T.C.
ISTANBUL GEDİK UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

ASSESSMENT OF THE EFFECTIVENESS OF RISK MANAGEMENT STRATEGIES IN PETROL PRODUCTION: A CASE STUDY OF BAIJI REFINERY

MASTER THESIS

Haneen Mohammed Mahdi AL-SHANDAH

Engineering Management Department

Master of Engineering Management in English

FEBRUARY 2024
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İSTANBUL GEDİK ÜNİVERSİTESİ
Lisansüstü Eğitim Enstitüsü Müdürlüğü

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LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜ

Bu çalışma …./…../2023 tarihinde aşağıdaki jüri tarafından Mühendislik Yönetimi Anabilim Dalı, Mühendislik Yönetimi (Tezli Yüksek Lisans) Programı Yüksek Lisans Tezi olarak kabul edilmiştir.

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DECLARATION

I, Haneen Mohammed Mahdi AL-SHANDAH, declare that this thesis titled “Assessment of the Effectiveness of Risk Management Strategies in Petrol Production: A Case Study of Baiji Refinery” is original work I completed this to receive my master's in management engineering. I further declare that neither this thesis nor any part of it has ever been submitted to or presented for a research paper or other degree at any other university or institution. (15 /02/2024)

Haneen Mohammed Mahdi AL-SHANDAH

DEDICATION

To my esteemed supervisor Assist. Prof. Dr. Tuğbay Burçin GÜMÜŞ

Your unwavering guidance, insightful feedback, and steadfast support have been the cornerstone of this research journey. Your mentorship has fueled my intellectual growth, and I am profoundly grateful for the invaluable lessons learned under your supervision.

To Gedik Istanbul University,

I am grateful to Gedik Istanbul University for providing a conducive academic environment and the resources essential for completing this thesis. The institution's commitment to excellence has been a driving force in shaping my scholarly endeavors.

To my respected professors,

Your teachings, encouragement, and scholarly inspiration have left an indelible mark on my academic pursuits. Your dedication to fostering a love for learning has been a source of motivation throughout this research endeavor.

To my loving family,

Your unwavering support, understanding, and encouragement have been my pillars of strength. This achievement is as much yours as it is mine, and I am deeply thankful for the sacrifices made and the love shared throughout this academic journey.

To my father,

Your wisdom, guidance, and unconditional love have shaped me into who I am today. This thesis is a tribute to the values you instilled in me and a token of gratitude for your unwavering belief in my potential. Thank you for being my pillar of strength and inspiration throughout this academic endeavor.

To my dear husband,

Your patience, encouragement, and belief in my abilities have been my constant motivators. Your unwavering support has been the bedrock upon which I built this thesis. Thank you for being my partner in both challenges and triumphs.

To my esteemed colleagues,

Your camaraderie, intellectual discussions, and shared experiences have enriched my academic pursuits. I am grateful for the collaborative spirit that has defined our professional journey together.

This thesis is dedicated to each of you, for your immeasurable contributions to my academic and personal growth. Your support has been the wind beneath my wings, propelling me to reach new heights

PREFACE

Through this research, I am delighted to share with you the findings and analyses of my efforts in completing my master's degree in Engineering management. While these pages represent the culmination of personal dedication and hard work, they also embody the support I have received from many individuals and institutions throughout this journey.

This scholarly endeavor reflects the results of my efforts and continuous hard work to achieve my academic and professional goals. This research aims the research goal is to investigate and analyze risk management practices in the Petroleum Refinery, with a particular focus on enhancing safety protocols, mitigating potential hazards, and optimizing operational efficiency. The significance of this research lies in its potential to identify gaps and weaknesses in the current risk management framework. By understanding these shortcomings, the study aims to propose and implement effective strategies and measures to minimize risks, prevent accidents, and ensure the overall safety and security of the refinery personnel, assets, and surrounding environment. Additionally, the findings of this research may contribute to the broader discourse on industrial risk management practices, offering insights and recommendations that can be applied to similar facilities in the petroleum refining sector.

I acknowledge that this journey would not have been possible without the support I received from my family and loved ones. Their dedication and unwavering support have greatly influenced my ability to complete this research. I am also indebted to my academic supervisors and faculty members who provided me with guidance and mentorship throughout the preparation of this research.

I express my gratitude to the divine for enabling the fruition of this research endeavor. I am deeply thankful to my esteemed supervisor, Dr. Tuğbay for his guidance, encouragement, and motivation throughout this journey. Collaborating with these distinguished scholars has been a privilege, and their insightful ideas and innovative approaches have significantly shaped the methodological framework of this research.

Certainly, here's a sample acknowledgment section for a thesis:

I extend my deepest appreciation to my family for their unwavering love, support, and understanding throughout this endeavor. Their encouragement and sacrifices have been my source of strength and motivation.

I am grateful to my friends and colleagues for their encouragement, camaraderie, and intellectual discussions, which have provided inspiration and motivation during challenging times.

In conclusion, this research represents a collective effort of many individuals who directly or indirectly contributed to its completion. I hope that its findings will be useful and valuable to the academic and professional community.

February   Haneen Mohammed Mahdi AL-SHANDAH

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ABBREVIATIONS

COMAH : Control Of Majer Accident Hazard
FMEA : Failure Mode and Effects Analysis
IOT : Internet Of Things
AI : Artificial intelligence
LPG : Liquid Petroleum Gas
NO. : Number
CPTED : Crime Prevention Through Environmental Design
PSM : Process Safety Management
QRAs : Quantitative Risk Assessment
RPN : Risk Priority Number
HSE : Health & Safety Executive
CCPS : Center of Chemical Process safety
API : American Petroleum Institute
AIChE : American Institute of Chemical Engineer
ASSP : American Society of Satey Professional
FTA : Fault Tree Analysis
IEC : International Electroclinical Commission
ETA : Event Tree Analysis
EI : Energy Institute
CSB : Chemical Safety Board
ISOM : Isomerization
ISIS : Islamic State of Iraq and Syria
SQGs : Sediment Quality Guidelines
ILCR : Incremental Lifetime Cancer Risk
HAZOP : Hazard and Operability Analysis
PHA : Preliminary Hazard Analysis
KBPSD : Thousand Barrels Per Stream Day
QRA : Quantitative Risk Analysis
QHA : Quantitative Hazard Analysis
SIL : Safety Integrity Level
JSA : Job Safety Analysis
RCA : Root cause Analysis
MOC : Management of Change
PRI : Petroleum Refinery Industry
bb : billion barrels

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ASSESSMENT OF THE EFFECTIVENESS OF RISK MANAGEMENT STRATEGIES IN PETROL PRODUCTION: A CASE STUDY OF BAIJI REFINERY

ABSTRACT

Baiji Petroleum Refinery holds significant importance as a facility dedicated to refining petroleum products, serving as the primary energy source for both domestic and industrial consumption in Iraq. Refineries play a crucial role in contributing to economic growth on a global scale. Operating as intricate and multifaceted systems, they undertake high-risk, multi-phase operations. Over the past three decades, evidence-based documentation of major accidents in refineries worldwide indicates substantial financial losses, reaching billions of US dollars. These accidents, often catastrophic, result in disruptions to refinery operations, causing production loss, asset and environmental damage, as well as fatalities and injuries.

Despite the severity of these incidents, existing literature underscores the insufficiency of robust risk assessment and effective risk management approaches in promptly identifying and evaluating major accident risks to prevent or mitigate their escalation. Hence, there is a critical need to reassess petroleum refinery risk management through the development of a more reliable, adaptable, and holistic risk modeling framework for investigating major accident risks.

This thesis introduces a proactive framework for advanced risk management to analyze and mitigate disruption risks in petroleum refinery operations. Through this research, various risk elements and their attributes that can interact and cause disruptions in Petroleum in Baiji Refinery operations were identified and analyzed to determine their criticality levels. The study reveals that the convergent impact of interactions between these risk elements and their attributes can lead to operational disruptions.

The Fuzzy Failure Mode and Effect Analysis (FMEA) methodology applied in oil refineries involves a comprehensive approach to assess and manage potential failures and their consequences. It integrates fuzzy logic to handle uncertainties associated with failure modes and their impacts on refinery operations. This methodology considers imprecise and incomplete information, providing a more realistic representation of risk. Through linguistic terms and fuzzy sets, it accommodates subjective judgments and expert opinions. Fuzzy FMEA in oil refineries facilitates a nuanced understanding of failure scenarios, enabling a proactive and adaptive risk management strategy to enhance the overall resilience and safety of refinery processes.

The analysis results, serving as a threshold value, can guide risk assessors and decision-makers in mitigating disruption risks in operations. The decision strategies formulated in this thesis, based on a comprehensive literature review and expert contributions, contribute valuable insights to the field of petroleum refinery operations risk management. The evaluation and ranking of risk elements and their attributes provide crucial risk information for duty-holders and decision-makers,

aiding in prioritizing resources for managing the most critical attributes of risk elements.

In summary, the methodologies proposed in this thesis can be tailored as a quantitative risk assessment tool for risk managers and decision analysts in the petroleum refining industry, particularly in scenarios where available information for risk analysis may be vague or incomplete.

Keywords: *Risk Assessment, Risk Management, Petroleum Refinery, Fuzzy Failure Mode and Effect Analysis (FMEA), Fuzzy Logic, Fuzzy Sets*

PETROL ÜRETİMİNDE RİSK YÖNETİM STRATEJİLERİNİN ETKİNLİĞİNİN DEĞERLENDİRİLMESİ: BAIJI RAFİNERİSİNİN VAKA İNCELEMESİ

ÖZET

Baiji Petrol Rafinerisi, Irak'ta hem iç hem de endüstriyel tüketim için temel enerji kaynağı olarak hizmet veren petrol ürünlerinin rafine edilmesine adanmış önemli bir tesis olarak büyük bir öneme sahiptir. Rafineriler, küresel ölçekte ekonomik büyümeye katkı sağlamak için önemli bir rol oynamaktadır. Karmaşık ve çok yönlü sistemler olarak işletilen rafineriler, yüksek riskli, çok aşamalı operasyonları gerçekleştirirler. Son on yılda, rafinerilerde dünya çapında yaşanan ciddi kazaların kanıt temelli belgelenmesi, milyarlarca Amerikan dolarına ulaşan önemli finansal kayıpları ortaya koymaktadır. Bu kazalar, genellikle felaketle sonuçlanmakta ve rafineri operasyonlarına kesintiye neden olmaktadır, üretim kaybına, çevresel zararlara, ölümlere ve yaralanmalara neden olmaktadır.

