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Original Article

Environmental Risk Assessment of Hydrocarbon-Rich Sludge of a Gas Refinery Using the Integrated Approach of PMBOK Standard Risk Management and FMEA Technique: A Case Study

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Abstract

Background: The present study aimed to assess the potential hazards of hydrocarbon-rich gas refinery sludge from the South Pars Gas Complex-First Refinery, Iran, and to analyze how these risks could impact the project goals based on the Project Management Body of Knowledge (PMBOK) guidelines.

Methods: Statistical population of this analytical, cross-sectional survey was 31 health, safety, and environment (HSE) experts from the study refinery selected by purposeful sampling. Environmental, health, safety, and technical risks were categorized and identified using the PMBOK guidelines. Delphi method and 5-point Likert scale questionnaire were employed to assess the significance of each risk. Priority one risks within each category were determined using Primavera Risk Analysis version 8.7 software.

Results: Following three Delphi steps, 17 out of 77 primary risks were identified and finalized. The first rank with the highest weight corresponded to time and cost group (the risk of soil contamination via sludge stored in the burn pit due to aliphatic and aromatic hydrocarbons), human resources group (radioactive materials accumulated on the inner surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being hazardous for human health), and quality group (failure to supply equipment and quality control systems and personal protective equipment).

Conclusion: The research findings pinpointed 17 risks within various domains, encompassing time and cost, human resources, quality, contract, scope, and communication. These identified risks necessitate a comprehensive, integrated approach to risk management for effective mitigation and resolution.

Keywords: Risk management, Refinery wastes, Hydrocarbon-rich sludge, PMBOK, FMEA, South Pars Gas Complex-First Refinery

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Introduction

Industrial advances and development plans in the gas industry, despite the numerous advantages they offer to society, also introduce various hazards and risks.[1] In the oil and gas industries, significant amounts of waste are produced, depending on the level of activity, the type of technology employed, the raw materials used, and the presence of recycling systems. Managing the reduction or control of this waste is of vital environmental importance.[2] Therefore, these sectors are obligated to manage the environmental impacts of their operations to establish and validate their adherence to environmentally responsible practices.[3,4] Given that industrial discharges result from distinct chemical and physical processes, and their unregulated release poses significant hazards to both humans and the surrounding ecosystem, it becomes imperative to discern, segregate, and categorize them according to their associated risk levels, employing established codified and standardized criteria, and to promptly ascertain their fate.[5,6]

Gas refineries are significant sources of a wide array of pollutants, encompassing hazardous organic substances present in solid, liquid, and gaseous forms. These pollutants include volatile organic compounds (VOCs), sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), hydrogen sulfide (H_2S), particulate matter, sulfuric acid, aerosols, and more. Moreover, gas refineries rank among the primary contributors to greenhouse gas emissions, notably carbon dioxide (CO_2) and methane (CH_4). Additionally, the wastewater discharged from oil and gas refineries is laden with various chemical constituents, including oil and grease, phenols, sulfides, ammonia, suspended solids, cyanides, and heavy metals. These oils exhibit diverse chemical compositions, comprising saturated acyclic hydrocarbons (paraffins), cyclic hydrocarbons, alkenes, aromatics, sulfur-containing compounds, heavy metals, and others.[7,8] At present, a significant environmental challenge in gas refineries pertains to the accumulation of hydrocarbon-rich sludge as a by-product at the conclusion of processes involving monoethylene glycol (MEG) recycling, condensate stabilizers, and industrial wastewater treatment facilities.

In this regard, risk management and assessment as a fundamental pillar for identifying all health, safety, and environment (HSE) risks, can assist projects in uncovering their critical aspects. Moreover, identifying these critical aspects and categorizing them based on the level of risk will play an effective role in devising appropriate responses, including preventive measures and safeguarding the production environment.[9]

Currently, various standards are employed in the field of project management across different countries. One of the most reputable and globally accepted project management standards is the Project Management Body of Knowledge (PMBOK) guidelines.[10] Hence, focusing on the subject of risk management, which is a component of the broader topic of risk discussed in the PMBOK, can play a significant role in recognizing, assessing, and managing risks related to health, safety and environment.[10]

