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Stakeholder Engagement Based Moral Hazard Analysis Model in FPSO-Tanker Oil Transfer

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Abstract

This study aims to address moral hazard risks in FPSO-tanker oil transfer operations by introducing a semi-quantitative model rooted in stakeholder engagement theory. The model, named SEMHAM (Stakeholder Engagement-based Moral Hazard Analysis Model), incorporates four engagement indicators to calculate the total involvement percentage (PTI): Occurrence Frequency Value (OFV), Responsibility Weight Value (RWV), Critical Role Value (CRV), and Process Impact Value (PIV) to calculate the Total Involvement Percentage (PTI). This metric quantifies the behavioral influence of each stakeholder in the offloading process. Using operational data from 17 offshore zones based on Pertamina's 2023 report, eight primary stakeholder roles were evaluated using a weighted activity matrix. The findings indicate that FPSO Crew and Ship Crew possess the highest PTI scores, signifying greater control and potential risk, whereas administrative actors such as agents and port authorities were identified as lower-risk participants. The SEMHAM model facilitates risk classification and recommends appropriate digital oversight, including IoT-based monitoring, smart contracts, and role-based dashboards. This approach enables the integration of behavioral risk metrics into digital governance systems, thus supporting real-time operational monitoring. The model also demonstrates potential scalability to more complex offshore energy domains, such as LNG terminals and deepwater operations, enabling broader stakeholder governance beyond the current FPSO-tanker context.

Keywords:

Stakeholder Engagement;
Moral Hazard;
SEMHAM Model;
Offshore Oil Transfer;
Digital Risk Governance.

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1- Introduction

The transfer of oil from Floating Production Storage and Offloading (FPSO) units to shuttle tankers is a high-risk and logistically complex operation in the offshore energy sector [1, 2]. The load transfer process FPSO–Tanker is illustrated in Figure 1. These operations involve multiple stakeholders including buyers, crew members, port authorities, agents, and regulators, each with distinct responsibilities and incentives. While numerous studies have addressed the technical aspects of FPSO-tanker transfers, such as Hawser tension analysis, structural safety, and spill prevention [3-5] attention has been given to the behavioral and governance-related risks resulting from stakeholder interactions. In particular, the issue of moral hazard, in which parties exploit informational asymmetries or insufficient enforcement [6], remains underexplored in the context of offshore oil logistics [7, 8].

Recent research on offshore operational risk has introduced semi-quantitative tools such as Fuzzy-FMEA, bowtie analysis, and event tree methods [9, 10]. However, these models often overlook the role of stakeholder engagement and responsibility distribution in contributing to systemic vulnerability. Meanwhile, studies on digital risk

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governance and smart maritime logistics [11, 12] emphasize the urgent need to integrate behavioral metrics into control systems that support transparency and accountability. This study addresses this gap by proposing a Stakeholder Engagement-based Moral Hazard Analysis Model (SEMHAM), a structured model that quantifies stakeholder participation across four indicators: Occurrence Frequency Value (OFV), Responsibility Weight Value (RWV), Critical Role Value (CRV), and Process Impact Value (PIV). These metrics generate a unified Total Involvement Percentage (PTI) score to identify the stakeholders most exposed to moral hazard and support the design of tiered digital oversight mechanisms.

Figure 1. **Load transfer process FPSO-Tanker**

The remainder of this paper is organized as follows: Section 2 presents the SEMHAM methodology, including stakeholder mapping and engagement scoring. Section 3 outlines the application of the model using operational data from Pertamina and analyzes the results. Section 4 compares the findings with those of prior research and discusses the theoretical and practical implications. Section 5 concludes the study and proposes directions for the further development and broader deployment of the SEMHAM model.

2- Research Methodology

This study employs a structured approach based on the Stakeholder Engagement-based Moral Hazard Analysis Model (SEMHAM) to quantitatively assess risk-prone stakeholder interactions [9, 14-16] during offshore oil transfer operations from the FPSO units to tankers. The methodology consists of four main components: (1) stakeholder role mapping, (2) quantitative engagement scoring, (3) total involvement index calculation, and (4) digital system integration.

2-1- Stakeholder Role Mapping

The SEMHAM approach aligns with recent advances in governance-oriented risk modeling and stakeholder-centric decision-support systems. Eight primary stakeholders were identified based on their participation across three operational phases: pre-transfer, transfer, and post-transfer. These include the buyer, shipper, FPSO crew, government, port authority, agent, stevedoring company (LUC), and surveyor. Using an activity breakdown from real FPSO-tanker operations, each stakeholder's responsibility was mapped to specific tasks including schedule confirmation, valve control, monitoring, supervision, documentation, and cargo discharge [17]. The SEMHAM approach aligns with cognitive-behavioral decision-making models that emphasize stakeholder role dynamics in digital transformation contexts. Roles and responsibilities were categorized across four engagement dimensions [18, 19]:

- Quality & Quantity
- Safety & Efficiency
- Regulation & Supervision
- Administration & Coordination

The SEMHAM model draws upon established principles in stakeholder governance and behavioral risk quantification, aligning with emerging approaches in socio-technical systems and decision support frameworks for risk-sensitive operations [20, 21].

2-2- Quantitative Engagement Scoring

The SEMHAM framework employs a semi-quantitative approach to evaluate stakeholder engagement using four core metrics: Occurrence Frequency Value (OFV), Responsibility Weight Value (RWV), Critical Role Value (CRV), and Process Impact Value (PIV) [21]. These metrics are derived from a stakeholder–activity matrix that captures the involvement patterns across n oil transfer activities segmented into three operational phases [22].