Bu olayların ciddiyetine rağmen, mevcut literatür, büyük kazaların risklerini zamanında tanımlamak ve değerlendirmek için sağlam bir risk değerlendirmesi ve etkili bir risk yönetimi yaklaşımının yetersizliğini vurgulamaktadır. Bu nedenle, petrol rafineri risk yönetiminin daha güvenilir, adapte olabilir ve bütünsel bir risk modelleme çerçevesi geliştirilerek yeniden değerlendirilmesi gerekmektedir. Bu tez, petrol rafineri operasyonlarında kesinti risklerini analiz etmek ve azaltmak için bir proaktif çerçeve sunar. Bu araştırma, Baiji Rafineri operasyonlarında kesintiye neden olabilecek ve etkileşim halinde olan çeşitli risk öğeleri ve niteliklerinin tanımlanmasını ve analizini içerir. Araştırma, bu risk öğeleri ve nitelikleri arasındaki etkileşimlerin bir araya gelmesinin operasyonel kesintilere neden olabileceğini ortaya koymaktadır.

Petrol rafinerilerinde uygulanan Bulanık Hata Modu ve Etki Analizi (FMEA) metodolojisi, potansiyel hataları ve sonuçlarını değerlendirmek ve yönetmek için kapsamlı bir yaklaşımı içerir. Bulanık mantığı, hata modları ve rafineri operasyonları üzerindeki etkileri ile ilgili belirsizliklerle başa çıkmak için entegre edilir. Bu metodoloji belirsiz ve eksik bilgiyi dikkate alır ve riskin daha gerçekçi bir temsilini sağlar. Dilbilgisi terimleri ve bulanık kümeler aracılığıyla, bu metodoloji öznel değerlendirmeleri ve uzman görüşlerini kapsar. Petrol rafinerilerinde bulanık FMEA, hata senaryolarının nüanslı bir anlayışını sağlar, böylece rafineri işlemlerinin genel direnç ve güvenliğini artırmak için proaktif ve uyarlanabilir bir risk yönetim stratejisi sağlar.

Bu tezin birincil sonuçları, operasyonlarda kesinti risklerini azaltma konusunda risk değerlendiricilerine ve karar alıcılara yol gösterebilecek bir eşik değeri olarak hizmet edebilir. Bu tezde formüle edilen karar stratejileri, kapsamlı bir literatür incelemesi ve uzman katkılarına dayanarak petrol rafineri operasyonları risk yönetimi alanına değerli bir katkı sağlar. Risk öğelerinin ve niteliklerinin değerlendirilmesi ve sıralanması, görevlilere ve karar alıcılara kritik risk öğelerinin en kritik niteliklerini yönetmek için kaynakları önceliklendirme konusunda önemli bir risk bilgisi sağlar.

Özet olarak, bu tezde önerilen metodolojiler, petrol rafine endüstrisinde risk yöneticileri ve karar analistleri için bir niceliksel risk değerlendirme aracı olarak uyarlanabilir. Bu özellikle risk analizi için mevcut bilgilerin belirsiz veya eksik olduğu senaryolarda geçerlidir.

Anahtar Kelimeler: *Risk Değerlendirmesi, Risk Yönetimi, Petrol Rafinerisi, Bulanık Hata Modu ve Etki Analizi (FMEA), Bulanık Mantık, Bulanık Kümeler.*

1. INTRODUCTION

This section delineates the context, aims, and challenges encountered in the research. It presents the study's objectives, accentuates the hurdles encountered,

1.1 Title

Assessment of the Effectiveness of Risk Management Strategies in Petroleum Production: A Case Study of Baiji Refinery

1.2 Abstract

Provide a concise summary of the study, including the research question, methodology, key findings, and implications.

1.3 Background

The global energy sector heavily relies on the petroleum industry, which supplies raw materials for essential products and fuels. Despite its vital role, this industry operates in a complex, volatile, and risky environment. Petroleum refineries, integral to this sector, engage in intricate processes converting crude oil into refined products.

Risk management is crucial in petroleum refineries due to the handling of hazardous materials, extreme conditions, potential equipment failures, human errors, natural disasters, and external threats. Unfortunately, some companies, like the North Refineries Company in Baiji, prioritize financial aspects over safety, disregarding the ethical responsibility to reduce accidents.

Hollister and Trout's 1979 remarks about safety costs carrying a heavy implicit cost still resonate. The complexity of petroleum refining processes introduces the risk of unforeseen interactions and failures. Incidents like the Texas City Refinery Explosion (2005), Burchfield Oil Depot Explosion (2005), Pemex

Headquarters Explosion (2013), Tianjin Explosions (2015), and Philadelphia Energy Solutions Refinery Fire (2019) underscore the industry's vulnerability.

The Baiji refinery in Iraq has faced numerous challenges, including terrorist attacks, fires, and clashes with ISIS in 2014, disrupting operations. Despite safety improvement efforts, the complex security and economic conditions in Iraq continue to pose risks, affecting safety indicators' effectiveness in anticipating unplanned events and failures. Reports suggest that operators at the Baiji refinery may lack complete equipment and understanding of technological failures and complex operations. Detailed information is covered in Chapter Two.

1.4 Problem statement

The petroleum refining industry serves as a fundamental pillar in global energy production, supplying crucial fuels and petrochemical products. However, its intricate operations are inherently laden with diverse risks, stemming from complex processes, the handling of hazardous materials, and external factors like geopolitical instability and environmental regulations. Effectual risk management strategies in petroleum refineries are essential to ensure personnel safety, environmental protection, and operational continuity.

Despite existing safety protocols, accidents persist in petroleum refineries, posing threats to human lives, the environment, and financial stability. These incidents underscore deficiencies in current risk management practices, necessitating a comprehensive examination of risk factors, mitigation measures, and safety culture in the industry.

Refinery operations involving intricate processes and hazardous materials require accurate risk identification and assessment to avoid severe consequences such as injuries, loss of life, environmental damage, regulatory non-compliance, and reputational harm. Insufficient risk identification may result from factors like reliance on historical data and an incomplete understanding of interconnected processes. Addressing this issue is crucial not only for personnel and environmental protection but also for maintaining operational continuity and public trust.

Despite technological advancements, Baiji refinery faces challenges in risk identification and assessment, leading to unforeseen accidents and environmental incidents. Emerging technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and predictive analytics offer potential benefits, yet there is a gap in understanding how these technologies can optimally enhance risk management in Baiji refinery settings (Smith, 2023).

While recent research has primarily focused on maintaining process equipment in petrochemical plants, this study centers on risk elements by identifying failure modes, evaluating potential impacts, and implementing targeted mitigation strategies.

Fostering a proactive risk prevention culture presents a challenge in the Baiji refinery, where traditional safety approaches often react to incidents rather than preventing them. Resistance to change within organizational cultures hinders the adoption of practices prioritizing risk prevention over reaction.

Stakeholders must acknowledge the need to reinvest in the oil market due to unpredictability in product prices and global economic volatility. The pressure on oil refinery players to scale up operations using sophisticated technology raises concerns about expanding refining without compromising safety. Despite the absence of an obvious solution, it is evident that catastrophic incidents continue to occur regularly.

In 2008, a fire at the Baiji refinery destroyed the liquefied petroleum gas (LPG) unit, resulting in the death of an engineer and injuries to several employees. Numerous accidents in Iraqi refineries have occurred, but clear information about these incidents is lacking (Alsabah newspaper, 2008).

The reality of refineries resorting to patchwork solutions to meet challenges opens the discussion on prospects for the development of this crucial sector.

1.5 Purpose of Thesis

This thesis's purpose to comprehensively investigate and propose effective risk management strategies for enhancing safety, operational efficiency, and environmental sustainability within petroleum refineries. The research will contribute to the development of proactive and adaptive risk management practices tailored to the specific challenges and complexities of refinery operations.

Research Objectives:

Identify and Categorize Risks: To categorize and analyze various types of risks inherent to petroleum refining operations, including process-related, operational, environmental, and safety risks.

Assess Risk Impact: To assess the potential impact of identified risks on the refinery's operational processes, personnel safety, environmental compliance, and overall performance.

Evaluate Current Practices: To critically evaluate the existing risk management practices and methodologies employed within Baiji refinery, identifying strengths, weaknesses, and areas for improvement.

Examine Regulatory Compliance: To examine the refinery's adherence to local and international regulatory standards about risk management and safety, and assess gaps, if any.

Develop Comprehensive Strategies: To develop comprehensive risk management strategies that encompass preventive measures, incident response plans, and continuous monitoring to ensure operational resilience.

Promote Safety Culture: To analyze the influence of organizational culture on risk management practices and propose methods to foster a safety-conscious culture among refinery personnel.

Case Study Analysis: To analyze historical incidents and case studies in the petroleum refining industry, extracting lessons learned and best practices to inform the proposed risk management strategies.

Provide Practical Recommendations: To offer practical recommendations and guidelines for the implementation of effective risk management practices, considering the unique characteristics of petroleum refinery operations.

Contribute to Knowledge: To contribute to the body of knowledge in risk management by offering insights, findings, and strategies that can be applied not only in petroleum refineries but also in other high-risk industries.

By achieving these research objectives, the thesis seeks to enhance the understanding of risk management challenges within the Baiji refinery and provide actionable strategies that safeguard personnel, assets, and the environment while ensuring uninterrupted operational excellence.

