Method analysis provide an overview of 14 major Occupational Safety and Health (OHS) risks identified at PT. X along with mitigation recommendations validated by an expert panel. These risks, previously identified through the HIRARC and HAZOP approaches, cover various operational aspects with the potential for significant impact. In general, expert consensus indicates that most risks require a strong emphasis on worker accident prevention, increased supervision, and the utilization of technology and training.

4. Discussion

This study demonstrates that the integration of HIRARC, HAZOP, and Delphi provides a more complete risk-control analysis than a single-method assessment. HIRARC produced a field-based picture of risks by linking each loading and unloading activity with observable hazards, while HAZOP deepened the analysis by examining deviations from normal operating conditions. Delphi then functioned as an expert-validation mechanism that evaluated whether the identified risks and proposed controls were consistent with practical experience. The three methods therefore operate as a triangulated framework: HIRARC identifies what can go wrong in the activity, HAZOP explains how the process may deviate, and Delphi validates which risks deserve managerial priority.

The comparison between HIRARC and HAZOP indicates both convergence and divergence. Convergent risks include heavy-equipment

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operation, unsafe binding and lifting, hazardous-material spill, container fall, night work, overload, dangerous weather, non-routine inspection, and PPE/training/communication problems. These overlapping risks should be treated as priority control areas because they were detected by both activity-based and deviation-based approaches. Divergent risks are also important: working at height, pipe relocation, hydraulic-tool failure, and truck-driver falls were more visible in HIRARC because they are task-specific field hazards, whereas communication disruption and inadequate access were more visible in HAZOP because they represent systemic or procedural weaknesses. This finding confirms that HIRARC and HAZOP are complementary rather than interchangeable.

A critical point in the findings is the absence of high or extreme risks in the HIRARC and HAZOP results. This does not necessarily mean that loading and unloading at the shorebase is free from serious hazards. Instead, it may reflect the presence of existing controls, the use of risk matrices with conservative scoring, and the respondents' perception that severe events are unlikely under normal controlled conditions. The result should therefore be interpreted as residual or assessed risk under the observed operational setting, not as inherent risk before controls. In high-risk shorebase operations, low and moderate classifications still require continuous attention because routine exposure, fatigue, weather variability, and human-equipment interaction can escalate into severe incidents if supervision and control discipline decline.

The findings are consistent with recent studies emphasizing the importance of structured risk assessment in port and oil-and-gas operations. For example, recent port-related HIRARC research identified moderate-level hazards as dominant in terminal operations and highlighted the importance of engineering measures, administrative controls, PPE, and safety culture [24]. A 2024 loading and unloading study using JSA and HAZOP at a port also reported the dominance of mechanical hazards and recommended SOP compliance, PPE use, administrative and engineering controls, and periodic safety training [23]. In oil-and-gas contexts, recent safety research emphasizes that hazard identification and risk assessment must be supported by safety communication and safety culture to improve safety knowledge and performance [25]. Studies on petroleum-product loading and refined-oil loading also show that human error, procedural control, and dynamic risk factors remain central in loading-unloading risk analysis [26, 27]. Compared with these studies, the present research contributes by combining field hazards, process deviations, and expert consensus in a single shorebase-specific framework.

The added value of the Delphi method is its ability to reduce subjectivity in the final interpretation of risk priorities. HIRARC and HAZOP both depend on scoring judgments, and such judgments may vary across workers or assessors. By involving experienced informants in two Delphi iterations, the study transformed individual risk perceptions into a more stable consensus. The low standard deviation and IQR values indicate that expert agreement was achieved, supporting the reliability of the proposed mitigation measures. Delphi also helped translate technical risk scores into practical managerial actions, such as increasing equipment inspection frequency, improving lighting for night work, strengthening shift rotation, ensuring load monitoring, and reinforcing communication across teams.

From a managerial perspective, the integrated results suggest several practical implications for shorebase operations. First, overlapping risks identified by both HIRARC and HAZOP should be included in a priority inspection checklist before loading and unloading begins. Second, night work and bad-weather operations should require additional permit-to-work controls, lighting verification, fatigue monitoring, and weather-based stop-work criteria. Third, lifting and heavy-equipment operations should be supported by competency verification, load-limit monitoring, rigging checklists, exclusion zones, and direct supervisor presence. Fourth, hazardous-material handling should be supported by spill-response readiness, leak-detection equipment, emergency drills, and clear communication protocols between operators and supervisors. These actions can strengthen operational governance and reduce the probability that moderate risks escalate into serious accidents.

4.1 Limitations

This study has several limitations. First, the analysis was conducted as a particular case study at PT. X, so the findings may not represent all

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shorebase or port operations. Second, the number of respondents was determined by operational roles and expert criteria rather than statistical sampling, which is appropriate for applied risk assessment but limits generalization. Third, the HIRARC and HAZOP scores rely on human judgment and may be influenced by experience, risk perception, and familiarity with existing controls. Fourth, the study did not use real-time sensor data or historical accident-frequency modeling, so future research should combine expert-based assessment with quantitative incident data, digital monitoring, and predictive risk analytics.

5. Conclusion

This study concludes that the integrated use of HIRARC, HAZOP, and Delphi strengthens the risk-control analysis of shorebase loading and unloading operations by combining field-based hazard identification, process-deviation analysis, and expert consensus validation. HIRARC identified 14 work-activity hazards consisting of 8 moderate-risk activities (57.14%) and 6 low-risk activities (42.86%), while HAZOP identified 14 operational deviations consisting of 8 low-risk deviations (71%) and 6 moderate-risk deviations (29%). No high or extreme risks were identified under the observed conditions, indicating that the assessed risk levels represent controlled or residual operational risks rather than the absence of serious hazard potential.

The main contribution of this study is the demonstration that HIRARC and HAZOP provide complementary insights. HIRARC is more effective for identifying direct hazards faced by workers, such as working at height, pipe relocation, hydraulic-tool failure, and truck-driver falls. HAZOP is stronger for identifying systemic deviations, including communication disruption, inadequate access, lack of PPE standardization, heavy-equipment malfunction, overload, and weather-related operational disruption. Delphi validation confirmed that priority attention should be directed to working at heights, hazardous-material handling, heavy-equipment operation, night work, bad weather, and human-equipment interaction.

Practically, the results support the implementation of stricter inspection discipline, competency-based training, improved lighting and shift management, load-monitoring systems, weather-based operational controls, spill-response readiness, and stronger cross-team communication. Future research should apply the integrated framework across multiple shorebases, include larger expert panels, and combine qualitative risk matrices with historical accident data, real-time monitoring, and predictive analytics to improve the robustness of shorebase risk management.

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Competing interests: The authors declare that they have no competing interests.

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