Stakeholder presence across activities is used to compute OFV, while the significance of each task, ranging from critical operational control to administrative documentation, is assigned predefined weights to generate the RWV. CRV reflects a stakeholder's presence in decision-making processes, and PIV measures the potential operational disruption resulting from stakeholder failure. The scoring inputs are based on standardized weighting logic determined by expert panels and operational guidelines. The result is a multidimensional engagement profile for each stakeholder, which supports further analysis and risk mapping. Each stakeholder was assigned a score based on their appearance, responsibility weight, criticality of their role, and process impact using the following four metrics:

- ***Occurrence Frequency Value (OFV)***

It measures how often a stakeholder is involved in operational activities [23]. A party is involved in the entire offloading process, calculated as the ratio between the number of appearances of that party in a particular stage and the total stages available, expressed as a percentage to give an idea of the relative proportion of involvement [24], as shown in Equation 1.

$$OFV = \frac{N_{appearance}}{N_{total\ activities}} \times 100\% \tag{1}$$

- ***Responsibility Weight Value (RWV)***

Evaluate the level of importance of each party's responsibilities by assigning different weights to each activity (4 for critical to 1 for supporting) and then calculate the weighted average to obtain a value that reflects the significance of the role in the overall process [25], as shown in Equation 2:

$$RWV = \frac{\sum(W_i - N_i)}{N_{total\ activities}} \tag{2}$$

where Wi is the activity weight, and Ni is the number of tasks. To compute the RWV, each operational activity was assigned a predefined weight ranging from 1 to 4 based on its criticality and influence on the overall offloading operation. The weighting logic followed a four-level classification adapted from a risk-based task analysis. The classifications are as follows (see Table 1):

Table 1. Weighting Scheme for Operational Activity Responsibilities

Weight	Category	Definition	Examples
4	Critical	Direct control overflow, safety, or measurement	Valve Control, Volume Verification
3	Important	Supervision or validation roles impacting process quality	Sampling, Supervision, Monitoring
2	Standard	Administrative or operational support	Clearance, Documentation, Navigation
1	Supporting	Minor tasks or data preparation	Notification, Licensing

These weights were defined based on engineering judgment using references such as Pertamina's operational procedures and offshore role descriptions from oil and gas production literature [26]. Scoring reflects stakeholder criticality during oil transfer, rather than during drilling operations.

- ***Critical Role Value (CRV)***

Scores on how frequently the stakeholder holds a gatekeeping or command function in the procedural flow. Measuring the level of criticality of a party's role in decision-making, calculated by considering the weight of the role and the amount of involvement in decision-making compared to the total existing decisions [27, 28], provides an idea of how significant the party's contribution is in the decision-making aspect, as shown in Equation 3.

$$CRV = \frac{N_{decision\ nodes}}{N_{total\ decision\ points}} \tag{3}$$

- ***Process Impact Value (PIV)***

Measures the extent to which each stakeholder's failure or inaction may affect logistics outcomes (delays and volume losses). Evaluating the influence of a party's involvement on the overall process [29], calculated by considering the weight of the impact and the number of impacts produced compared to the total impact, indicates the consequences of that party's involvement in the offloading process, as shown in Equation 4.

$$PIV = \frac{\sum(I_w - N_i)}{T_i} \tag{4}$$

where, PIV is the Process Impact Value, I_w is the Impact Weight (1-4), N_i is the Number of Impacts, and T_i is the Total Impact. The output of this engagement-scoring process is then consolidated into a unified metric that facilitates comparison across stakeholders, referred to as the Total Involvement Percentage (PTI), as detailed in the next section.

While the SEMHAM model did not assign differential weights across the four indicators *(OFV, RWV, CRV, PIV)*, the values for RWV, CRV, and PIV were derived through structured expert-informed assessments. A panel of five subject matter experts was involved in evaluating the operational roles based on responsibility intensity, process criticality, and potential impact. These experts were selected based on over ten years of professional experience in FPSO operations, maritime regulation, HSE auditing, and offshore logistics.

For RWV, operational responsibilities were classified into four weight levels: Critical (4), Important (3), Standard (2), and Supporting (1), with definitions and examples pre-determined by the research team and validated by the expert panel. Likewise, the scoring of CRV and PIV was conducted via structured forms, followed by cross-validation discussions to minimize subjective bias.

2-3- Engagement Matrix Construction

The entire dataset was derived from n activity lines across three operational phases. Stakeholders were tagged per activity and weighed using a semiquantitative matrix. This resulted in a stakeholder activity matrix (SAM), which supported a systematic calculation of each engagement dimension. To consolidate the engagement assessment into a single measurable indicator [30], the Total Involvement Percentage (PTI) was calculated for each stakeholder using the following formula:

$$PTI_i = \frac{OFV_i + RWV_i + CRV_i + PIV_i}{4} \tag{5}$$

where, PTI_i is the total involvement percentage for stakeholder i, OFV_i is Occurrence Frequency Value, RWV_i is the responsibility weight value, CRV_i is the critical role value, and PIV_i is the process impact value. This index provides a normalized measure of stakeholder dominance and potential risk influence across the operational process. Stakeholders with higher PTI values are considered to exert more control or influence and are therefore subject to more intensive monitoring in subsequent system designs. Risk mapping is performed by comparing PTI scores across all stakeholders, allowing the identification of those with elevated exposure to moral hazards, coordination bottlenecks, or decision-point vulnerabilities. This outputs feeds into both the risk prioritization and configuration of the digital monitoring system. Once high-risk stakeholders are identified through PTI analysis, the next step involves implementing digital technologies that can translate these analytical findings into actionable risk governance measures.