These goals are discussed in successive chapters of the research.

1.6 Significance of the Study

The significance of the study of risk in the Baiji refinery lies in its potential to contribute valuable insights, strategies, and knowledge to both the academic and industrial sectors. The study's significance can be summarized:

1.6.1 Enhancing safety and sustainability

The study can significantly impact the safety and sustainability of the Baiji refinery by identifying effective risk management strategies. By addressing potential risks and hazards, the thesis can help prevent accidents, protect the environment, and safeguard the well-being of employees and surrounding communities.

1.6.2. Industry best practices

The thesis can provide a platform for sharing best practices in risk management within the oil refining sector. By showcasing successful strategies, technologies, and approaches, the study can help refine industry standards and improve the overall safety culture.

1.6.3. Regulatory compliance

As the petroleum industry is subject to stringent safety and environmental regulations, the study's findings can guide refineries in aligning their risk management practices with regulatory requirements. This alignment can lead to improved compliance and reduced regulatory risks.

1.6.4. Organizational culture and awareness

By emphasizing the role of organizational culture in risk prevention, the study can foster a culture of safety consciousness within refineries. It can highlight the importance of training, communication, and employee involvement in risk management efforts.

1.6.5. Economic impact

Effective risk management contributes to uninterrupted operations, reduced downtime, and minimized losses. The thesis can underline the economic benefits of robust risk management practices, encouraging refineries to invest in prevention rather than dealing with consequences.

1.6.6. Academic contribution

The study can contribute to the academic understanding of risk management in the oil refining industry. It can become a foundational resource for students, researchers, and educators interested in exploring this field.

1.6.7. Decision-making support

The research can offer practical recommendations and decision-making frameworks that refinery management can utilize to make informed choices regarding risk mitigation strategies.

1.6.8. Continuous improvement

By analyzing past incidents, case studies, and lessons learned, the study can facilitate a culture of continuous improvement. Refineries can learn from mistakes and implement changes to prevent similar incidents in the future.

1.6.9. Industry resilience

Ultimately, the study contributes to building a more resilient and secure petroleum industry. It equips refineries with the knowledge and tools needed to adapt to changing circumstances and challenges, ensuring their sustained success.

In summary, the significance of the study lies in its potential to improve safety, sustainability, efficiency, and overall risk management practices within the oil refining sector. By addressing these critical aspects, the thesis can contribute to the well-being of employees, the environment, and the industry as a whole.

1.7 Scope and limitation

The scope of the thesis on risk management in an oil refinery encompasses a comprehensive examination of various aspects related to identifying, assessing, and mitigating risks within the context of refinery operations. It includes:

Risk Identification: Investigating different types of risks prevalent in Baiji Refinery, including process-related, operational, environmental, safety, and security risks.

Risk Assessment: Evaluating the potential impact of identified risks on refinery operations, personnel safety, environmental compliance, and economic viability.

Risk Mitigation Strategies: Exploring a range of strategies and methodologies to mitigate and manage risks effectively, including both preventive measures and responsive plans.

Emerging Technologies: Examining the integration of emerging technologies such as IoT, AI, and predictive analytics in enhancing risk management practices.

Organizational Culture: Analyzing the role of organizational culture in promoting safety awareness and proactive risk prevention.

Regulatory Compliance: Assessing the extent to which the refinery adheres to local and international safety and environmental regulations.

1.8 Limitations of the Thesis

Time Constraints: The thesis may have limitations due to time constraints, which could impact the depth of analysis and the number of case studies or real-life incidents that can be thoroughly investigated.

Data Availability: Availability of up-to-date and detailed data from specific refineries might be limited, which could affect the accuracy and specificity of the findings.

Case Studies: The thesis might rely on a limited number of case studies or real-life incidents, potentially limiting the generalizability of the findings to other refineries.

Limited Organizational Insights: The access to internal organizational data and information might be restricted, which could impact the depth of analysis of internal risk management strategies.

Technical Complexity: The thesis may not delve deeply into highly technical aspects of certain risk management tools or technologies, focusing more on the overall understanding and application.

External Factors: Factors beyond the refinery's control, such as geopolitical events or global economic fluctuations, could impact the analysis and recommendations.

1.9 Research Questions

The research questions addressed key aspects of risk management at Baiji Refinery, including strategies, technologies, safety, compliance, and efficiency. It particularly highlights the role of emerging technologies in addressing these aspects. These questions are the basis for exploring and analyzing the state of risk management practices at Baiji Refinery and proposing innovative improvement solutions. This research was collected by approaching specialists in the field of oil refining operations of the Northern Refineries Company in Baiji. These experts include specialized refinery engineers, refinery health and safety managers, senior refinery managers, and academics in the petroleum refining industry, in addition to consultants with extensive experience in this field. The use of interviews and observations in searching for information represents an important basis for this research. The study relied on field research or qualitative research in this context. Observations and interviews are conducted with specialists to obtain valuable information to collect and understand viewpoints and trends. In addition, a comprehensive evaluation was conducted before starting to write the thesis to understand the extent of risk management application in the Baiji Refinery and what tools are used to manage risks through questionnaire evaluation questions by a group of specialized experts. Through the use of a questionnaire distributed via email and a website link, which allowed respondents to complete the questionnaire easily and in the shortest possible time.

2. LITERATURE REVIEW

Discusses a variety of contemporary concerns in the petroleum refining business, as well as a study of recent large oil refinery events. The chapter also goes into numerous safety modeling methodologies and risk assessments, as well as their applications. It also gives an outline of the failure analysis approaches and modeling of uncertainty treatment methods that were employed in this study.

The authors posit that Iraq possesses significantly larger oil reserves than officially documented, likely exceeding existing estimates by approximately 200 billion barrels (bb). The development of this substantial oil wealth is contingent upon substantial foreign investment, technical support, and political stability.

This prospect carries profound implications for the worldwide oil market, oil prices. Nonetheless, harnessing this vast oil wealth necessitates considerable foreign investment, technical expertise, and, crucially, a stable political environment (Salameh, 2013).

Expectations are high for a significant increase in Iraq's oil production in the coming years. Production is projected to reach 12.72 million barrels per day. However, several challenges must be addressed to enable Iraq to fully maximize its oil potential. These challenges include political instability, government decisions, and infrastructure improvements. Despite these obstacles, Iraq has the opportunity to emerge as a leading global producer and distributor of crude oil (Salameh, 2013).
The transformation of Iraq's oil industry from 2008 to 2018 marked a significant phase in the sector's growth and its impact on the national economy. The oil sector comprises three distinct yet interconnected sub-sectors upstream, covering exploration, field development, and production; midstream, including pipelines, storage facilities, and export terminals; and downstream, involving crude oil refining, gas processing, petroleum product distribution, and petrochemicals manufacturing.

Despite the state's predominant role in initially developing the oil sector, the post-2003 period witnessed a notable opening to international oil companies (IOCs).

Various contractual arrangements, tailored to each sub-sector's unique characteristics, were proposed or adopted to govern relations with these IOCs. Continuous monitoring and research suggest that the most significant progress occurred in the oil exploration sub-sector, with IOCs heavily involved in valuable oil reserves across numerous key fields.

However, a series of "triple shocks," including the sharp decline in oil prices since June 2014 (economic risks), the impact of ISIS (security risks), and the Kurdistan Regional Government's seizure of certain oil fields in June 2014 and again in October 2017 (political risks), along with the potential for a prolonged drop in oil prices prevailing around a year ago, deepened the financial crisis within the state. This raised concerns among Iraqi decision-makers.

Moreover, apparent limitations in human, systemic, and institutional capabilities (commercial risks) prompted Iraq to grant substantial concessions to IOCs without realizing significant returns. Consequently, this article argues that a sub-sector-specific policy approach, both analytically and empirically, has adversely affected the development of that sub-sector, the broader oil industry, and its contribution to the national economy.

This situation underscores the absence of deliberate, coherent, and integrated oil and energy policy, as well as the "indicative, non-mandatory" nature of the national development plan. The consequences of these factors exacerbate structural imbalances, vulnerabilities to external factors, and an increased reliance on oil revenues, thereby hindering the desired structural transformation, diversification, and investment (Jiyad, 2011).

The Baiji Refinery is Iraq's most extensive facility for refining and manufacturing oil products, making up a significant portion of Iraq's overall refinery production. It possesses an annual production capacity of 15 million tons of petroleum products and can refine up to 310,000 barrels per day (equivalent to 49,000 cubic meters per day). This refinery plays a crucial role in Iraq's oil processing industry (Michael, 2015).

Back in 2008, approximately 500 Iraqi tanker trucks were exclusively tasked with transporting oil from the Beiji Refinery daily (Oppel, 2008).

The Baiji oil refinery in Iraq presents numerous environmental and worker-related hazards. The refinery's surroundings are contaminated with harmful chemicals, including heavy metals that surpass permissible limits, along with concerning concentrations of polluting gases (Al-Jebouri and Al-Samarrai, 2014).

Based on the rate of major and destructive incidents in the oil refining industry, it becomes evident that the consequences associated with such incidents, including fatalities, severe injuries, and material damages, necessitate a systematic and earnest approach to effectively mitigate the threats. This underscores the urgent need to enhance the risk management process within the oil refining industry by considering it from a broader perspective. This entails giving sufficient attention to addressing the risks of oil refining operations by taking into account uncertain information, exercising restraint, and implementing preventive measures when faced with decisions made in ambiguous circumstances.

This underscores the significance of the Baiji oil refinery as a crucial global facility that contributes to the acceleration of economic growth across diverse industrial sectors. and represent intricate, integrated systems that demand substantial capital investments and the establishment of continuous production infrastructure. Given the intricacy of this infrastructure, it becomes imperative to meticulously engineer operational procedures to safeguard petroleum safety.

