 https://doi.org/10.1051/e3sconf/202338801037

# A Comparative Analysis of Hazard Analysis Methods for Sustainable Energy Development

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**Abstract.** This paper discusses the potential risks and dangers associated with the oil and gas industry. This industry is essential for meeting energy needs and generating foreign exchange income, but it also poses significant risks, such as accidents, fires, explosions, and environmental contamination. Neglected work and safety procedures can result in catastrophic economic losses and have far-reaching effects on society and the environment. The study describes three significant accidents in the industry that were caused by internal and external factors. In order to comprehend the causes of these incidents, this study suggests three risk analysis techniques: Failure Mode and Effect Analysis, Fault Tree Analysis, and Hazard and Operability Study. The paper asserts that by employing these methods, incident data can be obtained to enhance security and reduce the likelihood of future accidents. Overall, this study emphasizes the significance of safety measures, environmental management, and total quality management in the oil and gas industry in order to avoid fatal outcomes and environmental impacts.

## 1 Introduction

The oil and gas industry are a crucial sector for a country's development, both in terms of meeting its energy and industrial raw material requirements and generating foreign exchange income. Additionally, the process of oil and gas processing is not simple, and it takes time to produce high-quality oil. In addition, the process of oil and gas processing requires multiple stages, extreme precision, and a very secure storage area. Due to the hazardous nature of oil and gas, the oil and gas industry is rife with dangers such as accidents, fires, explosions, and environmental contamination (Anis & Siddiqui, 2015). Oil and gas are combustible, so an accident involving them can be fatal. Neglected work can result in devastating economic losses and multiple environmental, social, and other consequences.

In the oil and gas industry, risk and potential danger are extremely high, and there have been three major accidents caused by multiple factors. The first incident occurred at Philadelphia Energy Solutions (PES), which is the largest oil refinery on the East Coast and can process up to 335,000 barrels of crude oil per day, in Philadelphia, Pennsylvania [1]. In the gasoline refining process, hazardous chemicals such as Hydrofluoric Acid are used as additives or catalysts (HF). The operation was initially successful and normal, but a leak occurred in one of the HF-containing pipes. The result was a massive fire and explosion. This occurred as a result of the company's failure to adhere to standard operating procedures (SOP) and the long-standing work environment conditions that made workers careless about the surrounding components.

Due to a lack of security and safety measures, the second accident occurred in a city in Texas and resulted in a massive explosion. The explosion resulted in 15 deaths, 180 injuries, and billions of dollars in losses, causing the economy to decline [2]. This was also the result of a shift change in which the previous operator failed to record the actual tank content, leaving the new operator uncertain as to whether the refining process could continue. The new operator finally began the machine and process. This resulted in a process difference between the machine and the operator, causing the valve to close for several hours and preventing the flow of fluid from the tower. Then, gas escaped the tower and triggered a massive explosion.

The third accident occurred in a well in Pittsburg County, Oklahoma, which was being used to extract oil from the ground [3]). The oil drilling process yielded numerous outcomes. During underground drilling, there are gases that must be prevented from entering the well. If the gas enters, it will not be detected and can cause explosive incidents. The lack of attention and awareness of the workers towards their work environment, coupled with the company's disregard for the capacity of the collected oil, resulted in an oil and mud leak that caused oil to continue to flow, rendered the pipe incapable of withstanding the flow, and caused a massive fire and explosion.

Multiple internal and external factors contributed to the occurrence of these three incidents of workplace accidents. These incidents necessitate additional investigation to determine the causes of these accidents. Consequently, a hazard analysis was conducted utilizing three techniques: Failure Mode and Effect Analysis,

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Fault Tree Analysis, and Hazard and Operatability Study. These three methods can be used to analyze the risks associated with these three incidents so that incident data can be gathered to improve safety and reduce the likelihood of future accidents with similar circumstances.

## 2 Methodology

The methodology employed in this study involved a qualitative research approach to investigate three incidents in the oil and gas industry in the region of the United States of America. These incidents were analyzed using three different hazard analysis methods, namely Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), and Hazard and Operatability Study (HAZOP). The qualitative research approach allowed for a comprehensive examination of the incidents and facilitated the application of the chosen hazard analysis methods to gain insights into the causes and contributing factors of these incidents. The selection of the incidents and the application of the hazard analysis methods were based on established best practices in the field of oil and gas industry safety and risk management. References to the literature on hazard analysis methods and their application in the oil and gas industry were consulted to inform the methodology employed in this study.[4–6]. Overall, this methodology aimed to provide a robust and rigorous analysis of the incidents and generate valuable findings for improving safety practices in the oil and gas industry.