2-4- Integration with Digital Risk Controls

To support real-time risk governance and reduce information asymmetry, SEMHAM is integrated with digital systems including IoT-based monitoring, blockchain-based document validation, smart contract enforcement, and role-based dashboards. These tools operationalize PTI by triggering alerts, controlling data access, and ensuring end-to-end transparency throughout the oil-offloading process. To enhance traceability and reduce information asymmetry, SEMHAM was designed for integration with a digital risk control system that includes the following:

- IoT-based Monitoring: Sensors embedded in tanks and pipelines to report volume flow, pressure, and anomalies in real-time [31-33].
- Blockchain Audit Trails: Immutable records of activity logs, timestamps, and documentation access [34, 35].
- Automated Alerts: Triggered by deviation from SOP or role-specific thresholds [34]
- Role-Linked Digital Dashboards: Each stakeholder receives real-time visibility in relevant data based on PTI level [32, 36].

The overall SEMHAM methodology is illustrated in Figure 2, which shows the step-by-step process from stakeholder identification to risk-based digital oversight recommendations.

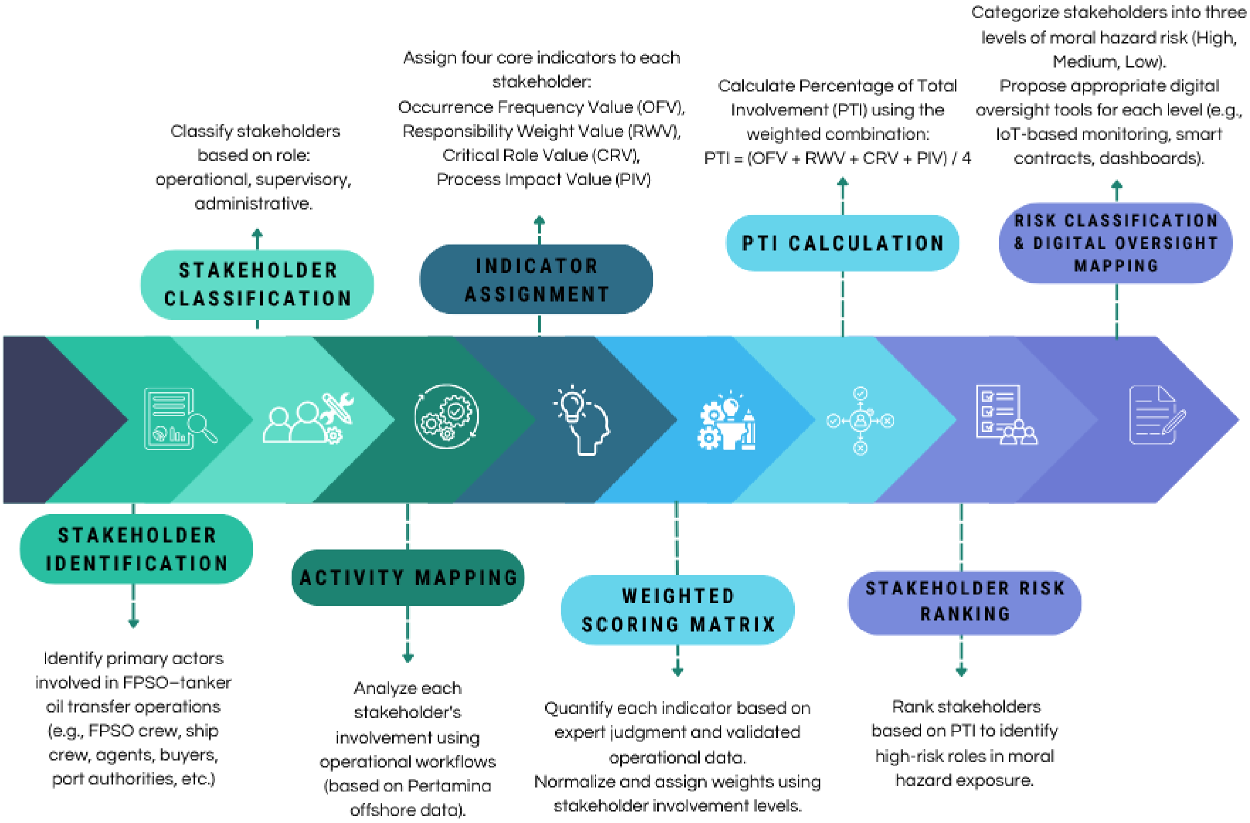

Figure 2. SEMHAM Methodological Workflow

3- Result and Analysis

3-1- Case Identification

Offshore oil transfer from FPSO units to tankers represents a dynamic, multi-stakeholder process prone to oversight and operational losses. To enhance the validity of the SEMHAM model, this study utilized operational data extracted from the official 2023 Annual Report of the PT Pertamina EP. This report provides comprehensive insights into the organizational structure, regional work zones, and key performance indicators relevant to stakeholder involvement in offshore oil transfer operations from FPSO units to tankers [23].