An examination of incidents occurring in oil refining operations has offered a lucid understanding of the factors that can accumulate and lead to significant disruptions. These factors, referred to as risk elements, represent inherent risks within operations that stem from uncertain information, oversight lapses, or a lack of awareness in risk management practices. These risk elements may be rooted in various aspects, including regulatory, technical, operational, or external conditions.

Taking a more expansive view of risk management will contribute to the enhanced enhancement of safety in petroleum refining operations. Consequently, this thesis incorporates a dynamic approach to hazard and risk identification, risk assessment, and the decision-making process for risk mitigation. These proactive risk aggregation techniques are adopted to promote optimal safety improvements.

Furthermore, issues pertaining to the management of wastewater within refineries and the emissions stemming from Iraqi refineries have exhibited adverse effects on the environment.

The intricacies inherent to petroleum refinery operations bear the potential for major accidents and consequential financial losses. This underscores the imperative to pinpoint and evaluate essential risk elements and their respective attributes. Such efforts are pivotal in sustaining operational reliability and availability (Mahmood and Al-Naima, 2010).

Moreover, an evaluation of the environmental ramifications of petroleum refineries, exemplified by the Al-Daura refinery in Baghdad, has been undertaken. This analysis has identified global warming, respiratory inorganics, and non-renewable energy as the most salient environmental impacts Chemical pollution represents an additional area of concern, with instances of heavy metals and pollutant gases surpassing acceptable limits in certain Iraqi oil refineries (Al-Samarrai and Abdeljabar, 2014).

2.1 Baiji Refinery

The primary national entity overseen by the Ministry of Oil is involved in the refining of crude oil and the production of light petroleum products. It was established under the Ministry of Oil Law No. (101) in 1976, with subsequent amendments as outlined in paragraph (4) of Article (7), operating under the title of the General Establishment for oil refining in the northern area, specifically Baiji. In 1997, following the enactment of Companies Law No. (22), it adopted the name North Refineries Company as a public entity. The company is situated in the city of Baiji within the Salahuddin province.

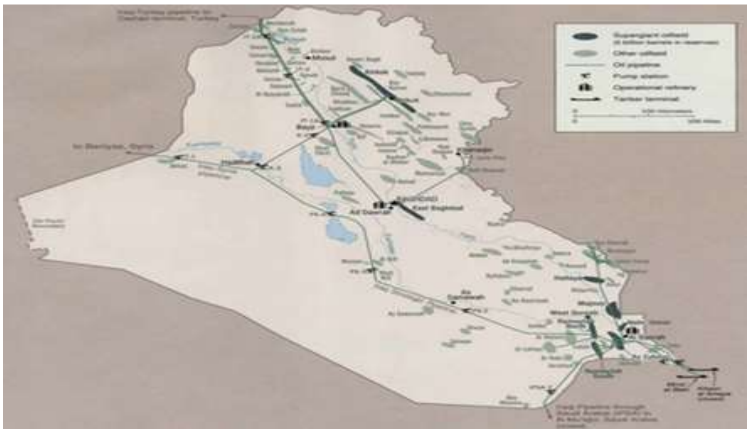


Figure 2.1: North Refineries Company in Baiji

Source: (Habeeb, 2022)

Table 2.1: Some of Baiji Refinery units

Units Description	Design Capacity	Actual Capacity	Date In Service
Gas sweeting unit	32,600 Nm^3/hr	32,600 Nm^3/hr	1983
LPG recovery unit	650 Ton/day	300 Ton/day	1986
Sulphur recovery unit	281 Ton/day	-------	1986

Source: (Habeeb, 2022)

Table 2.2: SalahAldin Department in Baiji refinery 70 KBPSD

Unit Description	Design Capacity
Crude Distillation Unit 3301	464 m^3/h
Light Distillate HDS Unit 3302	192 m^3/h
Gas Oil HDS Unit 3303	79.5 m^3/h
Catalytic Reforming Unit 3304	53 m^3/h
LPG Recovery Unit	540 ton/day

Source: (Habeeb, 2022)

Table 2.3: Salahaldin Department 2 KBPSD

Unit Description	Design Capacity
Crude Distillation Unit 4304	464 m^3/h
Light Distillate HDS Unit 4303	192 m^3/h
Gas Oil HDS Unit 4302	79.5 m^3/h
Catalytic Reforming Unit 4301	110 m^3/h
Isomerization unit	130 m^3/h

Source: (Habeeb, 2022)

Over the past thirty years, recorded incidents of significant accidents occurring in petroleum refineries globally have incurred estimated financial losses amounting to billions of US dollars. Many of these accidents qualify as catastrophic events, exerting severe repercussions on the seamless functioning of petroleum refinery operations. The outcomes of such incidents encompass adverse effects such as production interruptions, damage to assets, environmental harm, loss of life, and injuries.

Despite extensive documentation of these accidents, a prevalent concern addressed in the literature is the lack of robust risk assessment methodologies and effective strategies for managing major accident risks in petroleum refineries. The goal is to identify and evaluate these risks with the intention of preventing or mitigating their escalation into actual accidents. Consequently, there exists a pressing need to reassess the field of petroleum refinery risk management by developing a more dependable, adaptable, and comprehensive risk modeling framework specifically for investigating major accident risks.

This thesis introduces a proactive framework for advanced risk management, specifically designed to analyze and mitigate the risks associated with disruptions in the Baiji petroleum refinery. Throughout this research, various risk factors and their attributes that could interact and lead to disruptions in the Petroleum Refinery Process Unit were identified and analyzed. The primary objective was to assess the criticality levels of these factors. This thesis asserts that the cumulative impact of interactions among these risk elements and their attributes can indeed result in the disruption of petroleum refinery operations (Ishola, 2018).

2.2 The importance of risk management in petroleum Production

The importance of risk management in petroleum production cannot be overstated. This crucial element within the petroleum sector plays a central role in guaranteeing safety.

Efficiency, and sustainability of operations. Here are some key reasons highlighting the significance of risk management in petrol production:

Safety: Petroleum production processes involve complex machinery, high-pressure systems, and potentially hazardous materials. Effective risk management is essential to prevent accidents, protect workers, and minimize the risk of catastrophic incidents that can lead to injuries, fatalities, and environmental damage. The petroleum industry, given the high-risk nature of its products, upholds stringent safety standards within its production units. Among all the facets of petroleum project management, safety management in production takes precedence. Through the incorporation of humanistic management principles, the seamless operation of projects and the assurance of safety for personnel, facilities, and products are ensured. Consequently, there is a need to examine production safety policies from the perspective of humanistic management. The implementation of safety production measures alongside humanistic management practices can effectively mitigate risk factors, subsequently enhancing the economic efficiency of oil and gas companies.

Keywords: Petroleum engineering, Production safety, Humanistic management (Yongjun, 2018).

Environmental Protection: Petroleum production has the potential to harm the environment through oil spills, gas emissions, and other pollutants. Risk management helps identify and mitigate environmental risks, ensuring that production activities comply with regulations and minimize ecological impact.

In response to the growing environmental conservation movement, the petroleum industry has increasingly emphasized the need to minimize its environmental footprint. However, it's important that the exploration and production of petroleum can have adverse environmental effects, with the most significant impact stemming from the release of concentrated waste materials not naturally occurring in the environment. These waste materials encompass hydrocarbons, solids contaminated with hydrocarbons, water containing various dissolved and suspended solids, and a diverse range of chemicals (Guangting. 2007).

The most effective means of mitigating adverse environmental impacts entail the petroleum industry taking a proactive stance in managing its operations this proactive approach involves embracing a sense of environmental responsibility that extends beyond mere compliance with regulations, with a genuine commitment to safeguarding the environment while conducting business.

The petroleum operations necessitate a comprehensive understanding of various challenges encountered in the upstream petroleum sector. These challenges pertain to operations that generate waste materials, the methods employed for reducing the volume and/or toxicity of these wastes, and strategies for responsible waste management.

Asset Protection: Petroleum production facilities represent significant investments. Managing risks associated with equipment failure, natural disasters, or theft is crucial to protect assets and maintain production continuity.

Preserving assets holds paramount significance within the domain of oil refineries. The effective management of asset mobility and safety within the refinery is indispensable for the reduction of losses and the assurance of safety. This encompasses the initiation of corrosion control initiatives, the bolstering of corrosion surveillance, and the imposition of rigorous protocols for safeguarding against corrosion Furthermore, the application of ceramic coatings or heat-resistant surface treatments serves as a protective measure against chemical influences in petroleum refining facilities, with various additives having been identified to enhance the resilience of these coatings.

Asset protection within the petroleum production industry dates back to ancient civilizations. The practice of safeguarding valuable assets, whether they were gold or settlements, has been in existence for millennia. In earlier times, asset protection primarily relied on physical barriers and fortifications like medieval castles, which adapted over the years to counter emerging threats. In the contemporary era, asset protection has emerged as a fundamental responsibility of security professionals tasked with risk management and the implementation of security measures (Chizari, 2002).

Approaches to safeguarding assets involve a range of strategies, including risk management, crime prevention through environmental design (CPTED), and the implementation of layered protection strategies. Additionally, technological progress has led to the development of asset protection systems, such as tracking systems utilizing location transmitters and identification tags (Christopher et al., 2020). In summary, asset protection within the petroleum production industry has undergone a significant transformation, incorporating an array of strategies and technologies aimed at risk mitigation and the preservation of valuable assets.

Operational Efficiency: operational efficiency is crucial in the risk management of oil refineries. It helps to minimize operational risks and prevent environmental disasters and loss of human lives Effective risk management helps identify and address potential operational disruptions, proactively managing risks, production facilities can operate with

Greater efficiency, reducing downtime and production losses. Regulatory Compliance: The petroleum industry is heavily regulated to ensure safety, environmental responsibility, and public health. Risk management ensures that production facilities comply with local and international regulations, avoiding costly fines and legal issues (Cigolini and Rossi, 2010).

