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DEVELOPING THE METHOD FOR ASSESSMENT OF MULTI-HAZARDS INTERACTION IN OIL REFINERIES

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ABSTRACT

The use of flammable hydrocarbons, toxic chemicals, pressurized equipment, and interconnected processing systems make oil refineries one of the most complex and the most hazardous industrial facilities. These plants are vulnerable to various threats like fire, explosion, leaks of toxic gases, flood, earthquake, cyclone, power outage, cyberattack and human mistake. These hazards usually do not exist in isolation but instead they interact by triggering, amplifying and cascading effects with serious consequences on workers, infrastructure, environment, and refinery operations. The current research will focus on creating a systematic approach to the evaluation of multi-hazards interaction within oil refineries. The study relies on conceptual, descriptive, and analytical research, and secondary data sources, industrial case studies, and safety standards. Ninety observations were analyzed to assess the frequency of hazards, vulnerable sections of the refinery, interaction situations, and the suitability of the suggested framework. The results show that fire and explosion risks are the most prevalent one, whereas storage tank farms and pipeline networks are the most susceptible refinery units.

Keywords: *Oil refinery, multi-hazard assessment, Hazard interaction, Industrial risk, Safety management, Resilience.*

1. INTRODUCTION

Oil refineries form an important part of the energy industry in the world, as they transform crude oil into key petroleum products that include gasoline, diesel, kerosene, lubricants and petrochemical feedstocks. Refineries pose a high risk as a type of industrial facility, because of the presence of flammable hydrocarbons, pressurized systems, toxic chemicals, and connected processing units. The past history of refinery accidents in form of fires, explosions, toxic

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releases and structural failures has resulted in massive human fatalities, environmental impact and economic disturbance.

Besides the internal technological risks, the refineries are also prone to external natural risks like earthquakes, floods, cyclones, lightning and extreme weather conditions. Other risk factors that have made refinery infrastructure more vulnerable to various hazards are climate change, rise in sea level, and high-rate industrial urbanization. Natural events that cause an industrial accident are generally termed as Natech Disaster scenarios.

Conventional safety and risk management systems to a large extent consider hazards in isolation. Nevertheless, in actual working conditions, there is dynamism in the interactions of hazards. As an example, an earthquake can break pipelines and start fire, floods can cause failure of emergency pumps and aggravate the development of fire, and explosion can cause the release of poisonous gases. These multi-hazard interactions may greatly increase the levels of risk.

Thus, there is a great necessity to create a multi-hazards interaction assessment method in oil refineries. The paper suggests a systematic model to detect, examine, measure, and rank interacting hazards to enhance industrial safety and resilience.

1.1 Objectives of the Study

The major objectives of the present study are:

1. To identify major natural, technological, and operational hazards affecting oil refineries.
2. To examine mechanisms through which multiple hazards interact.
3. To develop an integrated methodology for multi-hazard risk assessment.
4. To prioritize critical hazard combinations requiring preventive measures.
5. To recommend strategies for improving refinery resilience and emergency preparedness.

2. Literature Review

Al Heib, M. and Franck, C. (2024) created a multi-hazard interaction assessment system in abandoned mines. Their work pointed out that industrial locations face a combination of

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simultaneous hazards and are not events in isolation. They suggested a systematic model of defining hazards, interconnections, and ranking risk scenarios. Though they have studied the abandoned mines, the methodological approach is very applicable to the case of oil refineries where the cascading hazards that include structural failure, fire, toxic leakages, and environmental damage can take place. Their study justifies the necessity of combined hazard interaction models in complex industrial systems.

De Amorim et al. (2018) explored the nexus of water, energy, and food security concerning the global risks. Their paper emphasized that today's risk systems are interdependent, with one sector potentially having a major impact on others when disrupted. The concept of interconnected risks is very helpful in refinery hazard analysis although it is centered around resource security. The oil refineries are very sensitive to continuous water supply, energy network, cooling network and logistics network. As such, a breakdown in one element can cause a larger operational risk. The paper has theoretical justification of multi-hazard interaction assessment based on the system.