The first step involved identifying the functional divisions of Pertamina Hulu Energi's upstream operations by mapping 17 key stakeholder activities relevant to FPSO-tanker oil transfer. These activities serve as operational 'zones' reflecting discrete points of stakeholder engagement. This structure forms the baseline for evaluating stakeholder presence, as visualized in Figure 3, which illustrates the binary distribution of involvement across the 17 defined transfer activities.

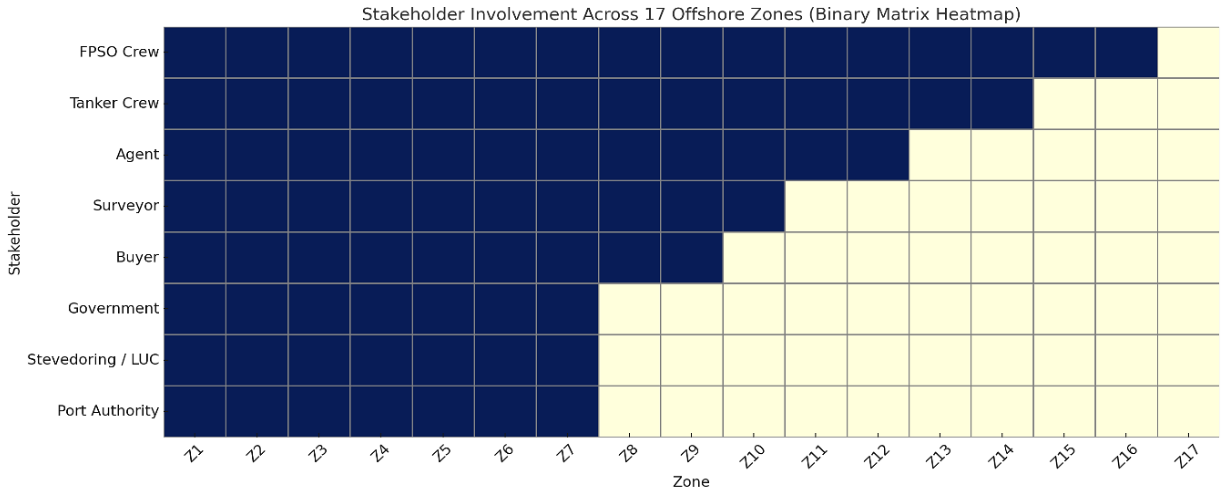

Figure 3. Matrix of Binary stakeholder involvement

As illustrated in Figure 3, the binary involvement matrix visualizes stakeholder engagement across 17 defined operational activities relevant to the FPSO–tanker oil transfer process. Each row corresponds to a stakeholder role, and each column represents a specific activity within the transfer operation. Dark blue indicates active involvement (value = 1), while light color indicates non-involvement (value = 0). Eight primary stakeholder roles were then defined based on their functional participation: FPSO Crew, Tanker Crew, Buyer, Surveyor, Agent, Stevedoring/LUC, Government (regulator), and Port Authority. Each stakeholder was mapped against these 17 activities using a binary matrix (1 = involved, 0 = not involved), informed by functional role descriptions, operational distributions, and field responsibilities outlined in the report. To expand the dimensionality of the engagement analysis, three additional weighted indicators were assigned:

- The Responsibility Weight Value (RWV) reflects the degree of operational responsibility carried by the stakeholder.
- Critical Role Value (CRV): Indicates the stakeholder's influence on decision-making or critical control points.
- Process Impact Value (PIV): Assesses the level of operational disruption likely to occur if the stakeholder fails to perform its role.

RWV, CRV, and PIV values were assigned using a functional analysis approach grounded in the literature, role hierarchy, and operational SOP logic. Stakeholders such as the FPSO Crew and Tanker Crew received the highest scores owing to their direct control over operations, while administrative actors such as Agents and Port Authorities received lower values. The four indicators, OFV, RWV, CRV, and PIV were then consolidated into a comprehensive metric called the Total Involvement Percentage (PTI), calculated as the average of the four dimensions. The final PTI table presents a stakeholder-specific engagement profile, providing a data-driven foundation for classifying risk potential and informing the design of the targeted digital governance mechanisms.

3-2- Stakeholder Role Mapping

A stakeholder activity matrix derived from the SEMHAM framework was implemented, as previously described. This matrix was populated using activity data across the pre-, mid-, and post-transfer phases to generate the weighted engagement scores (Table 2).

Table 2. Summarizes the stakeholder-activity mapping

Stakeholder	Stage	Zone/Activity (n)	Weight	Frequency	Score
FPSO Crew	Pre-Transfer	Storage Verification	3	1	3
FPSO Crew	Transfer	Monitoring Transfer	4	4	16
FPSO Crew	Transfer	Line Displacement	3	1	3
FPSO Crew	Transfer	Valve Control	3	1	3
				Total	**25**
Ship Crew	Transfer	Monitoring Transfer	4	4	16
Ship Crew	Transfer	Supervision	3	2	6
Ship Crew	Pre-Transfer	Verification	3	3	9
Ship Crew	Post-Transfer	Navigation	2	1	2
				Total	**33**
Agent	Pre-Transfer	Coordination	3	3	9
Agent	Transfer	Documentation	2	3	6
Agent	Post-Transfer	Administration	2	2	4
				Total	**19**
Surveyor	Transfer	Volume Verification	4	2	8
Surveyor	Transfer	Sampling	4	2	8
Surveyor	Transfer	Witnessing Transfer Operation	1	0	0
				Total	**16**
Buyer	Pre-Transfer	Schedule Confirmation	3	1	3
Buyer	Pre-Transfer	Volume Verification	4	2	8
				Total	**11**
Government	Pre-Transfer	Licensing	3	1	3
Government	Transfer	Supervision	3	1	3
Government	Post-Transfer	Clearance	2	2	4
				Total	**10**
Stevedoring / LUC	Post-Transfer	Unloading Preparation	2	1	2
Stevedoring / LUC	Post-Transfer	Unloading Operation	2	2	4
				Total	**6**
Port	Post-Transfer	Vessel Monitoring	2	1	2
Port	Post-Transfer	Mooring Facilities	2	2	4
				Total	**6**