Ensuring Financial Stability: Significant events in petroleum production have the potential to result in significant financial setbacks. Effectively managing risks serves as a safeguard for the financial stability of companies, preventing expensive accidents and insurance claims. When dealing with risk management in oil refineries, prioritizing financial stability is paramount. Taking into account uncertainties and financial risks is crucial during the planning process (Arkadej et al., 2006).

Unfortunately, most existing refinery planning models are deterministic and overlook uncertainty, making it challenging to effectively manage risks (Bagajewicz and Uribe, 2008).

However, by incorporating financial risk management strategies, it is possible to achieve higher expected profits and mitigate risks (Park et al., 2010).

Reputation Management: Reputation management is important in the risk management of oil refineries as it helps to identify and mitigate reputational risks public perception and corporate reputation are critical in the petroleum industry. High-profile accidents can result in long-term damage to a company's image. Effective risk management helps maintain a positive reputation by demonstrating a commitment to safety and responsibility (Fragouli, 2018).

Efficient Resource Management: In the risk management of oil refineries, optimizing resources holds significant importance. It facilitates the coordination of decisions across various facilities and addresses uncertainties inherent in operations. Through the formulation and resolution of optimization problems, refineries can ascertain the ideal equilibrium between the extraction and storage of crude oil over time, considering constraints like storage capacity, price volatility, and extraction options. The identification and mitigation of risks enable petroleum production facilities to streamline resource allocation, ensuring efficient utilization of manpower, equipment, and financial resources (García, 2022), (Gaïgi and Goutte, 2021).

Embracing Innovation and Adaptation: Innovation and adaptation play a pivotal role in the risk management of oil refineries. These refineries, being intricate systems, confront numerous risks, including major accidents that may lead to substantial losses and operational disruptions. A culture of continuous improvement and adaptability is fostered through risk management. Recognizing and tackling emerging risks and challenges enables the industry to innovate and maintain resilience amidst evolving market conditions (Ishola, 2018).

Long-Term Sustainability: Sustainable petroleum production involves minimizing negative social, environmental, and economic impacts. Effective risk management contributes to the industry's long-term sustainability by addressing these concerns and working toward responsible resource extraction (Domnikov and Khomenko, 2015).

Enforcing Regulations: Incorporating humanistic management principles into safety production necessitates strict adherence to regulatory requirements. Often, corporate executives misconstrue humanistic management, believing that safety production regulations can be somewhat lenient, thereby diminishing the overall effectiveness of safety management. This underscores the importance of continually enhancing these regulations and imposing constraints on personnel activities and behavior in the real-world contexts of oil and gas companies.

enforcing regulations in risk management of oil refineries involve implementing safety standards, conducting health risk assessments, and complying with process safety management (PSM) regulations (Taher and Elkilani, 2010).

2.3 Types of Risks in Petroleum Protection

The petroleum industry stands as a pillar of global commerce, providing the lifeblood of energy for countless applications. Yet, beneath its vital role lies a complex web of risks that span the spectrum of operations. In this comprehensive section, we will explore and dissect the multifaceted types of risks inherent in petroleum protection, illuminating the various challenges faced by the industry in safeguarding its valuable assets, ensuring the safety of its workforce, and preserving the environment.

Operational Risks:

Operational risks are the lifeblood of daily activities in the petroleum sector. They encompass the threats posed by accidents, equipment malfunctions, and human errors. These risks, if left unchecked, can disrupt production, lead to asset damage, and result in injuries or, tragically, fatalities. The mitigation of operational risks involves the implementation of rigorous safety protocols, regular equipment maintenance, and comprehensive staff training programs (Yanting and Liyun, 2011).

Operational risks within the realm of petroleum operations are a substantial concern, primarily due to their potential to result in accidents and environmental contamination. For petroleum enterprises, the implementation of effective risk management is paramount. It involves establishing a comprehensive system and mechanism for the control and mitigation of these risks. While Quantitative Risk Assessments (QRAs) are a common approach to evaluating risks in petroleum operations, they may not offer a sufficiently comprehensive coverage of operational risks, leaving the door open for unforeseen accidents (Casal and Olsen, 2016).

Furthermore, the correlation between operational risk and oil supply chain management remains an inadequately explored area, underscoring the pressing need for more in-depth analysis and assessment of operational risks at various stages of the oil supply chain. Given that oil and gas projects are exposed to risks across all phases, the application of robust risk management practices becomes indispensable. These practices are essential for addressing uncertainties and mitigating potential legal repercussions (Cigolini and Rossi, 2010).

In the realm of petroleum refinery operations, complexity reigns, and various risk elements lurk that have the potential to disrupt operations significantly. Consequently, it is imperative to not only identify but also assess these critical risk elements and their associated attributes. Such assessments are pivotal in ensuring the reliability and uninterrupted availability of operations within the petroleum refining domain.

In the sphere of petroleum refinery operations, complexity prevails, and numerous risk factors exist that can substantially disrupt operations. Therefore, it is crucial not only to identify but also to evaluate these essential risk factors and their related characteristics. Such evaluations are pivotal in guaranteeing the dependability and continuous availability of operations within the petroleum refining sector (Zahari and Zulhafiz, 2020).

Environmental Risks:

The petroleum industry, by its very nature, has a substantial environmental footprint. Oil spills, gas emissions, and the release of hazardous chemicals are potential environmental risks that cast shadows on the sector. Such incidents can wreak havoc on ecosystems, contaminate water sources, and severely damage a company's reputation. To address these environmental risks, the industry adheres to stringent regulatory compliance, responsible waste management practices, and the continuous development and adoption of eco-friendly technologies (Jafarinejad, 2017).

The petroleum industry carries substantial environmental risks, encompassing incidents such as fluid spills, emissions, and pollution sources (Ahmad and Sajjad, 2015).These risks can unleash a cascade of adverse consequences, including soil degradation, harm to vegetation, and potential health hazards for humans (Block and Whitehead, 2011).

To mitigate these perils and safeguard both human health and the environment, the petroleum industry must implement a suite of environmental protection measures (David and Nersesian, 2014). These protective measures encompass a range of strategies, including environmental audits, comprehensive waste management plans and practices, certification procedures for disposal processes, well-thought-out contingency plans, and rigorous employee training programs ,Furthermore, the establishment and enforcement of environmental regulations play a pivotal role in curbing potential environmental impacts, Recent advancements in the field of "environmental justice" have underscored the importance of considering the environmental ramifications of petroleum activities on minority communities. This burgeoning awareness highlights the critical need to understand and address these risks, not only for the sake of well-informed urban environmental policy-making but also for effective emergency preparedness planning.

Market Risks:

The petroleum industry operates within a volatile marketplace, where external factors such as geopolitical tensions, supply and demand fluctuations, and currency exchange rates can all exert significant influence. These market risks can impact a company's profitability and overall stability. To manage market risks, companies often employ hedging strategies and diversify their portfolios to minimize exposure to market volatility (Rosenfeld and Feng, 2011).

These risks encompass the fluctuations in oil prices, which possess the potential to exert an impact on the profitability of companies operating within the oil and gas sector (Cheremisinoff and Rosenfeld, 2010)

To gauge the extent of oil price risk exposures within the U.S. oil and gas sector, researchers have employed the Fama-French-Carhart's four-factor asset pricing model. This model has been augmented with the inclusion of oil price and interest rate factors (Cigolini and Rossi, 2010).

The outcomes of this analysis reveal the noteworthy influence of oil price fluctuations on the returns of companies within the sector (Mohanty and Nandha. 2011).

In general, the oil price risk exposures of U.S. oil and gas companies within this sector tend to be positive and statistically significant (Ifeanyi and Ezeonu, 2018).

Nevertheless, it's worth noting that these risk exposures exhibit variations over time and among different firms and industry subsectors.

Geological Risks:

Exploration and drilling activities in the petroleum industry inherently carry geological risks. These risks manifest as uncertainties surrounding reservoir characteristics, including unexpected formations, pressure imbalances, and drilling complications. To mitigate geological risks, advanced exploration techniques and geological modeling are employed to improve the accuracy and predictability of drilling operations.

Several papers have delved into the geological risks associated with petroleum production in Iraq, particularly in the Baiji region. An examination of the Al-Baiji Oil Refinery uncovered instances of chemical pollution within its vicinity, characterized by elevated concentrations of heavy metals such as cadmium, nickel, lead, and vanadium that exceeded the permissible limits (Sissakian et al., 2011). Furthermore, the refinery exhibited levels of nitrogen dioxide (NO_2) and oxygen (O_2) gases that were deemed unacceptable (Sissakian and Fayyadh, 2022).

When considering geological hazards on a broader scale, Iraq as a whole grapples with various types of hazards, including those stemming from floods, karstification, and the presence of swelling clays (Sarhan and Ghadhib, 2022).

Nevertheless, it is noteworthy that tectonic activity emerged as the least impactful hazard within the region (George and Grabowski, 2014).

It's essential to emphasize that these hazards were not specifically investigated within the context of petroleum production in the Baiji area.

Financial Risks

Financial risks are ever-present in the capital-intensive world of petroleum production. Companies often take on substantial debt to fund projects, making them vulnerable to fluctuations in oil prices and unexpected project delays. Effective financial risk management involves prudent financial planning, risk assessment, and the development of contingency plans to weather financial storms.

Financial risks within the sphere of petroleum production in Iraq are subject to the influence of a multitude of factors. The nation's heavy dependence on oil revenues renders it susceptible to the oscillations in global oil prices and market (David and Grantham, 2010).

The landscape of political instability, encompassing elements such as conflict, terrorism, and policy volatility, also introduces risks pertaining to foreign direct investment (FDI) in the oil sector (Fahad, 2014).

Furthermore, the imperative for extensive repairs and reinvestment in Iraq's petroleum infrastructure compounds the financial risks at hand (Bishop and Shah, 2008).

Even the underdeveloped colossal fields situated in southern Iraq, despite boasting low unit development costs, demand substantial investments (Yokoi and Sato, 2004).