Numerous research efforts have been conducted in this field. For example, one study identified the challenges associated with implementing project control processes at the Iranian South Oil Company, following the PMBOK standard, and offered suitable solutions.[11] Their findings revealed that the primary challenges included financial issues, a lack of familiarity, and inadequate infrastructure. The solutions proposed primarily focused on cost-saving measures and structural construction. In another case study, researchers aimed to optimize risk management in financial projects related to sewage networks using PMBOK methods.[12] They recognized that financial and political factors played a crucial role in risk identification. A research team developed an integrated HSE risk assessment model based on the PMBOK standard.[13] Their results indicated that among the four groups of HSE risks in the Work Breakdown Structure (WBS), the HSE risk associated with the construction project's cost was considered a high-risk area. The main source of risk was identified as the failure to allocate costs for hiring supervisors, experts, and HSE officers in alignment with the project phases. Furthermore, a study utilized PMBOK guidelines to investigate project communication management within the organization during a case study at the National Gas Company of Lorestan Province, Iran.[13] The outcomes revealed that effective communication within the organization reduced delays in processes. Additionally, enhancing communication management improved all knowledge areas outlined in the PMBOK Guide, resulting in reduced time and cost, optimal resource utilization, and increased organizational efficiency and sustainability. Lastly, researchers delved into time and risk management modeling based on PMBOK principles in oil projects and proposed improvement solutions.[14] Their findings highlighted that idealistic planning, a lack of consideration for actual conditions, neglecting the timing of activities in relation to potential risks, and ignoring project control points and the critical path were key factors contributing to project delays.

In a study, the risks of a refinery megaproject were assessed using ISO 31 000 and PMBOK.[15] The study established a risk limit for the project, which was set at 5% of the total investment costs. In other words, if the current stage consumed 5% of the annual budget, it indicated the project's level of riskiness. During the phases of risk identification and qualitative risk analysis, the study identified 170 risk events. These risk events had a 21% probability in the categories of strategy and planning, 4% in the compliance aspect, and the remaining 54% in the operation/infrastructure aspect. According to their research hypotheses, the study concluded that the project development stage carried a higher risk compared to the implementation stage. Notably, the high-risk category was linked to business strategy risk. Their results demonstrated that using both PMBOK and ISO 31000 frameworks for risk management complemented each other. A study examined the utilization of the project risk management process.[16] In this context, they conducted a case study in Bangalore, India, and introduced a risk structure composed of 9 risks and 39 risk factors, which are typically present in projects. This structure was developed by reviewing the literature and incorporating recommendations from experts. Another study assessed the application of failure modes and effects analysis (FMEA) as a risk management tool in information and communication technology projects, aligning with PMBOK guidelines.[17] The research indicated that FMEA is a valuable tool for enhancing risk quality analysis and contributing to the overall success of a project. A study employed risk management tools rooted in FMEA and PMBOK principles in a practical case study.[18] This approach was applied during the implementation of enterprise resource planning (ERP) at the largest Brazilian postal and logistics services. The study found that the proposed model was highly effective in identifying and categorizing risks. Furthermore, this model facilitated the documentation of strategies and action plans needed to address these risks.

On one hand, some of the undeniable consequences of accidents in projects, such as their impact on project timing, quality, cost, workforce, and the organization's position, have often been either neglected or addressed in a one-dimensional manner in previous studies. By adopting a comprehensive project management perspective in risk assessment, combined with multidisciplinary research, we can achieve greater success in project implementation and risk management. On the other hand, it is essential to apply a project management approach when organizing and managing environmental and health risks in the oil and gas industry. Given the environmental and health risks associated with hydrocarbon-rich gas refinery sludge produced by the South Pars Gas Complex (SPGC) - First Refinery (Phase I), this current research aims to address and manage these environmental challenges. It seeks to provide an integrated model for managing environmental and health risks associated with hydrocarbon-rich gas refinery sludge, following the PMBOK standard.

Materials and Methods

This research is applied in terms of purpose, analytical and cross-sectional in terms of nature and survey in terms of method in the time frame of 2020-2022 in South Pars Gas Complex-First Refinery located in the southeast of Iran (Figure 1).

The statistical population consisted of HSE and environmental experts as well as managers of the refinery studied, who were selected by purposeful sampling, with a total of 31 subjects. The sample size was estimated to be 30 based on Cochran's formula as follows (equation 1):

$$n = \frac{\frac{t^2 pq}{d^2}}{1 + \frac{1}{N}\left(\frac{t^2 pq}{d^2} - 1\right)} \quad (1)$$

Where, p = 0.5, the probability of the presence of the attribute, q = 0.5, the probability of the absence of the attribute, t = 1.96, the degree of confidence, d = 0.05, the probability of error.