The first approach is called Failure Mode and Effect Analysis (FMEA), and it involves analyzing a number of different factors to get rid of known problems and stop errors from happening during the manufacturing process [7]. The second approach, known as Fault Tree Analysis (FTA), is a method of deductive analysis that is useful in locating the primary source of the issue. This method does this by investigating both the immediate and underlying factors that contribute to incidents [8]. The third approach, known as Hazard and Operability Study (HAZOPS), is used to identify potential issues in ongoing operations that have the potential to affect production efficiency as well as safety [9]. The HAZOPS analysis focuses on conducting a structured analysis of ongoing operations and making use of "what-if" scenarios in order to identify any potential alterations to the design's intended outcomes. After that, appropriate preventative measures can be put in place to either eliminate or significantly lessen the potential adverse effects.

## 3 Data Analysis and Result

The first incident occurred at Philadelphia Energy Solutions in Philadelphia, Pennsylvania. The occurrence was analyzed using the FMEA technique. Table 1 displays the outcomes of the FMEA method's application to risk analysis.

**Table 1.** Result of Hazard Analysis with FMEA method

| No | Work Activities | Potential Failure Mode | Potential Failure Effects | Severity (S) | Potential Causes | Occurance (O) | Detection (D) | RPN (S x O x D) |
|---|---|---|---|---|---|---|---|---|
| 1 | Corrosion Fast Elbow Pipe | A Gas Leak Occurs | Poisoning Due To Toxic Gas | 8 | Not Replacing New Pipes | 5 | 4 | 160 |
| 2 | | The Pressure Gets Higher | It's Hard To Breathe | 7 | Gas Leaks Make Pressure Rise | 6 | 6 | 252 |
| 3 | | Fire | Burnt Skin | 8 | Gas Leaking from Flammable Pipe | 5 | 8 | 320 |
| 4 | Use of Hydrogen Fluoride Gas | A Gas Leak Occurs | Poisoning Due To Toxic Gas | 9 | Corroded and Leaking Elbow Pipes | 3 | 4 | 108 |
| 5 | | Skin Damage | Wounded Skin | 9 | | 2 | 5 | 90 |
| 6 | Absence of Emergency Isolation Valve | Hydrocarbon Gas Disperses Quickly | Fire and Explosion | 7 | Gas Leaks Are Flammable | 3 | 8 | 168 |
| 7 | | Oil Leak | Triggering Fires | 6 | Too High Pressure | 4 | 7 | 168 |
| 8 | The Guard Turns On The Water Pump Manually | Exposed to Hydrogen Fluoride Gas | Poisoning Due To Toxic Gas | 8 | Not Using PPE | 3 | 2 | 48 |
| 9 | | Skin Becomes Damaged | Skin Cannot Heal | 8 | Exposure to HF Toxic Substances | 2 | 4 | 64 |
| 10 | | PPE is Damaged | Shortness of Breath Inhaling Smoke | 7 | Chemical Substances Are 3 of 8 Hazardous Substances | 2 | 7 | 98 |

The first event analysis results are based on Table 1 of the Results of Hazard Analysis. According to the FMEA Method, there are four activities with a total of ten possible risks. The rapid corrosion of the elbow pipe, the use of hydrogen fluoride gas, the absence of an emergency isolating valve, and the guard manually turning on the automatic water pump are the leading causes of accidents. According to the RPN value calculation, the most severe accidents occurred in activities involving elbow pipe corrosion, which causes fires. This makes this risk the most dangerous and gives it the highest RPN score, 320, with a severity score of 8, an occurrence score of 5, and a detection score of 8. In addition, there are several RPN values that are quite large above 100, including up to six risks, and four risks below 100. The risk associated with exposure to extremely hazardous HF (Hydrofluoric Acid) gas has the lowest RPN value, with a value of 48. Based on the results of incident 1, the FMEA table reveals that the greatest risk for fire and explosion is the rapid corrosion of elbow pipes caused by a lack of maintenance by the company. In addition, the operator's lack of awareness creates additional risks for other workers.

The second incident occurred in Texas City, where a massive explosion occurred due to inadequate security and safety measures. Using the HAZOP method, the incident was evaluated. The outcomes of the HAZOP Method can be seen in Table 2: Hazard Analysis Using the HAZOP Method Outcomes.