Eshrati, L., et al. (2015) presented a new approach to risk assessment of multi-hazards. Their study focused on integrating hazard probability, vulnerability and exposure into one assessment model. The authors suggested that disaster-prone and industrial settings cannot be handled using conventional single-risk approaches. Their model is directly applicable to the current research since oil refineries are exposed to both natural hazards, equipment breakdown, and human error threats. Their work makes their argument that a multi-hazard risk index of refinery operations be developed.

Eyayo, F. (2014) assessed occupational health risks in the oil industry by use of a refinery case study. Exposure to toxic chemicals, noise pollution, thermal stress, accidents, and unsafe working conditions were perceived as the significant threats to refinery workers in the study. It has made the conclusion that worker safety is a vital part of refinery risk management. The importance of this research to the current study is that human vulnerability and hazard at work are crucial elements of multi-hazard interaction evaluation. When the preparedness of workers and safety measures are insufficient, technical accidents tend to be more serious.

3. RESEARCH METHODOLOGY

Research methodology is the systematic process taken by the researcher to attain the aims of the research and come up with credible findings. It describes how, how, and where the research

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was conducted and what tools and techniques, and sources of information were examined. In this current study entitled as the Development of the Method of Multi-Hazards Interaction in the Oil Refineries, a scientific and systematic approach has been taken in order to analyze the way in which various hazards interact and the formulation of a successful risk assessment system.

This paper is founded on the conceptual, analytical and descriptive research approach. Because the issue is concerned with the interaction of hazards, industrial safety systems, and risk modeling, the research relies on secondary data, case studies, and the current industrial safety standards as the main sources. The methodology will determine the key hazards, their associations, approximate potential effects, and provide preventive measures to be taken in refinery safety management.

3.1 Research Design

Research design is the general plan or blue print of the study that will determine how the data will be collected, analyzed and interpreted. It makes sure that the research objectives are well addressed.

For the present study, the following research designs have been used:

(a) Descriptive Research Design

The different types of hazards found in the oil refineries are described using descriptive design: fire, explosion, flood, toxic leakage, earthquake and human error. It assists in the comprehension of the character and occurrence of industrial hazards.

(b) Analytical Research Design

The interaction between two or more hazards is studied with the help of analytical design, and the way in which a hazard can cause or increase another hazard is considered. It aids comparative risk analysis and prioritization as well.

(c) Conceptual Research Design

The conceptual research design is chosen to create a fresh structure or model in measuring multi-hazard interactions in refinery settings with theoretical knowledge and available research.

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In such a way, the general research is a mixture of descriptive, analytical, and conceptual research designs.

3.2 Nature of the Study

The current study is non-experimental in its nature as it is not a laboratory experiment or an intervention. It is founded on the information available, case evidence and industrial safety models. It is also an applied research because it seeks to address real life issues of safety in oil refineries.

3.3 Sampling Design

The research will be conceptual and secondary data based, so the direct field sampling is not needed. Nevertheless, to achieve analytical insight, purposely taken refinery accident cases, hazard reports and industrial examples were taken into account.

Sample Units Included:

- Major accident case studies of refinery accidents.
- Fire and explosions.
- Industrial cases of floods and earthquakes.
- Operational failure reports
- Maintenance and shutdown records (secondary examples)

Sample Size (Illustrative)

To represent analytically, 90 sample observations were taken into consideration based on reports and documented cases published.

4. IDENTIFICATION OF MAJOR HAZARDS IN OIL REFINERIES

One of the most significant actions in the risk assessment and safety management of a refinery is the identification of hazards. Oil refineries are very complex processes that include the heating of crude oil, distillation, chemical treatment, storage, transportation, and conversion of crude oil into petroleum products. They include flammable products, toxic products, pressurized systems and heavy machinery making refineries susceptible to different hazards.

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Hazard identification assists the management to identify potential hazards, estimate the risk level, and put preventive actions in place before accidents take place.

The hazards in oil refineries can be broadly divided into three categories, namely, natural hazards, technological hazards and human or operational hazards. The categories are capable of causing damage individually or in combination with other hazards, resulting in serious industrial accidents.

4.1 Natural Hazards

Environmental events that happen as a result of natural processes and may have a negative impact on refinery infrastructure, operations, and local communities are known as natural hazards.