Moreover, the overall financial sector within Iraq, encompassing the banking system and other financial markets, confronts various challenges, including deficiencies in infrastructure and limited access to financial resources. These challenges can exert an impact on the financing of petroleum production initiatives (Nasr, 2011).

These intricate and multifaceted factors underscore the complex and ever-evolving nature of financial risks entailed in petroleum production in Iraq.

Consequently, it is imperative for potential investors to exercise prudence and meticulous assessment when considering involvement in this domain.

Health and Safety Risks

The well-being and safety of both employees and contractors hold utmost importance in the petroleum sector. Risks related to health and safety include accidents, exposure to hazardous substances, and the potential occurrence of catastrophic events such as explosions and fires.

In the context of petroleum protection at the Baiji Refinery in Iraq, heightened attention is directed towards health and safety risks. The refinery is a significant producer of considerable amounts of waste, including heavy metals and harmful gases, which possess the potential to have adverse effects on both human health and the environment (Otitolaiye and Al-Harethiya, 2022).

Investigative studies have shed light on the fact that residents residing in the vicinity of the refinery confront a heightened risk of developing a spectrum of health ailments. These health disorders encompass conditions such as cancer, respiratory issues, cardiovascular ailments, and reproductive disorders (Myung and Shin, 2010). Furthermore, assessments have revealed that the levels of heavy metals present in the soil and water surrounding the refinery surpass the permissible thresholds (Al-Jebouri and Al-Doori, 2014).

Moreover, the existence of pollutants including hydrogen sulfide, nitrogen dioxide, carbon monoxide, and critically low oxygen levels in the immediate vicinity of the refinery poses substantial health hazards.

It is imperative to institute a suite of measures aimed at the mitigation and eradication of these risks. These measures include but are not limited to bioremediation, the continual monitoring and evaluation of emissions, and concerted efforts to reduce benzene levels.

However, it remains essential to underscore that additional research and systematic investigations are imperative to comprehensively address these pressing issues and furnish dependable outcomes to inform decision-making processes.

Political and Regulatory Risks

The petroleum industry operates on a global scale, often in regions where political instability prevails. Changes in government policies, taxation, and regulatory environments can significantly impact a company's profitability and project feasibility. To mitigate political and regulatory risks, companies conduct thorough risk assessments and closely monitor political developments in the regions where they operate.

The petroleum industry operating within Iraq contends with a set of political and regulatory risks. The prevailing political instability, coupled with issues related to corruption and bureaucratic hurdles, renders the nation less appealing to foreign investors (Fahad, 2014).

This, in turn, acts as a deterrent to foreign investments in the oil sector. Furthermore, the issue of Iraqi refinery effluent pollution bears substantial adverse consequences. Refineries find themselves grappling with challenges in meeting environmental regulations, compounded by a lack of government commitment to enact environmental (Rahi et al., 2021).

The trajectory of the petroleum sector's development in Iraq has been marred by a confluence of factors, including the precipitous decline in oil prices, security concerns, and political uncertainties. These factors have led to concessions being granted to International Oil Companies, with little discernible reciprocal benefits (Jiyad, 2018).

Energy and oil and gas projects, including those within the petroleum refinery industry, wield significant influence over sustainability. Nevertheless, a reliable sustainability assessment system for refineries remains conspicuously absent (Hamidreza et al., 2018).

As for the petroleum refining industry in Jordan, it has been classified as a natural monopoly predicated on the subadditivity of the cost function. This classification signifies an efficient market structure within the sector (Awad and Ajlouni, 2012).

Supply Chain Risks

The petroleum industry relies on a complex supply chain that spans exploration, drilling, transportation, and refining. Disruptions within this intricate web, whether due to equipment breakdowns, transportation bottlenecks, or supply shortages, can lead to production delays and financial losses. Companies employ sophisticated supply chain management strategies to mitigate these risks and ensure the uninterrupted flow of operations Within Iraq, the petroleum industry grapples with supply chain risks stemming from the volatility and intricacy engendered by regional shifts in politics, society, and economics (Kumar, 2021).

However, a variety of supply chain management strategies have the potential to positively and significantly impact the performance of supply chains in the oil and gas sector. These approaches involve elements such as information sharing, collaborative decision-making, and the fair distribution of risks and rewards. Additionally, the industry faces challenges, including aging infrastructure, a shortage of skilled human capital, inefficient fragmented business processes, and limited access to emerging technologies. These factors have prompted petroleum companies in the Persian Gulf region to adopt outsourcing strategies to achieve cost savings. Furthermore, the oil and gas sector, including the petroleum supply chain, is vulnerable to significant disruption risks, such as the threat of piracy in Africa. Effectively addressing these risks requires the adoption of a holistic perspective rooted in complex system governance (Al-Doori, 2018).

Considering these factors, it becomes clear that supply chain risk management holds paramount significance within the petroleum industry. This management is essential for mitigating disruptions and uncertainties while simultaneously safeguarding business sustainability, enhancing flexibility, and fortifying resilience Batoul (Ansari and Thies, 2016).

Technological Risks

Advancements in technology are both a boon and a bane in the petroleum industry. While they offer opportunities for increased efficiency, they also introduce technological risks, such as system failures, cyber-attacks, and data breaches. Robust cyber security measures, continuous monitoring, and technological readiness are crucial components of mitigating these risks.

In the realm of petroleum production within Iraqi refineries, technological risks loom as a significant area of concern (Jie and Weibin, 2013).

Social Risks

In the realm of petroleum production within Iraqi refineries, social risks loom as a significant area of concern. Research findings indicate that employees at the Aden Petroleum Refinery in Yemen encounter a spectrum of hazards with the potential to impact their well-being. These hazards encompass physical, chemical, biological, mechanical/ergonomic, and psychological factors, (Darwish Mm M, 2020).It's worth noting that projects within the petroleum refinery industry (PRI) inherently possess elements of unsustainability owing to their potential adverse effects on both the environment and society. However, they do contribute positively to economic development (Rahi and Jaeel, 2021).

Moreover, issues related to chemical pollution originating from oil refineries, as illustrated by the Al-Baiji Oil Refinery in Iraq, center on potential health risks for both workers and the surrounding community. In certain cases, levels of heavy metals and pollutant gases have been discovered to surpass acceptable limit (Hasheminasab and Gholipour, 2021).

2.4 Risk Management Strategies in Petroleum Production

The selection of an appropriate risk management strategy to optimize petroleum refinery operations is a complex task with multiple criteria. Decision-makers in these refineries often face challenges in making optimal choices due to the intricate nature of their decision environment. Complexity arises from numerous conflicting criteria that need consideration, and insufficient information about alternative risk prevention, control, and mitigation strategies can lead to suboptimal decisions. The perspective of decision-makers on available risk information plays a crucial role in making robust decisions concerning major accident risks (Yang and Haugen, 2016).

Moreover, when there is a lack of consensus among decision-makers regarding a systemic issue, it can result in biased outcomes or conflicts of interest during the decision-making process. Therefore, decision-makers need to consider both qualitative and quantitative data in the decision-making process, choosing between the two based on the selected decision-making algorithm (Opricovic, 2009).

To enhance the risk management of petroleum refinery operations effectively, informed decisions based on a consistent evaluation of proposed alternatives are imperative. This requires the use of a robust and flexible decision-making algorithm. In this chapter, an advanced decision methodology is presented. This methodology offers a systematic approach to selecting a robust strategy for preventing, mitigating, and controlling factors contributing to the disruption risk in petroleum refinery operations. This includes identifying potential risk elements and their associated attributes that have the potential to disrupt petroleum refinery process unit operations.

The formulation of a comprehensive research plan is vital for effectively addressing a research problem and ensuring the soundness and validity of the research. The development of a systematic approach to tackle significant research inquiries depends on the chosen research methodology. This research primarily adopts a strategy centered on the selection and integration of the most suitable qualitative and quantitative methods to provide insights into various facets of the research problem.

In constructing an effective research design, it is crucial to establish a close connection between research questions, methodology, data collection techniques, the characteristics of the data, and the data analysis process (Hox and Boeije, 2005). The research design is conceptualized within the framework of a specific theoretical perspective accommodating both qualitative and quantitative data. Recognizing that no single method universally applies to all research questions, approaching a research problem by incorporating multiple methods becomes essential, as different methods are not mutually exclusive.

The application of research methods and data collection techniques involves the utilization of various theories, along with the collection and integration of both qualitative and quantitative data within a single research design. This approach allows mitigation of the limitations of one method by leveraging the strengths of the other. In this research, data acquisition and substantiation are based on a combination of approaches, including the use of questionnaires, a thorough review of the existing literature, expert opinions, brainstorming sessions interviews, and case studies (Gill et al., 2008).The effectiveness of risk management strategies in petroleum production Risk management approaches within the realm of petroleum production in Iraq have proven effective in safeguarding sustainable economic progress and fostering foreign investment. Iraqi leadership acknowledges the imperative need for financial resources and expertise from both International Oil Companies and National Oil Companies to attain their production and revenue targets (Susana, 2017). The intricate and fluctuating nature of risk metrics in Iraq is counterbalanced by the exceptional levels and diversity of support the nation receives from international governments and non-governmental organizations (Albu, 2018).

The application of risk management methodologies in oil field ventures serves to diminish the adverse repercussions of unfavorable incidents (Grantham, 2010).

It is paramount to integrate risk evaluation with economic, technical, social, and political considerations to formulate comprehensive risk mitigation strategies (Mbanugo and Agunwamba, 2011).

In oil and gas enterprise, exemplifies a fully integrated risk management system that permeates the entirety of the company's operations, with all personnel sharing the overarching responsibility of identifying and reporting risks (Abdullah and Rana, 2019).

Collectively, the implementation of risk management strategies assumes a pivotal role in ensuring the security, profitability, and enduring prosperity of petroleum production endeavors in Iraq.