Table 2 shows the frequency and weighted presence of each stakeholder across operational phases, illustrating dominance patterns in specific task categories, such as verification, control, and documentation.

Figure 4 illustrates the total engagement score of each stakeholder calculated from their cumulative participation in 21 operational activities. The FPSO Crew and Ship Crew dominate the chart, with scores significantly higher than those of the other stakeholders. This reflects their active role in process-critical tasks such as monitoring, valve control, and navigation. Conversely, entities such as the Port Authority and LUC exhibit lower total scores, which is consistent with their supportive or peripheral roles. These quantitative results confirm the qualitative mapping and lay the groundwork for engagement-based risk classification in the subsequent sections.

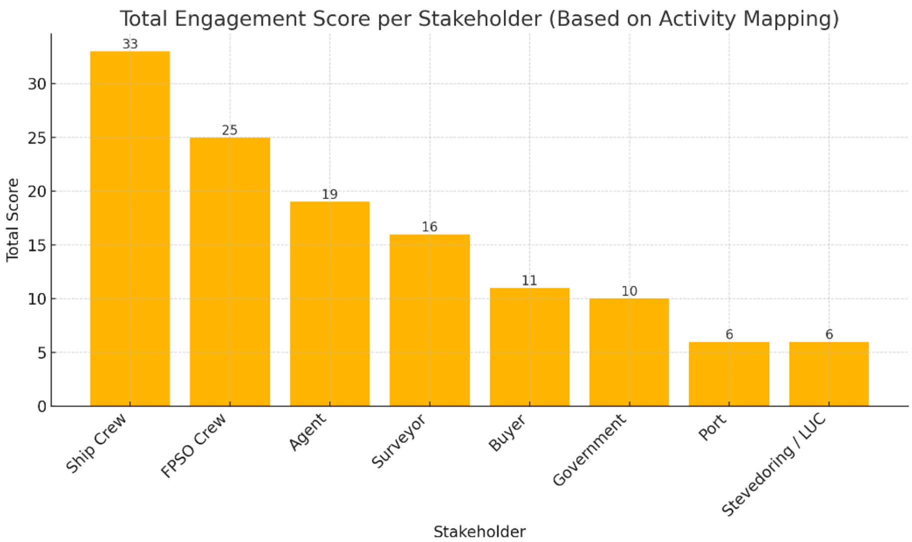

Figure 4. The total engagement score of each stakeholder in offloading FPSO to tankers

3-3- Engagement Metrics

The engagement of each stakeholder was evaluated through four core SEMHAM metrics: Occurrence Frequency Value (OFV), Responsibility Weight Value (RWV), Critical Role Value (CRV), and Process Impact Value (PIV). These indicators provide a multi-dimensional view of each actor's presence, responsibility, influence, and potential risk contribution in FPSO-tanker oil transfer operations. As shown in Table 3, FPSO Crew demonstrated the highest OFV (0.86) and RWV (3.80), indicating consistent participation in operational tasks and high task criticality. The Ship Crew closely followed, with substantial responsibility for navigation and cargo supervision. Agents and Surveyors also played significant roles, particularly in the documentation and verification procedures, as reflected in their mid-range scores.

Table 3. Engagement Metrics per Stakeholder

Stakeholder	OFV	RWV	CRV	PIV	PTI
FPSO Crew	0.86	3.80	0.63	0.83	1.53
Ship Crew	0.81	3.60	0.58	0.78	1.44
Agent	0.71	3.40	0.52	0.72	1.34
Surveyor	0.62	3.10	0.50	0.70	1.23
Buyer	0.55	2.80	0.46	0.62	1.11
Government	0.42	2.40	0.38	0.55	0.94
Stevedoring / LUC	0.45	2.20	0.35	0.50	0.88
Port	0.45	2.20	0.35	0.50	0.88

These results directly address the study's objective of quantifying stakeholder involvement and translating it into risk-informed governance recommendations using the SEMHAM model. In contrast, the Government, Stevedoring (LUC), and port authorities registered lower OFV and RWV values, aligning with their more administrative or supportive roles. However, their CRV and PIV values, although lower, still indicate the potential for indirect risk exposure, particularly in clearance and coordination tasks. Having visualized the comparative performance across all engagement metrics, we consolidated these values into a unified Total Involvement Percentage (PTI) to guide stakeholder risk profiling as shown in Figure 5.