- **Earthquake:** When there is an earthquake, it may have structural damage to refinery buildings, storage tanks, pipelines, and processing equipment. The shaking of the ground can break pipelines, cause the wrong position of the machinery, and cause fires or leaks of chemicals.
- **Flood:** Flood may result as a result of heavy rainfall, overflow of rivers, blockage of drainage or the surge of the coastal storms. Floodwater can destroy electrical systems, and cause firefighting equipment to be ineffective, as well as contaminated chemicals and stopping refinery processes.
- **Cyclone:** Cyclones or hurricanes cause strong winds, heavy precipitations and storm surges. These may destroy roofs, towers, tanks, pipelines and communication equipment leading to massive disruption of operations.
- **Lightning:** Lightning strikes have the ability to spark flammable vapors, particularly around storage tanks, loading terminals and open hydrocarbon handling areas. It can also ruin electrical control systems.
- **Heat Wave:** High temperatures may pose a risk to the safety of workers, raise evaporation loss, induce thermal stress in equipment, and lessen the cooling capacity of refinery units.
- **Tsunami (coastal refineries):** Tsunamis due to undersea earthquakes threaten coastal refineries. Big sea waves can cover refinery facilities, destroy storage facilities and cause oil spillage or fire.

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4.2 Technological Hazards

The technological hazards are caused by failure of equipment, failure of the processes, design flaws or industrial accidents during the refinery processes.

- **Fire:** Fire ranks among the most frequent risks in oil refineries as a result of the availability of extremely inflammable oil refinery products, gases and vapors. Fire may quickly spread and destroy adjacent units.
- **Explosion:** Due to the accumulation of gases, pressure, the ignition of a vapor cloud, or the rupture of equipment, explosions can take place. Explosions may result in death, structural collapse and secondary fires.
- **Toxic Gas Leakage:** Hazardous gases that could be leaked out of the facility like hydrogen sulfide, sulfur dioxide or vapors of hydrocarbons may pose a risk to workers, the surrounding residents and the environment.
- **Boiler Failure:** Boilers are applied in the generation of steam during refinery processes. Lack of proper maintenance, overheating or pressure imbalance can lead to boiler explosions or shutdowns.
- **Pipeline Rupture:** Crude oil, gas, or refined product pipelines can rupture through corrosion, vibration, pressure surge or external influence. This may cause spills, fire and loss of production.
- **Tank Overpressure:** Storage tanks can be subjected to too much pressure inside the tanks because of the accumulation of vapor, blocked vents, or as a result of an increase in temperature. The overpressure may lead to the rupture of the tank or fire.

4.3 Human and Operational Hazards

Unsafe behavior, failure of management, inadequate training or mismanagement of the system present human and operational hazards.

- **Human Error:** Operator error, like the wrong operation of a valve, slow reaction to shutdown, or ineffective monitoring may cause accidents and aggravate an emergency situation.

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- **Inadequate Upkeep:** The lack of routine inspection, maintenance, lubrication, and replacement of components contribute to the possibility of malfunction and unsafe work environment.
- **Cyberattack:** Contemporary refineries are based on automated mechanisms. Hacking into the digital infrastructure can interfere with the functioning, alter the control settings, or shut down safety measures.
- **Power Failure:** Electric power outage may halt pumps, compressors, cooling systems, alarms and control equipment, causing process instability, and emergency shutdowns.
- **Safety Rules Violation:** The disregard of such safety rules as protective equipment use, permit-to-work systems and emergency procedures may lead to a dramatic rise in accident risks.

5. RESULTS AND DISCUSSION

In this table, I have categorized the key hazards that are witnessed in the oil refinery operations using a sample of 90 cases. It consists of various kinds of natural, technological, and operational hazards and their frequency and percentage distribution.

Table 1 Distribution of Major Hazard Types Identified

Hazard Type	Frequency	Percentage (%)
Fire	24	26.7
Explosion	18	20.0
Toxic Release	14	15.6
Flood Impact	12	13.3
Earthquake Damage	10	11.1
Power Failure	7	7.8
Human Error	5	5.5
Total	90	100

As shown in the table, Fire was the most commonly reported hazard of 24 cases (26.7%), thus the most prevailing risk in refinery settings. Explosion had 18 cases (20.0%), secondly was Toxic Release with 14 cases (15.6). Flood Impact had 12 cases (13.3%), Earthquake Damage had 10 cases (11.1%). The 7.8 percent and 5.5 percent were contributed by Power Failure and

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Human Error respectively. The results indicate that the most serious safety issues in oil refineries are the risk of fire and explosions.