The steps of collecting and analyzing research data have been presented in Figure 2:

Through a combination of library research and field studies, the risks associated with hydrocarbon-rich sludge in the refinery under investigation were identified. Subsequently, these risks were categorized according to the PMBOK standard, which includes dimensions such as time, cost, human resources, quality, contracts, scope, and communication. In this research, the identification of risk sources, determination of risk factors and criteria for the risk matrix, and the assessment of environmental and health risks were accomplished using pertinent data. This data encompassed information related to refinery projects, specified requirements, obligations, checklists from prior projects, recorded risks, existing reports, incident statistics, historical exposure to common risks, health damage statistics, environmental costs attributed to project activities, the type and quantity of effluents in various refinery units, their collection and maintenance procedures, and the healthcare system and its management within the complex. The analysis and categorization of these findings were performed in alignment with the PMBOK theory, which encompasses six key processes: risk management planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning, and risk monitoring and control.

Each item's consequence is determined by multiplying the total sum of severity items by their weighing factor (WF(. The 1st, 2nd, 3rd, 4th, and 5th levels of consequences correspond to the final scores of consequences within the ranges of 1-4, 5-8, 9-12, 13-15, and 16-19, respectively. To classify risk levels as a decision-making criterion, control actions and recommendations were drawn from one of the most common methods, which includes (1) low-risk level

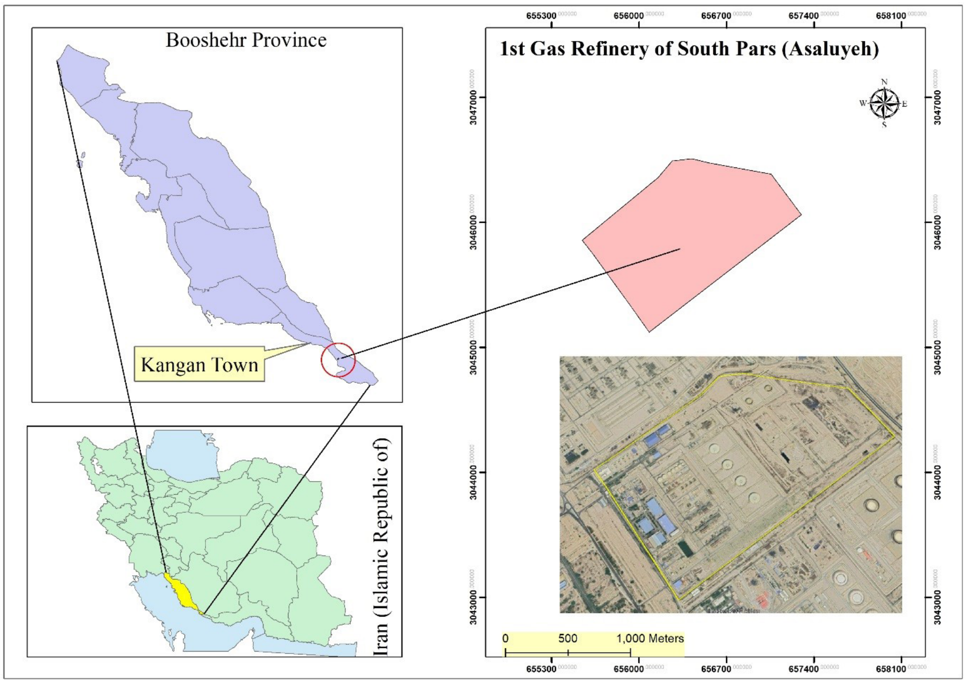

Figure 1. Geographical Location of South Pars Gas Complex-First Refinery, Iran

(the green area), (2) medium-risk level (the yellow area), and (3) high-risk level (the red area).[17,18] Additionally, the risk matrix has been displayed in Table 1.

In this study, responses proposed for each of the four levels of the risk matrix, ranging from 1 to 4, are as follows:

- Risks that can be managed by existing procedures (no need for control action).
- Risks that require the creation of precise methods and awareness.
- Risks that have a high priority in need of control action.
- Risks that require immediate action.

After following the aforementioned steps outlined in the PMBOK standard, a project management roadmap has been developed for the personnel involved in the studied refinery. This roadmap is designed to be adaptable to the organization's specific needs and efficiently utilize all allocated resources, including budget, time, and human resources, for the optimal management of environmental and health concerns related to sludge generation. In the next step, using a questionnaire, environmental experts were asked to list the risks of each index using their knowledge, experience and expertise in cooperation with the panel members (HSE experts of the refinery). To determine the importance of risks, a questionnaire and the Delphi method were reintroduced to the refinery experts. They were requested to assign an importance coefficient to each risk using a 5-point Likert scale. Subsequently, Primavera Risk Analysis version 8.7 software was employed to identify the top-priority risks within each category of indicators. The research steps are illustrated in Figure 3.