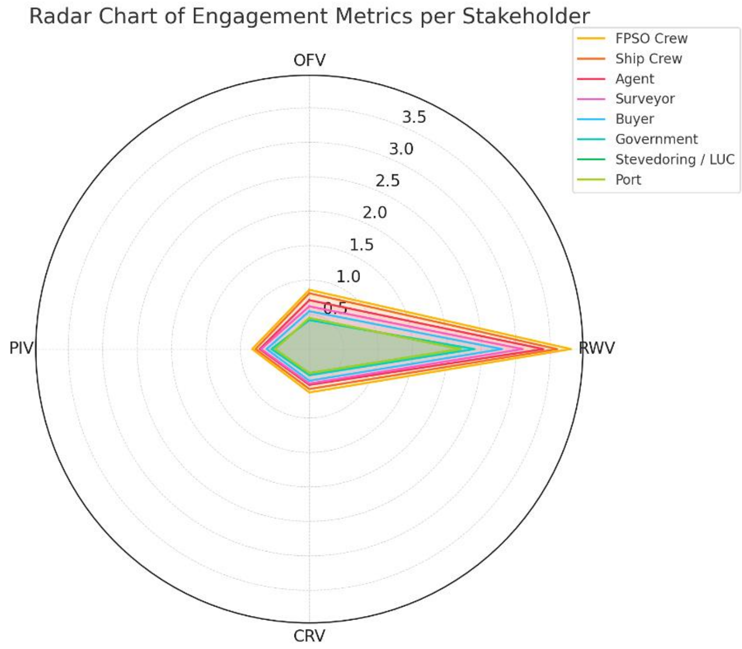

Figure 5. Comparison of engagement metrics per stakeholder

Figure 5 provides a multidimensional visualization of stakeholder engagement through a radar chart depicting the four SEMHAM indicators, OFV, RWV, CRV, and PIV for each actor involved in FPSO-tanker oil transfer operations. The radar chart illustrates how certain stakeholders exhibit consistent dominance across all dimensions. For instance, FPSO Crew and Ship Crew form broad and balanced polygons, reflecting their pervasive involvement and critical operational roles. Their engagement was especially strong in the RWV and PIV dimensions, indicating not only frequent participation but also high-impact responsibilities. In contrast, Surveyors, Agents, and Buyers show strong asymmetric profiles in RWV or CRV, but moderate profiles in OFV. These patterns suggest specialized yet high-stakes involvement such as documentation or verification. The government, LUC, and port authorities form smaller polygons, consistent with their support or compliance-oriented functions. The radar chart complements the bar graph in Figure 3 by offering a holistic and comparative view. This allows for the quick identification of high-risk stakeholders whose polygon areas cover more surface, making it a practical tool for prioritizing monitoring and control mechanisms. The integration of these four indicators results in the Total Involvement Percentage (PTI), a unified score that reflects the overall stakeholder dominance and risk exposure. The next section presents the PTI ranking and its implications.

3-4- PTI Score Result and Stakeholder Risk Profile

The Total Involvement Percentage (PTI) score not only reflects overall stakeholder engagement but also serves as a practical indicator of moral hazard risk. Stakeholders with higher PTI values exhibit both operational dominance and decision-making authority, which makes them crucial for risk-focused governance planning. Table 4 presents the classification of stakeholders based on their PTI scores, identifying those with elevated risk profiles and recommending appropriate digital control mechanisms. The FPSO Crew and Ship Crew, for example, fall into the High-Risk category, necessitating advanced monitoring systems, such as IoT-based real-time sensors, smart contracts, and automatic alerts. Moderate-risk stakeholders may benefit from role-based access and periodic audits, whereas low-risk actors should remain under standard compliance procedures.

Table 4. Stakeholder Risk Classification Based on PTI

Stakeholder	PTI	Risk Level	Control Recommendation
FPSO Crew	1.53	High Risk	Real-time monitoring, automated alerts, smart contracts
Ship Crew	1.44	High Risk	Real-time monitoring, automated alerts, smart contracts
Agent	1.34	Moderate Risk	Periodic audit, role-based access, semi-automated tracking
Surveyor	1.23	Moderate Risk	Periodic audit, role-based access, semi-automated tracking
Buyer	1.11	Moderate Risk	Periodic audit, role-based access, semi-automated tracking
Government	0.94	Low Risk	Standard documentation and compliance oversight
Stevedoring / LUC	0.88	Low Risk	Standard documentation and compliance oversight
Port	0.88	Low Risk	Standard documentation and compliance oversight

The classification presented in Table 4 quantitatively distinguished high-, moderate-, and low-risk stakeholders based on their PTI scores. The score serves as a composite indicator of stakeholder engagement intensity and the associated operational risk. To guide governance prioritization, PTI scores were classified into three risk levels:

- PTI ≥ 1.4 is classified as "High Risk," reflecting stakeholders with dominant operational presence and critical control roles, whose failure may cause major disruptions in the oil transfer process.
- PTI between 1.1 and 1.4 is considered "Moderate Risk," indicating actors who support essential processes but are not solely responsible for critical control points.
- PTI ≤ 1.1 represents "Low Risk" stakeholders, typically fulfilling administrative or oversight functions without direct operational control.

These thresholds are based on the internal logic of the SEMHAM scoring framework, in which the PTI score is derived by averaging four weighted dimensions (OFV, RWV, CRV, and PIV). This categorization is further supported by the observed distribution of simulation results and aligns with risk governance principles to prioritize digital oversight mechanisms where the operational risk is greatest.