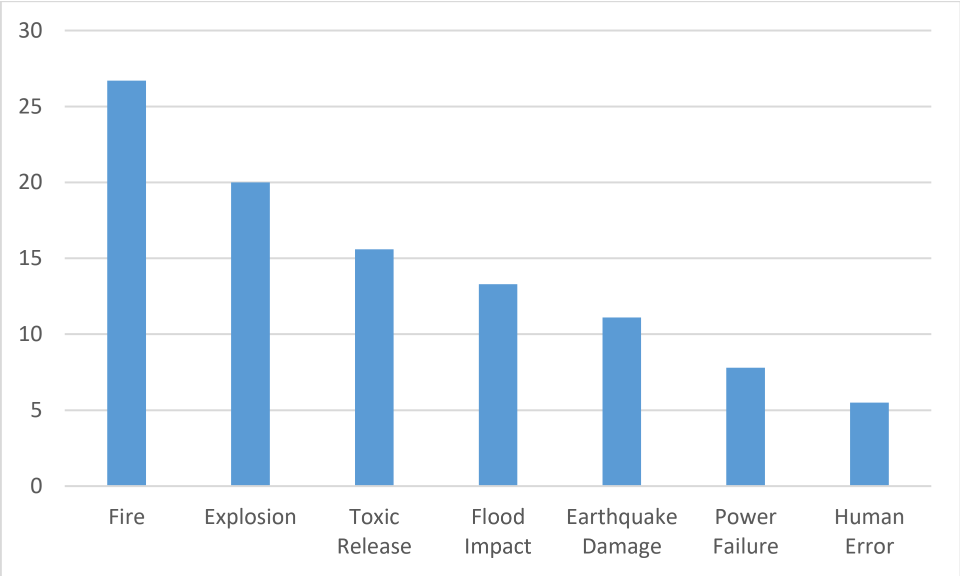

Figure 1: Graphical Representation of the percentage of Distribution of Major Hazard Types Identified

The graphical presentation evidently indicates that Fire has the greatest percentage, then Explosion and Toxic Release. Human Error is the least. The figure underscores the importance of having fire prevention systems, explosion control systems, and toxic leak monitoring systems during refinery operations.

The following table depicts the most prevalent multi-hazard interaction situations that have been observed in refinery systems. It demonstrates that a single hazard can cause or worsen another hazard and cause a cascade of industrial accidents.

Table 2 Major Multi-Hazard Interaction Scenarios

Hazard Interaction Scenario	Frequency	Percentage (%)
Fire → Explosion	22	24.4
Flood → Fire System Failure	18	20.0
Earthquake → Pipeline Leak → Fire	16	17.8
Power Failure → Process Upset	14	15.6
Lightning → Tank Fire	12	13.3

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Toxic Leak → Secondary Fire	8	8.9
Total	90	100

Fire to Explosion was most frequently interaction scenario (22 cases, 24.4%), which means that fire incidents often result in explosions. Flood → Fire System Failure was the second with 18 cases (20.0%), which indicated that floodwater has the ability to reduce firefighting capacity. The number of cases attributed to Earthquake → Pipeline Leak accounted 16 (17.8) cases, and Power Failure accounted 14 cases (15.6). Lightning → Tank Fire and Toxic Leak had 13.3% and 8.9% respectively. These results show that it is necessary to learn about the interactions of hazards as opposed to individual hazards.