To effectively manage the risks associated with process units and prevent the unintended loss of hazardous materials (OGP, 2011), the petroleum refining industry has established various regulations and guidelines promoting environmental health and safety.

These regulations and guidelines include:

In the United Kingdom, the Health and Safety Executive (HSE) enforces major accident prevention regulations known as the Control of Major Accident Hazards (COMAH) regulations. The primary objective of the COMAH Regulations is to prevent major accidents involving hazardous substances and minimize potential harm to individuals and the environment.

The European Commission has developed regulations aimed at preventing major accidents, known as the Seveso III directive (Directive 2012/18/EU). The central purpose of the Seveso III directive is to proactively prevent major accidents involving dangerous substances and reduce the adverse impacts of such incidents on human health and the environment. Baiji's oil refineries generate significant volumes of recalcitrant oily sludge, presenting substantial challenges for both biodegradation and efficient disposal into designated landfill sites (Raouf and Mahmod, 2019).

The employment of risk analysis methodologies within the petroleum exploration and production sectors proves invaluable for the recognition and subsequent mitigation of industry-specific risks (Samimi, 2020). The inherent volatility of competitive regulations, amplified risk factors and evolving consumer demands collectively underscore the imperative need for robust risk management strategies (Saul and Schiozer, 2004).

Notably, Chinese oil refineries confront formidable financial hurdles, grappling with narrow or negative profit margins despite the burgeoning demand for petroleum products (Heaton, 2004).

Petroleum production companies implement a range of risk management strategies tailored to their specific needs and challenges. Here are some key strategies:

Thorough Risk Evaluation: The identification and evaluation of potential risks form the bedrock of proficient risk management. Various research efforts have scrutinized risk assessment in the realm of petroleum production in Iraq. Minimizing the risks linked to petroleum projects is essential for achieving production objectives (Abduljabbar and Breesam, 2022).

These risks can be broadly classified into four categories: operational, financial and administrative, economic and political, and potential risks (Alajmeen, 2020).

Operational risks hinge on factors such as the existence of explosive devices and mines in exploration zones, as well as inadequate storage practices for flammable materials, Financial and administrative risks are influenced by issues like corruption within oil companies and managerial or assistant mismanagement (Elsayed, 2021).

Economic and political risks are sensitive to variables such as companies facing blacklisting and a reduction in global market demand for oil (Grantham, 2010). The most noteworthy potential risk involves the potential control of oil-rich areas and regions by terrorist groups. Furthermore, the dissemination of pandemics, such as the Coronavirus Disease 2019 (COVID-19), should be regarded as a potential risk due to its repercussions on global oil prices (Zumberge, 2015).

Safety Protocols and Training: Enforcing rigorous safety protocols and delivering thorough training to employees is crucial to reduce operational and health risks. This involves the implementation of emergency response plans, conducting safety drills, and providing continuous safety education.

In the petroleum production sector in Iraq, the significance of safety procedures and instructional programs is pronounced, especially considering the industry's rapid expansion and the increasing frequency of workplace accidents and injuries (Wameedh et al., 2011).

It has been underscored that management practices and leadership approaches play a pivotal role in upholding safety standards within the Petroleum sector (Mahony, 2012). Furthermore, the adoption of virtual reality-based safety training systems like omVR has been put forth as a viable method for training personnel involved in petroleum refineries, with a focus on enhancing safety (Haller and Holm, 1999). Conversely, the discipline of system safety engineering prioritizes the significance of safety constraints rather than concentrating solely on identifying (Vasilevich, 2016). In a comprehensive sense, there exists a pressing requirement to delve into safety performance and institute effective managerial strategies and training initiatives to safeguard the petroleum production endeavors in Iraq.

Environmental management: in the operations of Iraqi refineries raises significant concerns, primarily due to the adverse consequences associated with the pollution of refinery effluents. Emissions from Iraqi refineries have extensive ramifications, particularly concerning environmental contaminants like Couscous Pollutants, Liquid Pollutants, and Strong Pollutants. Equally critical is the management of wastewater within these refineries and the proper treatment of refining waste. However, it is worth noting that, thus far, oil refineries operating in Iraq have faced substantial challenges in effectively fulfilling their environmental responsibilities, with the government demonstrating little commitment to enacting even basic environmental legislation. This notable lack of action has profound implications for the well-being of the local population and the agricultural activities in the region (Rahi and Jaeel, 2021).

Financial Risk Mitigation: Petroleum companies use financial risk management tools like hedging to protect against fluctuations in oil prices. Diversification of investments and prudent financial planning also play a crucial role in financial risk mitigation.

Financial risk within the Baiji refinery operations raises concerns, largely stemming from the substantial energy expenses incurred and the heavy reliance on conventional energy sources, specifically fossil fuels. This dependence has consequently triggered a surge in greenhouse gas emissions) Mahdi and AL-Doury, 2019).

Insurance: Many petroleum companies invest in insurance policies that cover various risks, including accidents, environmental liabilities, and business interruptions. Insurance serves as a safety net in case of unexpected events.The subject of insurance within the Baiji refinery's petroleum production operations warrants further investigation.

Given the inherent risks associated with the petroleum industry, encompassing the potential for extensive damages and the requisite repair and compensation, it becomes imperative to explore protective insurance mechanisms (Raouf and Mahmod, 2019).

2.5 Risk Assessment Approach and Applications in the Petroleum Refining Industry

The initial step in managing risks is conducting a risk assessment (John, 2013). As Wang and Trbojevic (2007) explain, this involves a systematic process where the likelihood and potential consequences of hazardous situations are comprehensively evaluated to make informed decisions regarding safety measures. However, analyzing complex risk scenarios for large engineering systems has become increasingly challenging due to significant challenges such as acquiring consistent historical failure data and handling inherent uncertainties (Yang and Wang, 2015).

For example, when assessing the safety of a complex operation like a petroleum refinery, adopting an innovative and high-level risk assessment approach is essential. This is particularly crucial due to the lack of historical failure data, the inherent vagueness of risk parameters, and the incomplete input in a risk model. To establish an effective risk assessment for petroleum refinery operations, a choice can be made between qualitative and quantitative safety approaches, depending on the availability of historical data and the involvement of experts or other decision-makers. The risk assessment process for petroleum refinery operations typically involves three phases: risk identification, risk analysis, and risk evaluation.

Risk Identification: The initial step involves identifying potential causes of failure events systematically, understanding how a sequence of potential failure events can lead to accidents (Mabrouki et al., 2014).

Risk Analysis: This process determines the nature and level of risk associated with system operations. Risk analysis provides a logical and scientifically based understanding of the causes and consequences in risk management (Slovic et al., 2004). Most risk analysis models rely on a quantitative approach that mathematically quantifies risk levels in terms of likelihood and consequences (Deng et al., 2011).

Risk Evaluation: Risk evaluation is a logical approach to weigh the results of risk analysis, focusing on the most critical risk elements or hazards with significant consequences. This process is crucial for assessing the risk level associated with a system or its operation and setting risk limits (Mokhtari et al., 2012).

2.5.1 Quantitative risk analysis (QRA)

in the oil refinery field involves the use of numerical data and statistical methods to assess the likelihood and consequences of potential risks associated with refining processes. This approach allows for a more precise and quantitative understanding of the risks involved in order to prioritize mitigation efforts and optimize decision-making. Here are some key components and methodologies of Quantitative Risk Analysis in the oil refinery sector:

Consequence Modeling:

QRA often begins with consequence modeling, where the potential outcomes of identified hazards are quantified. This involves assessing the impact of events such as fires, explosions, or chemical releases on personnel, equipment, the environment, and nearby communities (Hale and Gulati, 2020).

Event Tree Analysis (ETA):

ETA is used to model the various possible outcomes following an initiating event. This quantitative technique helps in estimating the probabilities associated with different branches of the event tree, enabling a probabilistic assessment of the overall risk (Ishola and Wang, 2020).

Fault Tree Analysis (FTA):

FTA is employed to analyze the combination of events that could lead to specific undesired outcomes. By breaking down complex systems into a series of logical events and gates, FTA helps in understanding the probability of failure paths leading to undesirable consequences (Johnson and Lee, 2019).

2.5.2 Quantitative hazard analysis (QHA)

QHA involves assigning numerical values to hazards and assessing their potential consequences. This quantitative analysis allows for the calculation of risk metrics, such as the likelihood of an event occurring and the severity of its consequences (Lee, 2019).

Probabilistic Risk Assessment (PRA):

PRA is a comprehensive approach that combines both consequence modeling and probability assessment. It involves the use of probabilistic methods to evaluate the likelihood of specific events and their consequences, providing a holistic view of risk (Wilson, 2011).

Frequency-Severity Analysis:

This analysis involves evaluating the frequency of specific events (such as equipment failures, leaks, or spills) and their associated severity. By combining these factors, it helps in quantifying the overall risk profile of refinery operations.

Monte Carlo Simulation:

Monte Carlo Simulation is utilized to model the variability and uncertainty in different parameters that influence risk. By running multiple simulations with varying input values, it provides a probabilistic distribution of potential outcomes, aiding in risk assessment and decision-making.

Risk Matrices:

Risk matrices are used to visually represent the likelihood and consequences of identified risks. By categorizing risks into different severity levels, organizations can prioritize mitigation strategies for high-risk scenarios (Wilson, 2011).

Societal Risk Assessment:

In addition to assessing risks to the facility and personnel, QRA in the oil refinery field may also consider the potential impact on nearby communities. Societal Risk Assessment involves evaluating the risks posed to individuals and property in the surrounding areas.

Quantitative Risk Analysis in the oil refinery field provides a data-driven and systematic approach to understanding and managing risks. By quantifying the probabilities and consequences of potential events, refineries can prioritize safety measures, allocate resources effectively, and make informed decisions to enhance overall risk resilience (Lee, 2019).