**Table 2.** Result of Hazard Analysis with HAZOP method

| *No* | *Hazard Source* | *Frequency* | L | C | L*C | *Color* | *Risk Level* |
|---|---|---|---|---|---|---|---|
| 1 | *Worker Attitude* | 3 | 2 | 3 | 6 | | *Low Risk* |
| 2 | *Environmental conditions* | 2 | 2 | 2 | 4 | | *Low Risk* |
| 3 | *Worker Negligence* | 4 | 3 | 4 | 12 | | *High Risk* |
| 4 | *Operators Leave Work Faster Before Shifts Are Complete* | 5 | 4 | 5 | 20 | | *Critical Risk* |
| 5 | *Not Performing Capacity Recording* | 4 | 5 | 4 | 20 | | *Critical Risk* |

The results of the second incident's analysis were obtained using Table 2 Results of Hazard Analysis. Using the HAZOP Method, which is based on observations, the risk of a large explosion was determined to stem from five sources: worker attitudes, environmental conditions, worker negligence, operators leaving early before the end of the shift, and failure to record capacity at the conclusion of work activities. Table 2 displays the likelihood (L) and consequences (C) values derived from the HAZOP method's hazard analysis. The results of the HAZOP table indicate that operators who leave work before the end of their shift and do not record their capacity at the conclusion of their work activities pose the greatest risk. The two greatest sources of danger are described in a variety of ways in order to determine their causes and methods of prevention. The work attitudes of operators who do not adhere to SOPs and regulations are a hazard posed by the first source, which is operators leaving work earlier before the shift is over. The deviation is that the worker does not finish the job properly and simply leaves, which is caused by the worker's lack of discipline in following the existing SOP because the worker's supervision has not been improved to the point where the worker does not feel supervised. As a result (consequences), operators who leave work early will leave machines or recordings unfinished and information will be lost. The weekly supervision of workers by the unit supervisor and the posting of signs or posters outlining the necessary procedures are actions that can be taken.

The second source, which is not recording capacity, has a source of danger in the form of careless and unsupervised operators. The deviation occurs when employees leave the workplace too quickly to be recorded. This is due to the workers' lack of discipline in adhering to existing SOPs, which is a result of insufficiently improved supervision, such that workers do not feel truly supervised. As a result (consequences), the operator is unaware of the capacity's specifics and begins to start the machine without knowing its current capacity, causing an overflow and a fire. Actions that can be taken include implementing a more optimal system, such as knowing the tank's capacity, and providing operators with additional training on the company's SOP.

The third incident occurred at a well in Pittsburgh County, Oklahoma, where oil was being extracted from the ground. The event was examined using the FTA technique. Figure 1 displays the results of the FTA method's application to hazard analysis.

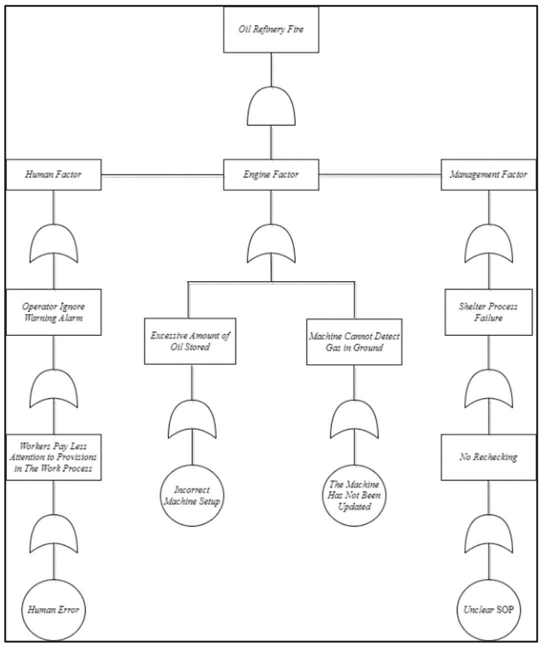


**Figure 1.** Result of Hazard Analysis with FTA method

On the basis of Figure 1, the results of the analysis of the third incident were determined. Utilizing the FTA Method, which is based on Fault Tree Analysis, for oil refinery fire accident investigations. Human factors, machine factors, and management factors were identified as the primary contributors to this issue. Where the root causes of these three factors are human error, improper machine setup, outdated or unupdated machines, and unclear standard operating procedures. Human error and ambiguous SOPs are the primary causes of failure. This causes the machine to fail to communicate with the operator. The operator also disregards the warning alarm, resulting in an excess of oil and gas from the ground. The used machine is also inadequate for oil drilling, as there is no automatic stop system when the machine reaches its maximum capacity.