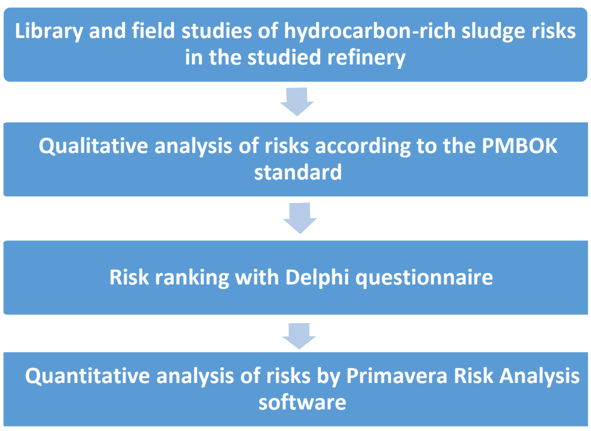

Figure 2. Flowchart of Research Steps

Results and Discussion

Identifying the Risks of Hydrocarbon-Rich Sludge Produced in the Refinery Studied Based on the PMBOK Standard

The results of the three rounds of Delphi, which included increasing consensus indices, are summarized in Table 2. In the first round of Delphi, the panel members identified many of the factors extracted from successful research as having a high and very high impact on the model's design. A total of 77 risks were identified for hydrocarbon-rich sludge produced in the studied refinery, and the Kendall rank correlation coefficient for member responses on these 77 risks was calculated to be 0.187.

In the second round, as a precautionary measure, all the risks obtained from theoretical sources, as well as those suggested by panel members, were presented alongside the average scores from the first round and each member's previous opinions to the expert panel. Out of the initial 77 risks presented in the second round, 17 were recognized by the panel members as having very high importance, signified by an average score exceeding 3.5. The Kendall rank correlation coefficient for member responses regarding the order of these 77 risks, which held high and very high importance coefficients in this round, was calculated to be 0.414.

In the third round, as all risks had received high or very high importance coefficients, indicated by an average score greater than 3.5, based on expert evaluations, no risks were eliminated. The Kendall rank correlation coefficient for member responses concerning the order of risks with high and very high importance in this round was calculated at 0.579. Following standard Delphi methodology and in alignment with the increased quantitative statistical values and specific consensus indicators observed across the three Delphi rounds, the need for a fourth round was deemed unnecessary. Consequently, in agreement with the panel, the Delphi process was formally concluded. The Kendall rank correlation coefficients in the third round were all higher than 0.7, which indicates a strong consensus among experts regarding the identified risks.

The obtained results led to the identification of 17 risks (Table 2). Similar to the results of previous studies,[19] the integrated model of PMBOK and FMEA has caused significant improvements in risk identification and management. An earlier research demonstrated the success of integrating PMBOK and FMEA models, particularly in risk identification and classification.[18]

Table 1. Integrated Risk Assessment Matrix Based on the PMBOK Method[19]

		Consequences				
		Negligible 1	Marginal 2	Moderate 3	Critical 4	Catastrophic 5
Likelihood	Frequent 5	5	10	15	20	25
	Probable 4	4	8	12	16	20
	Occasional 3	3	6	9	12	15
	Possible 2	2	4	6	8	10
	Remote 1	1	2	3	4	5

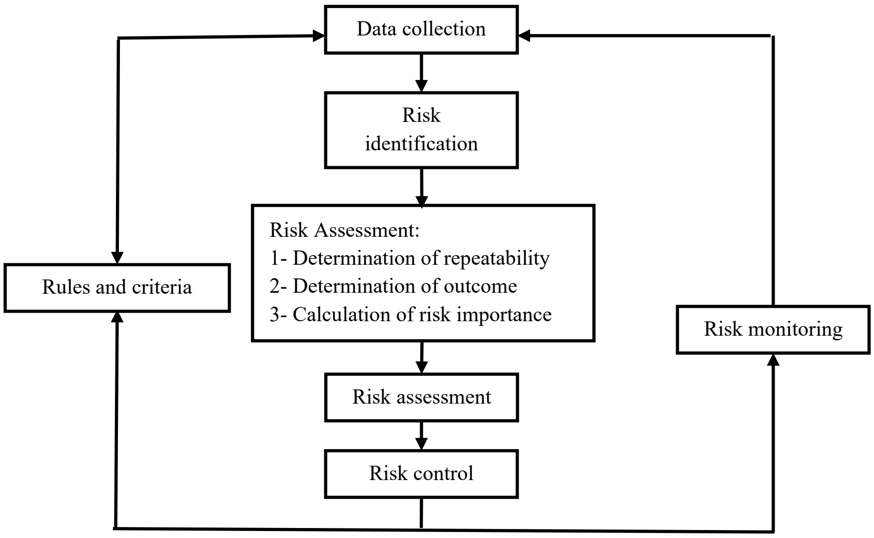

Figure 3. Flow Chart of Risk Management Steps

Table 2. Comparison of the Results of the Consensus Indices of the Three Rounds of Delphi