Figure 6 illustrates the PTI (Total Involvement Percentage) scores for each stakeholder group involved in the FPSOtanker oil transfer process using a color-coded bar chart based on risk classification. The PTI scores, ranging from 0.88 to 1.53, represent cumulative stakeholder engagement across 21 critical activities. FPSO Crew and Ship Crew emerged as the highest-ranked actors with PTI values of 1.53 and 1.44 respectively, placing them in the high-risk category. Their intensive engagement in real-time transfer operations from monitoring to valve control makes them central to operational continuity. Therefore, they require enhanced digital oversight through real-time monitoring systems, smart contracts, and automated alerts. Agent, Surveyor, and Buyer occupy the Moderate Risk tier (PTI 1.11–1.34). These stakeholders significantly contribute to coordination, validation, and documentation, albeit with limited direct control. Risk management strategies for these actors should include periodic audits, semiautomated monitoring, and role-based access systems. On the lower end, the government, stevedoring/LUC, and port authorities recorded PTI values below 1.00, falling into the Low-Risk category. Although not deeply embedded in technical operations, these actors play both supporting and regulatory roles. Their risk is more administrative and can be managed through standard compliance, oversight, and documentation protocols. This visual reinforces the rationale behind the tiered control recommendations presented in Table 4 and validates the SEMHAM model's capacity to distinguish operational dominance and its implications for governance prioritization.

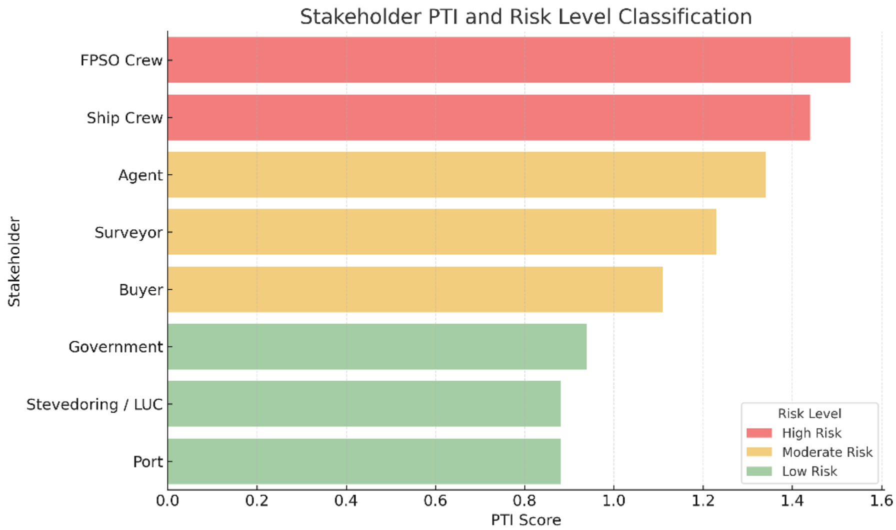

Figure 6. **Total Involvement Percentage**

4- Discussion

4-1- Comparison with Previous Studies

Although not all studies explicitly use the term "moral hazard," a structured governance model has been proposed to address such risks through the integration of ethical values, compliance commitment, and stakeholder awareness within organizational systems [37]. While this approach relies on normative principles, the SEMHAM model provides an operational framework by translating stakeholder behavioral risk into measurable indicators, namely Occurrence Frequency Value (OFV), Responsibility Weight Value (RWV), Critical Role Value (CRV), and Process Impact Value (PIV). Both frameworks emphasize the importance of proactive governance in reducing behavioral risk, but SEMHAM further enables integration into digital oversight systems and offshore stakeholder classification schemes.

A systematic review also underscored that moral hazard often emerges due to information asymmetry, weak monitoring, and agency conflicts, particularly in high-stakes sectors, such as finance, transportation, and agriculture [6]. These insights reinforce the importance of incorporating digital surveillance, transparency, and role-based accountability principles that align closely with SEMHAM's structure of SEMHAM. While explicit documentation of moral hazard in FPSO-tanker operations remains limited, SEMHAM provides a forward-looking framework for anticipating and managing behavioral risk in offshore environments.

Furthermore, several studies have implemented semi-quantitative risk models, such as Fuzzy-FMEA, bowtie analysis, and event tree analysis, to assess operational risks in offshore oil and maritime logistics. For instance, Fuzzy-FMEA has been applied to identify failure modes in offshore platforms, emphasizing mechanical and procedural threats, whereas Bow-Tie Analysis has been used to map accident pathways and mitigation strategies in maritime pilot operations [38, 39]. In comparison, SEMHAM focuses specifically on stakeholder engagement metrics, thus complementing traditional models by addressing the behavioral dimension of offshore risk governance.

4-2- Implications for Offshore Stakeholders and Risk Governance

Stakeholder classification based on (Percentage of Total Involvement) offers a strategic lens for risk governance in offshore operations. High-risk actors such as the FPSO Crew and Ship Crew should be prioritized for real-time surveillance technologies, including IoT-based anomaly detection and blockchain-secured logging. Medium-risk roles, such as Agents, Surveyors, and Buyers, may be managed using restricted-access dashboards and role-specific audit trails. While low-risk stakeholders, such as Port Authorities and Government Agencies, hold minimal operational PTI, they remain crucial for oversight integrity. This tiered framework not only informs the proportional deployment of monitoring technologies but also lays the groundwork for transparent digital governance. Furthermore, the model provides foundational insights for adapting stakeholder oversight schemes in more complex contexts, such as LNG terminals or deepwater operations, where behavioral governance plays an increasingly critical role.