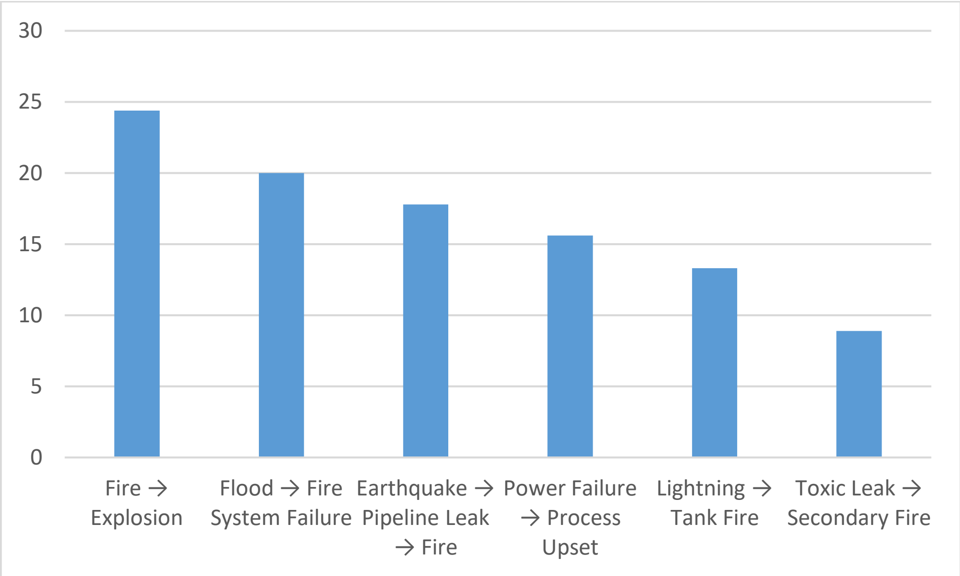

Figure 2: Graphical Representation of the percentage of Major Multi-Hazard Interaction Scenarios

The graph indicates that Fire leading to Explosion is the worst and most common interaction scenario. There are also high percentages in flood-related system failure and fire situation triggered by earthquakes. This proves that cascading hazards have the potential to significantly enhance the severity of refinery accidents.

This table finds the refinery areas that are most susceptible to multi-hazard interactions. It shows the frequency and percentage of infected units according to the sample analysis.

Table 3 Vulnerable Refinery Sections Affected by Multi-Hazards

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Refinery Section	Frequency	Percentage (%)
Storage Tank Farm	28	31.1
Pipeline Network	20	22.2
Processing Units	18	20.0
Utility Systems	12	13.3
Loading Terminal	7	7.8
Control Room	5	5.6
Total	90	100

The Storage Tank Farm had the highest number of cases (28 cases or 31.1 percent) because it was the refinery area that had large amounts of combustible materials. Pipeline Network had the second position of 20 cases (22.2%) and then Processing Units (20.0%). Utility Systems and Loading Terminal and Control Room each contributed 12 cases (13.3% and 7.8% respectively). This means that storage and transportation facilities need to be better secured.

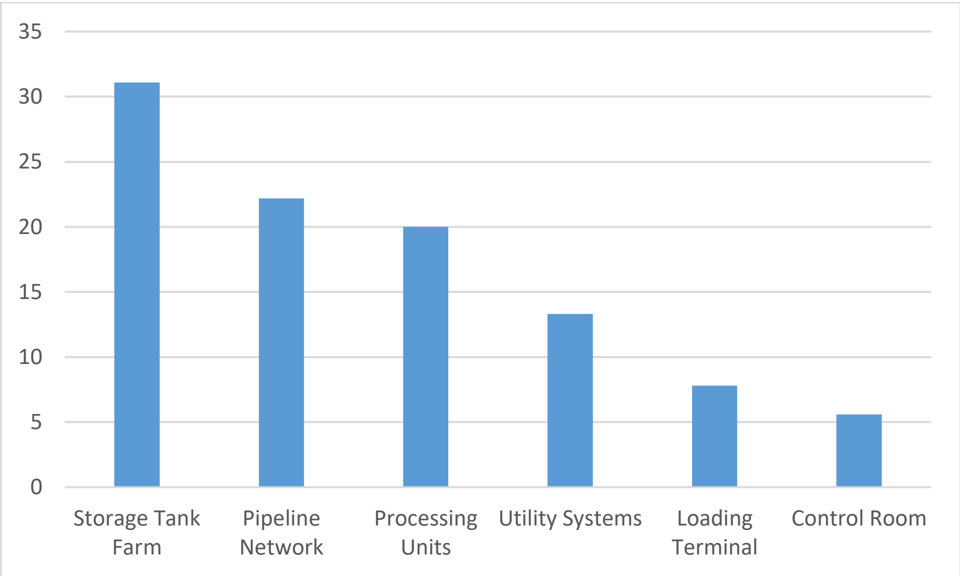

Figure 3: Graphical Representation of the percentage of Vulnerable Refinery Sections Affected by Multi-Hazards

As can be seen in the graphical view, the largest part of vulnerable sections is occupied by Storage Tank Farms, the next one is pipelines and processing units. The lowest share is in control rooms. The value placed on the figure is that it is important to improve fireproofing, leak detection, and emergency shutdown in tank farms and pipelines.