PMBOK-Based Classification	Type of Risk	Risks	Kendall Rank Correlation Coefficient		
			Delphi R-1	Delphi R-2	Delphi R-3
Time and cost	Environmental	Annual release of high volume of carbon dioxide and sulfur dioxide into the environment	0.275	0.587	0.787
		High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination	0.225	0.504	0.731
		High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.347	0.497	0.767
		Absence of a supplementary treatment system for the refinery effluents	0.272	0.536	0.827
		Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge	0.213	0.500	0.722
	Health	Potential possibility of natural radioactivity pollution in burn pit	0.084	0.628	0.787
	Technical-Safety	Failure to comply with the rules related to the design, construction and emptying of pits	0.438	0.606	0.818
	Environmental	Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons.	0.227	0.612	0.832
		Risk of groundwater pollution due to sludge leakage after storage in burn pit	0.108	0.697	0.909
Human resources	Health	Direct contact of workers with sludge during collection, discharge, repair and washing of equipment	0.300	0.496	0.973
		Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health	0.238	0.559	0.817
		Causing respiratory problems for the staff supervising the operation and the staff of evaporation ponds	0.310	0.663	0.874
Quality	Technical-Safety	Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery	0.207	0.638	0.833
		Failure to provide equipment and quality control systems, personal protective equipment	0.258	0.663	0.874
Contract	Technical-Safety	Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.156	0.377	0.788
Scope	Technical-Safety	No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities	0.179	0.603	0.782
Communication	Technical-Safety	Political and economic sanctions and difficulty in providing the equipment needed for the refinery	0.225	0.559	0.808

This integrated model also supports the development of strategies and action plans for risk response, aligning with the findings of this study. Additionally, another study has further affirmed the effectiveness of the combined FMEA and PMBOK approach.[20]

Quantitative Analysis of the Risks of Hydrocarbon-Rich Sludge Produced in the Studied Refinery

This stage in the risk management process is the transition from a well-defined plan to a potential scenario. It aims to quantify and determine the precise impact of risks on project objectives. During this phase, risks are integrated into the project schedule to elucidate their effects on the entire project. This process typically occurs both before and after the risk response planning stage to evaluate the effectiveness of the plans. For instance, if the projected cost of preventing undesirable risks exceeds the expected cost of their occurrence, this stage helps assess the incurred loss, and if necessary, adjustments can be made to the risk response planning. The results related to the quantitative analysis of the risks of hydrocarbon-rich sludge produced in the refinery studied have been shown in Table 3. As can be seen, the first rank with the highest weight was assigned to time and cost group (the risk of soil contamination via sludge stored in the burn pit due to aliphatic and aromatic hydrocarbons), human resources group (radioactive materials accumulated on the inner surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being hazardous for human health), and quality group (failure to supply equipment and quality control systems and personal protective equipment). The top-ranked risk, with a score of 3.384, is the failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge. Following closely as second priority risks, with scores of 1.632, are the risks associated with the high volume of sludge stored in the burn pit, where there is a possibility of leakage and potential soil and groundwater contamination. The third priority risks, with scores of 1.314 and 1.152, pertain to the absence of a supplementary treatment system for the refinery effluents and the high volume of waste resulting from the storage and refining of hydrocarbon-rich sludge produced in the studied refinery, respectively. Additionally, there are risks related to the annual release of a high volume of carbon dioxide and sulfur dioxide into the environment, with a score of 0.824, and the failure to supply equipment and quality control systems, including personal protective equipment, with a score of 0.72. All other risks have been categorized as fourth priority risks (as indicated in Table 3).

The final phase of risk management involves taking necessary measures to minimize the impact of negative risks on project objectives. Table 3 outlines these measures and the designated individuals or departments responsible for implementing agreed-upon responses to the risks associated with the production of hydrocarbon-rich sludge in the studied refinery. Four strategies for addressing negative risks are identified: avoidance, transference, mitigation, and acceptance. The results presented in Table 3 underscore the critical importance of avoiding the risk of "Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge," which is the most significant risk identified in this research. In this regard, the HSE project team is responsible for conducting a thorough review and providing training for personnel in the workplace, focusing on sludge management, component measurement, and monitoring and inspection. By taking these steps, the project's objectives can be shielded from the adverse effects of this risk. For risks related to the hydrocarbon sludge of the refinery, only one measure has been proposed for the risk of "Political and economic sanctions and difficulty in obtaining the required refinery equipment." In this case, the project management team should seize the opportunity to work toward self-sufficiency without making any alterations to the project plan. According to the results obtained in the current research, the management strategies for monitoring and reducing the environmental and health risks of the sludge in South Pars Gas Complex (SPGC)- First Refinery (Phase I) have been presented as follows:

Various methods are employed to address the risk associated with the "Annual release of a high volume of carbon dioxide and sulfur dioxide into the environment." These methods include: Catalytic removal of sulfur dioxide from flue gas.[21] Contacting flue gases with an alkaline absorbent, such as lime or limestone. Eliminating sulfur dioxide pollutants from the air using liquid ammonia and converting them into ammonium sulfate fertilizer.[22]

Following the identification of sources with high greenhouse gas emissions, plans have been developed to address this issue. The implementation of these plans is expected to result in a substantial reduction of these gases. The proposed strategies include: (1) Reducing flaring, (2) Enhancing energy efficiency, (3) Implementing carbon capture and storage (absorbing and storing CO2), (4) Utilizing waste heat recovery from the exhaust gases of gas turbines employed in refineries.[23]

To control the risk of "High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination", a large volume of sludge can be reduced by recycling. Some of the sludge recycling techniques in order to reduce its volume for hydrocarbon or fuel extraction include solvent extraction, centrifugal purification, application of surfactant for enhanced oil recovery, sludge pyrolysis, microwave radiation, ultrasonic irradiation, freezing and thawing and foam flotation.[24]

To manage the risk of "High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery, one of the solutions is the method of recycling hydrocarbon sludge to the cycle of production and processing of its hydrocarbon materials to produce other products.

Table 3. Quantitative Analysis of the Risks of Hydrocarbon-Rich Sludge Produced in the Studied Refinery and Risk Response Planning

PMBOK-Based Classification	Type of Risk	Risks	Risk Importance Coefficient	Risk Level	Prioritization	Response Strategy	Risk Response	Response Person
Time and cost	Environmental	Annual release of high volume of carbon dioxide and sulfur dioxide into the environment	0.824	M	3	Mitigation	Establishing regular and periodic inspection systems	Project team-HSE
		High volume of sludge stored in the burn pit, where there is a possibility of leakage and soil and groundwater contamination	1.632	H	2	Mitigation	Inspection and greater accuracy of insulating and covering pits to prevent leakage and pollution of soil and groundwater	Project team-HSE
		High volume of waste resulting from storage and refining of hydrocarbon-rich sludge produced in the studied refinery	1.152	H	2	Mitigation	Accuracy and review and training of people at work with sludge, measuring, monitoring and inspecting components	Engineering team-HSE
		Absence of a supplementary treatment system for the refinery effluents	1.314	H	2	Avoidance	Construction of supplementary treatment system	Engineering team
		Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge	0.606	M	4	Mitigation	Visiting and creating proper insulation of lands	Project team-HSE
	Health	Potential possibility of natural radioactivity pollution in burn pit	0.45	M	4	Mitigation	Use of personal protective equipment	Project team-HSE
	Technical-Safety	Failure to comply with the rules related to the design, construction and emptying of pits	0.348	M	4	Avoidance	Establishing a suitable design, repair and maintenance	Engineering team-HSE
	Environmental	Risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons.	0.344	M	4	Mitigation	Regular and periodic monitoring of the surrounding soils	Project team-HSE
		Risk of groundwater pollution due to sludge leakage after storage in burn pit	0.276	M	4	Mitigation	Regular and periodic monitoring of the surrounding wells	Project team-HSE
Human resources	Health	Direct contact of workers with sludge during collection, discharge, repair and washing of equipment	0.252	M	4	Mitigation	Periodic examinations, inspection and more accuracy	Project team-HSE
		Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health	0.176	M	4	Avoidance	Use of appropriate and standard personal protective equipment (gloves and masks)	Project team-HSE
		Causing respiratory problems for the staff supervising the operation and the staff of evaporation ponds	0.042	L	4	Avoidance	Periodic examinations, inspection and more accuracy	Project team-HSE
Quality	Technical-Safety	Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery	3.384	H	1	Avoidance	Accuracy and review and training of people at work with sludge, measuring, monitoring and inspecting components	Project team-HSE
		Failure to supply equipment and quality control systems, personal protective equipment	0.72	M	3	Avoidance	Periodic maintenance and inspections of facilities and connections, sealing connections and fixing leaks	Project team-HSE
Contract	Technical-Safety	Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery	0.696	M	4	Mitigation	Planning for technical and economic comparison to use technology	Engineering team