## 4 Discussion

The FMEA analysis revealed that rapid corrosion of elbow pipes caused by a lack of maintenance by the company posed the greatest risk of fire and explosion. This finding indicates that the company's neglect of maintenance activities poses a substantial threat to the structural integrity of the pipes, which can result in potential fire and explosion hazards. In addition, the FMEA analysis revealed that the operator's lack of awareness created additional risks for other employees, indicating the need for enhanced operator training and awareness programs to mitigate potential risks. Not only resulted in significant economic losses but these conditions if not corrected also had potential environmental impacts such as pollution and contamination. Additionally, the lack of operator awareness and adherence to standard operating procedures created additional risks for other workers and the environment, leading to further hazards and consequences.

The HAZOP analysis identified deviations from normal operating conditions that could result in incidents in the oil and gas processing operations. The investigation revealed that inadequate monitoring and control of tank contents during shift change was a significant contributor to one of the incidents. This finding highlights the significance of strictly adhering to standard operating procedures (SOPs) during shift changes in order to prevent potential incidents.

The Fault Tree Analysis (FTA) revealed the potential event combinations that could result in incidents. The analysis revealed that the lack of attention and awareness of workers toward their work environment, as well as the company's disregard for the capacity of the collected oil, contributed to one of the incidents. This finding suggests the need for enhanced training and supervision of workers, as well as enhanced monitoring and management of oil collection processes, in order to prevent future occurrences of a similar nature.

These findings highlight the need for robust risk management practices in the oil and gas industry, particularly in the areas of maintenance, training, and adherence to standard operating procedures to prevent incidents with environmental and energy-related impacts. The application of Total Quality Management (TQM) principles can play a crucial role in addressing these issues. TQM, which emphasizes continuous improvement, proactive risk management, and employee involvement, can be applied to enhance safety measures, optimize processes, and foster a culture of accountability and awareness among all stakeholders involved in the oil and gas industry [10]. By integrating TQM principles into the industry's risk management practices, it is possible to achieve better outcomes in terms of environmental sustainability, energy efficiency, and overall operational excellence, leading to safer and more sustainable operations in the oil and gas industry. Overall, the integration of TQM with risk management practices can contribute to reducing incidents and improving environmental and energy performance in the oil and gas industry [10–13]. TQM, environmental management, and health and safety management, when combined, form an integrated management system that can improve organizational performance, reduce costs, and minimize the organization's impact on the environment and society.

A company may, for instance, use TQM to identify and address quality issues in its products and services, while incorporating environmental and health and safety considerations to ensure that the products and services are safe for consumers and the environment.

TQM, environmental management, and health and safety are three complementary management approaches that organizations can use to improve performance and ensure sustainable development.

## 5 Conclusion and Recommendations

There are several recommendations or suggestions for implementing a safety management system for each incident, including:

1. The first incident was plagued by fires and explosions caused by inadequate pipe management, which also accelerated the corrosion of the pipes. On the basis of this incident, it is recommended to conduct maintenance and checks on pipe components, develop an inspection program to identify areas where corrosion occurs, ensure the company has adhered to safety standards, and conduct a complete inspection and replacement of all oil refinery equipment. In addition to performing additional activities required to prevent leakage incidents.
2. The second incident is plagued by carelessness on the part of workers who do not maintain accurate records and operators who leave work before their shift ends. On the basis of this incident, it can be recommended that a more efficient system be implemented, such as knowing the tank's capacity and conducting additional training for operators to follow the company's SOP, as well as weekly supervision of workers by supervisors in the unit and the provision of signs or posters outlining the necessary procedures.
3. In the third incident, workers ignored the alarm due to the operator's lack of awareness, which led to an excess of load capacity, a fire, and a large explosion. On the basis of this incident, it can be suggested that the best way to prevent human error is to train new employees and conduct routine work inspections. In addition, the company can review the SOP that has been implemented and make modifications or enhancements.

In relation to environmental aspect impacted by these three incidents, the environmental consequences of the fires and explosions highlight the urgent need for comprehensive maintenance and inspection protocols in oil refineries to minimize the risk of similar incidents and their detrimental effects on the environment. Additionally, measures should be taken to ensure that the system is environmentally friendly, such as monitoring and controlling emissions, reducing waste, and promoting sustainability practices among workers.

It is crucial to also incorporate Total Quality Management into the organization to raise awareness about the potential impacts of environmental, health, and safety aspects on the quality of products and services. This includes emphasizing the importance of adhering to load capacity limits, proper waste disposal, emissions monitoring, and other relevant environmental regulations.

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