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This table shows the answers to the questions on the effectiveness of the suggested multi-hazard assessment framework in enhancing the safety management of refinery and risk mitigation.

Table 4 Effectiveness of Proposed Multi-Hazard Assessment Method

Response Category	Frequency	Percentage (%)
Highly Effective	40	44.4
Effective	28	31.1
Moderately Effective	14	15.6
Less Effective	5	5.6
Not Effective	3	3.3
Total	90	100

Most of the respondents gave the method Highly Effective with 40 responses (44.4%). Effective reported 28 respondents (31.1) and Moderately Effective 14 (15.6). Just 5.6% said it was Less Effective and 3.3% Not Effective. These results reveal that the suggested methodology is highly accepted.

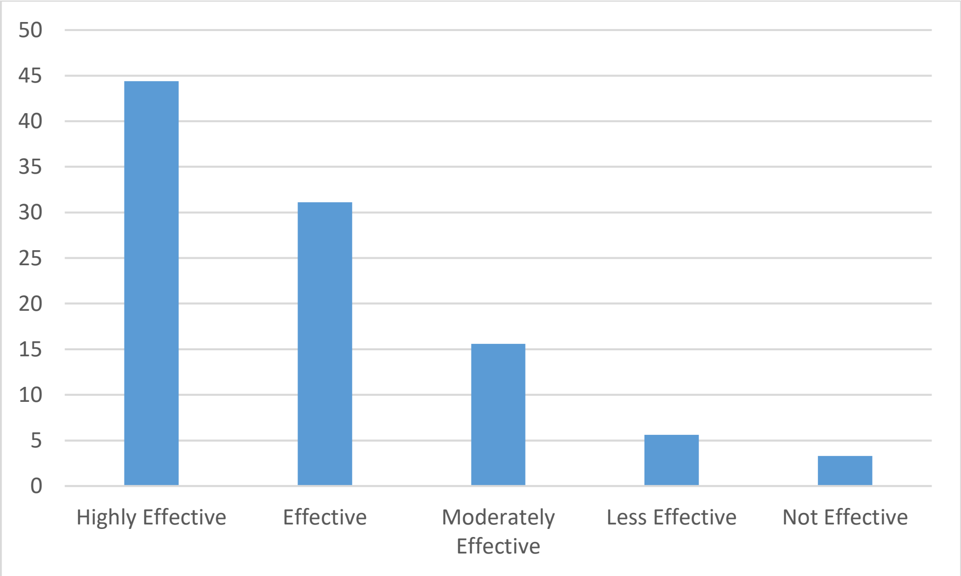

Figure 4: Graphical Representation of the percentage of Effectiveness of Proposed Multi-Hazard Assessment Method

The graph distinctly indicates that the percentage of Highly Effective is highest, followed by Effective. Few respondents chose less effective categories. This proves that the suggested

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multi-hazard interaction assessment approach is feasible, helpful, and valuable to risk management in refinery.

6. CONCLUSION

The combination of natural, technological and human-made hazards in which one incident can cause or amplify another, resulting in catastrophic cascading accidents have rendered oil refineries more complex safety challenges. Thus, traditional single-hazard management techniques cannot be used to address the contemporary refinery risks. The current paper has come up with a systematic approach to the evaluation of multi-hazards interaction by identification of hazards, analysis of interactions, estimation of probabilities, evaluation of consequences, vulnerability assessment, and combined risk scoring. The results indicate that fire and explosion are the two most relevant threats, whereas failures caused by floods and incidents triggered by earthquakes are also a significant contributor to the total refinery risk. The most vulnerable parts, where special protection measures were to be taken, were found to be storage tank farms, processing units, and pipeline networks. The analysis of the sample also proved that the suggested framework is very effective in enhancing the hazard prioritization, emergency planning, and preventive decision-making. The paper identifies the necessity of refinery safety systems to move beyond the conventional isolated hazard analysis to integrated and resilience-based risk management methods.

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