Table 3. Continued

PMBOK-Based Classification	Type of Risk	Risks	Risk Importance Coefficient	Risk Level	Prioritization	Response Strategy	Risk Response	Response Person
Scope	Technical-Safety	No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities	0.576	M	4	Mitigation	Holding identification and educational classes	Project team-engineering team
Communication	Technical-Safety	Political and economic sanctions and difficulty in providing the equipment needed for the refinery	0.558	M	4	Acceptance	Trying to be self-sufficient	Project Management

Regarding the risk of "Absence of a supplementary treatment system for the refinery effluents", the existing treatment process should be significantly upgraded and equipped with a biological treatment unit and physical absorption units.

To control the risk of "Contamination of the lands of the gas refinery with burnt oils, catalytic beds, hydrocarbon sludge, amine sludge, soda sludge and refinery sludge", the use of plants resistant to petroleum compounds can be a suitable and efficient and at the same time economical method to reduce or decompose toxic organic compounds of sludge in the soil of the surrounding lands.

Regarding the risk of "Potential possibility of natural radioactivity pollution in burn pit, a research team in the South Pars Refinery clearly showed that it is necessary to take special measures and spend money and budget to protect employees when entering these places, and it is vital to equip those spaces with drainage, washing, transportation and disposal of collected sludge.[25]

To avoid risk effects of "Failure to comply with the rules related to the design, construction and emptying of pits", it is essential to comply with the relevant standards when designing and building a burn pit, to use modern technologies and to use nanotechnology to purify and safe the pollution caused by the construction of the pit and to comply with the HSE rules related to the process of emptying the pit.

According to the probability of "The risk of soil pollution due to the storage of hydrocarbon-rich sludge produced in the studied refinery in the burn pit due to the presence of some aliphatic and aromatic hydrocarbons", at least two layers with a leak detection system between the layers should be used to enclose the pit to minimize the possibility of sludge leaking into the surrounding soil. The soil of the pit should be tested according to the ASTM-2487 standard (sampled at least three times).[26] There should not be any stone fragments larger than 0.75 inches in diameter in the pit. The HSE group must continuously monitor the burn pit site to ensure that the materials enclosing the pit are not cracked.[27]

To avoid "Risk of groundwater pollution due to sludge leakage after storage in burn pit, when locating burn pits or sludge evaporation ponds, the selection of geologically vulnerable sites should be avoided, such as karst areas and gravel terraces that form subsurface aquifer layers. If a burn pit is used to store hydrocarbon-rich sludge, at least two layers should be used during the construction of the burn pit along with a leak detection system between the layers to enclose the pit. The burn pits should be built at a distance of 100 feet from swamp lands, 500 feet from private water sources and 1000 feet from public water sources. The minimum internal slope should be 3 (horizontal) and 1 (vertical) and its maximum should be 2 (horizontal) and 1 (vertical). The floor of the burn pit should be 20 inches above the upper seasonal groundwater level of the area. There should not be stone pieces with a diameter greater than 0.75 inches in the burn pit.[27]

To prevent and reduce the effects of risks caused by "Direct contact of workers with sludge during collection, discharge, repair and washing of equipment", it is necessary to prevent and control accidental releases of fluids through regular inspection and maintenance of storage and transmission systems, including continuous monitoring of pumps, valves and other potential leakage points, to implement leakage response programs, to provide sufficient capacity to store process fluids for maximum process recovery and thus prevention of excessive discharge of process fluids in the oily wastewater discharge system. Moreover, design and construction of sewage maintenance ponds and hazardous substances with appropriate anti-penetrating surfaces is necessary to prevent contaminated water from penetrating soil, groundwater and human damage. On the other hand, it is essential to separate sewage and ponds containing sewage and hazardous substances.

To avoid the hazards caused by Accumulation of radioactive materials deposited on the internal surfaces of pipes, valves, pumps, heat exchangers, tanks, boilers and other equipment and the risk of these materials being dangerous for human health, the training guide should be designed to inform various types of personal protective equipment, firefighter protective clothing, existing respiratory protective equipment as well as many other types of protective equipment, including crash and safety belts and vehicles. Optimizing radiation protection involves the installation of lead shields for workers. However, during certain operations, specific precautions should be taken. It is essential to avoid making any significant changes in worker concentration periods in different areas of the refinery without conducting a prior radiological evaluation.