5- Conclusion

This study introduced the Stakeholder Engagement-based Moral Hazard Analysis Model (SEMHAM), a semi-quantitative framework designed to assess stakeholder behavior and exposure to moral hazard in FPSO-tanker oil transfer operations. By applying the engagement metrics Occurrence Frequency Value (OFV), Responsibility Weight Value (RWV), Critical Role Value (CRV), and Process Impact Value (PIV) across eight stakeholder roles, the model generated a Total Involvement Percentage (PTI) score. The highest PTI score reached 82.4% for the FPSO crew, confirming their dominant operational influence and high moral hazard potential in offloading operations.

From a systems design perspective, SEMHAM integrates behavioral governance into digital control systems. By mapping PTI scores to tiered risk levels, the model supports the implementation of targeted oversight mechanisms, such as IoT-based monitoring, blockchain-secured logging, and smart contract execution. This offers a structured and scalable method to translate stakeholder dynamics into an enforceable digital accountability framework. Regarding broader applicability, the modular structure of SEMHAM allows its deployment in other offshore and energy supply chain contexts, including LNG terminals, subsea well operations, and multiparty shipping contracts. Its capacity to identify latent governance gaps across varying degrees of automation and operational complexity makes it a versatile tool for evolving maritime and energy landscapes.

Ultimately, this model provides a novel contribution by offering a formalized response to the challenge of moral hazard in FPSO-tanker operations, a domain in which such behavioral vulnerabilities have often been underrepresented in prior models. SEMHAM not only fills a critical methodological gap, but also paves the way for proactive moral hazard mitigation through stakeholder-centered design, positioning it as a foundational framework in digital risk governance.

5-1- Limitations and Future Work

Moreover, the applicability of SEMHAM to more complex offshore energy projects, such as LNG terminals and deepwater operations, offers an opportunity for methodological expansion. In such settings, stakeholder networks are more extensive, automation levels are higher, and risks are distributed across longer value chains. SEMHAM's indicator-based structure of SEMHAM supports such scalability by allowing the inclusion of additional roles and customized engagement weights. However, adapting SEMHAM to LNG contexts would require modifications to the stakeholder-activity matrix and integration with advanced digital controls, such as Digital Twins or AI-based predictive algorithms. Therefore, future developments should focus on refining SEMHAM's dimensions of SEMHAM and testing it in LNG-related scenarios to ensure its compatibility and analytical reliability.

In addition to scalability challenges, this study also relied on expert judgment to derive several stakeholder indicator values, particularly RWV, CRV, and PIV. Although five experts with over a decade of relevant field experience participated in the scoring and classification process, this limited number may constrain the generalizability across other offshore domains. Future research should, therefore, consider expanding the expert panel and reapplying the SEMHAM framework in different operational contexts to assess indicator consistency. Nevertheless, the structured scoring approach, diverse expertise, and cross-validation steps helped preserve objectivity in model development.

6- Nomenclature

Term/Symbol	Full Form/Name	Description
FPSO	Floating Production Storage and Offloading	A floating facility used for offshore oil production, storage, and offloading to tankers.
SEMHAM	Stakeholder Engagement-based Moral Hazard Analysis Model	A semi-quantitative model designed to assess stakeholder behavior and risk of moral hazard in offshore oil transfers.
PTI	Percentage of Total Involvement	A composite index that reflects how involved each stakeholder is, used to assess dominance and risk exposure.
OFV	Occurrence Frequency Value	Measures how frequently a stakeholder is involved in operational activities.
RWV	Responsibility Weight Value	Reflects the importance of a stakeholder's tasks, based on predefined criticality levels.
CRV	Critical Role Value	Evaluates the stakeholder's influence in decision-making or control roles within the operation.
PIV	Process Impact Value	Assesses the operational impact if a stakeholder fails to perform their role.
IoT	Internet of Things	A network of interconnected sensors/devices used for real-time monitoring of flow, pressure, and anomalies.
LUC	Loading/Unloading Company	Refers to the stevedoring entity responsible for cargo handling at the port.
SAM	Stakeholder Activity Matrix	A matrix that maps stakeholder roles to operational tasks during pre-transfer, transfer, and post-transfer phases.
w	Weight (Task Criticality Score)	Numerical weight (1–4) representing how critical a task is; used in RWV and PIV.
n	Number of Activities	The total number of activities performed by a stakeholder.
I	Impact Weight	Value representing the severity of operational disruption if the task fails (1–4 scale).
p	Total Impacts	The total number of distinct process disruptions linked to a stakeholder.
r	Role Weight	A score reflecting how critical the stakeholder's decision-making role is. Used in CRV.
i	Stakeholder Index	Identifies the *i-th* stakeholder in calculations.
j, k, l	Indexes	Used for activities (j), decisions (k), and impacts (l) in metric computations.

7- Declarations

7-1- Author Contributions

Conceptualization, H.P.; methodology, H.P.; validation, H.P.; formal analysis, H.P.; investigation, D.M.R.; resources, S.S. and J.S.; data curation, H.P. and D.M.R.; writing—original draft preparation, D.M.R.; writing—review and editing, H.P.; visualization, H.P.; supervision, J.S.; project administration, H.P.; funding acquisition, H.P. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7-3- Funding

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7-4- Institutional Review Board Statement

Not applicable.

7-5- Informed Consent Statement

Not applicable.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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