To control the risk of causing respiratory problems for the staff supervising the operation and the staff of evaporation ponds, it is crucial to implement new technologies in the refinery's process units. Continuous monitoring should be conducted to reduce or eliminate the flaring of high volumes of acid gases, which can negatively impact the health of employees. The industrial units within the refinery must provide a self-declaration report on flue gas and measure the ambient air composition. Additionally, existing units should be mandated to install an online monitoring system for constant observation and Internet-based monitoring, as outlined in the written plan by the General Environment Department. These measures are essential for reducing air pollutants in the working environment of refinery employees.

In order to prevent the hazards resulting from the failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery, several actions should be taken. The government is mandated to annually review the requirements and standards concerning hydrocarbon sludge management and other ongoing processes in gas refineries. This review process should also include optimizing implementation methods to align with technological advancements. The HSE group plays a vital role in this context. They need to actively monitor the storage and discharge of hydrocarbon sludge in the burn pit, ensuring compliance with environmental standards. Furthermore, the HSE group's experts should diligently inspect the materials that enclose the burn pit to confirm that there are no cracks or vulnerabilities in the containment structure.[24] These combined efforts are essential in preventing and mitigating the associated environmental and health risks.

To prevent the hazards arising from "Failure to provide equipment and quality control systems, personal protective equipment," it is imperative that the instruments and equipment are adequately supplied and maintained. They should be kept in a clean and serviceable condition to minimize the likelihood of breakdowns and ensure that personal protective equipment is readily available and in good working order. This proactive approach helps mitigate potential risks and enhances overall safety and quality control.

To mitigate the hazards associated with "Ignoring the costs of storage and refining of hydrocarbon-rich sludge produced in the studied refinery," it is vital to create an accurate estimate of the volumes and associated costs. Subsequently, a technical evaluation committee should be established at the refinery to provide a realistic expense assessment. In a risk assessment for the cable bridge construction project based on the PMBOK standard in Sari city, Iran, cost and time management emerged as the riskiest areas within the PMBOK framework. This risk led to deviations from the project's planned schedule and budget, as specified in the contract. As a result, it is advisable to identify and address these high-risk areas early in the planning phase to effectively implement preventive measures. Contractors should also consider appropriate contract terms and conditions as a project baseline.[28]

To prevent the hazards associated with "No recognition of the risks resulting from hydrocarbon-rich sludge produced in the studied refinery and related activities," several steps should be taken. First, organize training sessions for workers to enhance their understanding of the scope of refinery activities and the associated risks. Additionally, when selecting contractors, prioritize those with appropriate ratings, a strong project portfolio, and extensive experience and knowledge of refinery operations. These measures will help improve awareness and preparedness for managing the risks associated with hydrocarbon-rich sludge in the refinery.[28]

To mitigate the risk associated with "Political and economic sanctions and difficulty in providing the equipment needed for the refinery," certain measures should be implemented. It is essential to establish protocols for storing goods, equipment, and chemicals required by refineries and water treatment plants. Actively engage with intermediary companies, and simultaneously negotiate with several suppliers that are approved by the project management headquarters within the refinery. To address this risk, various strategies can be adopted, including purchasing goods with cash payments that incorporate overhead costs, utilizing letters of credit to acquire supplies from neighboring countries and arranging re-shipments by sea or air to obtain similar goods and equipment from other regions such as China and Eastern Europe.[29]

Conclusion

The outcome of the risk assessment for hydrocarbon-rich sludge management in the gas refinery, conducted according to the PMBOK standard at the South Pars Gas Complex-First Refinery in Iran, unveiled a total of 77 identified risks, of which 17 were deemed highly significant. These 17 risks were further categorized into six distinct risk groups, encompassing time and cost, human resources, quality, contract, scope, and communication. These risks were then prioritized into four groups, with the highest priority assigned to the quality risk concerning "Failure to comply with HSE environmental standards during the management of hydrocarbon-rich sludge produced in the studied refinery," which presented a considerable risk. The findings of this research emphasized the paramount importance of addressing these risks associated with hydrocarbon sludge. The top priorities included risks related to soil contamination due to hydrocarbons in sludge storage, the accumulation of radioactive materials in equipment, and the challenges associated with providing equipment, quality control systems, and personal protective gear. The study highlights the efficacy of applying various facets of the PMBOK standard in risk assessment to effectively identify, evaluate, and manage environmental and health risks linked to sludge production. It is evident that mitigating these crucial risks and controlling their impact on project timelines, costs, and quality can significantly contribute to achieving project objectives. Consequently, it is recommended to appoint a dedicated risk management and control manager to oversee the entire risk management process in the refinery's sludge section.

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Competing Interests

The authors declare that they have no conflict of interest.

Ethical Approval

There was no need for ethical considerations in conducting this study.

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