2.5.3 Qualitative risk analysis

In the oil refinery field involves a more subjective and descriptive approach to identifying, assessing, and manage potential risks associated with refining processes. This method focuses on understanding the nature of risks, their causes, and their potential consequences without assigning numerical values. Here are key aspects and methodologies of Qualitative Risk Analysis in the oil refinery sector (Andersen and Mostue, 2012).

Hazard and Operability Studies (HAZOP):

HAZOP is a systematic and structured approach that involves a multidisciplinary team reviewing the design and operational aspects of a process to identify potential hazards and operability issues. This qualitative method helps in understanding deviations from normal operating conditions (Al-Mansoori, 2014).

Safety Integrity Level (SIL) Assessment:

SIL assessments are used to qualitatively evaluate the reliability of safety instrumented systems (SIS) in place to mitigate process-related risks. This involves determining the effectiveness of safety barriers and control measures in preventing or mitigating incidents (Ramaiah and Gokhale, 2011).

Job Safety Analysis (JSA):

JSA is a qualitative technique that involves breaking down specific job tasks into steps, identifying potential hazards associated with each step, and assessing the risks involved. This approach helps ensure the safety of personnel involved in various tasks within the refinery.

Environmental Impact Assessment (EIA):

EIA in the oil refinery field qualitatively assesses the potential environmental impacts of refinery activities. This includes evaluating the consequences of potential spills, emissions, and other pollutants on ecosystems, air quality, and water bodies (Ali, 2016).

Bowtie Analysis for Major Accident Hazards

Bowtie analysis is applied to major accident hazards, providing a visual representation of the relationships between causes, preventive measures, and consequences. This qualitative method aids in understanding the effectiveness of safety barriers and identifying potential weaknesses (Petrovsky and Elrikh, 2012).

Root Cause Analysis (RCA):

RCA is employed to qualitatively identify the root causes of incidents or failures in refinery processes. By systematically analyzing events, RCA helps uncover the underlying reasons for accidents or deviations from normal operations (Pham and Tran, 2015).

Scenario-Based Risk Assessment:

Scenario-based assessments involve developing narratives around potential future events and their consequences. This qualitative approach helps in preparing for and mitigating risks associated with unexpected developments, such as equipment failures, regulatory changes, or market shifts.

Change Management Assessment:

Assessing risks associated with changes in processes, equipment, or personnel is crucial in the refinery field. A qualitative evaluation of change management processes helps identify potential risks related to modifications and ensure that safety measures are appropriately considered (Karwan and Majeed, 2021).

Catastrophic Event Analysis:

This analysis involves qualitatively examining the potential consequences of catastrophic events, such as large-scale fires or explosions. Understanding the nature and extent of such events is crucial for developing emergency response plans and mitigation strategies.

Qualitative Risk Analysis in the oil refinery field provides a holistic understanding of risks by considering various aspects of operations, personnel, and the environment. While it may lack the precision of quantitative methods, it complements quantitative analyses and helps in developing a comprehensive risk management strategy for oil refineries (Kaminski et al., 2016).

2.6 Risk Evaluation, as Recommended in Various Safety and Risk Assessment Literature, Include

i. Failure Mode Effect and Analysis (FMEA)
ii. Hazard Operability Study (HAZOP)
iii. Preliminary Hazard Analysis (PHA)
iv. Fault Tree Analysis (FTA)
v. Event Tree Analysis (ETA)
vi. Bow-tie Analysis

I. Failure Mode Effect and Analysis (FMEA):

One of the valuable tools for assessing and managing risks in complex systems and operations is Failure Mode Effect and Analysis (FMEA). It is a systematic approach used in various industries to identify and mitigate potential failures in systems, processes, and products. FMEA helps in understanding potential failure modes, their effects, and the likelihood of occurrence. Organizations can prioritize and implement appropriate preventive or corrective actions based on the analysis of failure modes and their impacts.

FMEA consists of three key elements: failure modes, effects, and analysis. The process involves several steps**:** (Pham and Tran, 2015).

Identification: Identifying all potential failure modes in a system or process through brainstorming and considering all possible ways in which a failure can happen.

Assessment: Analyzing each failure mode to determine its severity or impact on the system or process. This assessment helps in understanding the potential consequences of failure, such as safety hazards, production delays, or customer dissatisfaction.

Detection: Evaluating the likelihood of detecting each failure mode before it affects the system. This step helps in identifying the effectiveness of current detection methods and areas where improvements are needed to identify failures at an early stage.

Risk Priority Number (RPN): Multiplying severity, likelihood of occurrence, and detection ratings to calculate a Risk Priority Number (RPN) for each failure mode. The RPN serves as a prioritization tool to focus on high-risk failure modes that require immediate attention (Stamatis**,** 2003).

Action Planning: Developing action plans based on the RPN to mitigate identified risks. These actions can include design changes, process improvements, additional inspections, or training programs to enhance detection capabilities.

FMEA has proven effective for risk management and quality improvement in various industries, including automotive, aerospace, healthcare, and manufacturing. By proactively identifying and addressing potential failure modes, organizations can reduce costs, improve reliability, enhance customer satisfaction, and ensure compliance with regulatory requirements.

II. Hazard and Operability Study (HAZOP)

The Hazard and Operability Study (HAZOP) technique holds widespread application in the petroleum refinery industry for the systematic identification and analysis of potential hazards and operability issues within process systems. HAZOP aims to thoroughly scrutinize deviations from the intended design and operational parameters of a system, pinpointing potential causes and consequences of hazardous events. Various tools are employed during the HAZOP process to ensure a comprehensive analysis and effective risk mitigation **(**IEC 61882, 2016).

Guidewords: In the HAZOP process, guidewords are instrumental in stimulating systematic thinking and uncovering potential deviations. These guidewords, such as "No," "More," "Less," "Part of," "Reverse," and "Other than" are applied to diverse process parameters like flow, temperature, pressure, and composition. This application helps explore potential deviations from normal operating conditions.

Deviation Parameters: The systematic examination of process variables or parameters, known as deviation parameters, constitutes a crucial aspect of HAZOP studies. These parameters encompass flow rates, temperatures, pressures, levels, compositions, and other relevant variables specific to the analyzed refinery process. The consideration of deviations in these parameters aids in identifying potential hazards and operability issues **(**Isimite and Rubini, 2016).

Nodes and Branches: HAZOP studies frequently utilize graphical representations, such as process flow diagrams and piping and instrumentation diagrams, to identify nodes and branches within the process system. Nodes represent specific process equipment or units, while branches represent the process streams flowing into or out of these nodes. Analyzing nodes and branches is instrumental in identifying potential deviations and their consequences (Mansoori and Mansoori, 2014).

Consequence Analysis: An essential tool employed during HAZOP is consequence analysis, which evaluates the potential impacts or consequences of identified deviations. This assessment involves gauging the severity of each consequence concerning safety, environmental impact, and production disruption.

Consequence analysis facilitates the prioritization of identified hazards based on their severity and aids in determining appropriate risk control measures.

Risk Assessment: To quantitatively evaluate the risk associated with identified hazards, risk assessment techniques, such as risk matrices or risk scoring systems, are often integrated into HAZOP studies. These tools assign numerical values to the likelihood and severity of each hazard, enabling prioritization and the allocation of resources for effective risk mitigation.

III. Preliminary Hazard Analysis (PHA) in the Petroleum Refinery Industry

The Preliminary Hazard Analysis (PHA) stands as a pivotal tool within the petroleum refinery sector, employed to systematically identify and analyze potential hazards in the early stages of project or process design. This proactive approach facilitates the early detection of hazards, allowing for the implementation of suitable risk mitigation measures to enhance safety and prevent incidents in petroleum refineries. Several reputable references offer guidance on conducting PHA specifically tailored for petroleum refineries: (Suslick and Schiozer, 2004).

1. Center for Chemical Process Safety (CCPS):

The CCPS, a division of the American Institute of Chemical Engineers (AIChE), has issued valuable resources on hazard evaluation procedures, including PHA. Their guidelines, exemplified by "Guidelines for Hazard Evaluation Procedures" (2nd edition), furnish comprehensive information on conducting PHA across various industries, with a specific focus on petroleum refining (Center for Chemical Process Safety (CCPS), 2018).

2. American Petroleum Institute (API):

As a prominent trade association in the petroleum industry, API plays a significant role in developing standards and recommended practices. API's "Recommended Practice 750: Management of Process Hazards" provides guidance on executing PHA within refinery operations. It delineates the steps, methodologies, and considerations essential for identifying and analyzing hazards specific to petroleum refineries (American Petroleum Institute (API), 1991).

3. Lees' Loss Prevention in the Process Industries:

The book "Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control" by Frank Lees offers a comprehensive overview of process safety and hazard analysis. It encompasses various hazard analysis techniques, including PHA, with a specific emphasis on their relevance to the petroleum industry (Lees. 2012).

4. American Society of Safety Professionals (ASSP):

The ASSP, a provider of professional resources on occupational safety and health, offers publications such as technical papers and articles that frequently delve into topics related to hazard analysis and risk management in petroleum refineries. These resources provide valuable insights into the application of PHA techniques in refinery operations. American Society of Safety Professionals (ASSP) (www.assp.org., 24.12.2023).

5. Petroleum Refinery Engineering Textbooks:

Textbooks dedicated to petroleum refinery engineering, such as "Petroleum Refining in Nontechnical Language" by William L. Leffler and "Refining Processes Handbook" by Surinder Parkash, often incorporate sections on hazard analysis and safety management. These texts not only offer practical information but also include case studies that aid in comprehending and implementing PHA within the unique context of petroleum refineries.

By referring to these esteemed resources and adhering to industry standards, operators and engineers in the petroleum refinery domain can access comprehensive guidance for conducting effective PHA studies. This ensures the identification and mitigation of hazards, thereby fostering the safety and reliability of refinery operations (Bierly, 2000).

IV. Fault Tree Analysis (FTA) in the Petroleum Refinery Industry

Fault Tree Analysis (FTA) stands as a potent tool in the petroleum refinery sector, systematically employed to analyze and comprehend the causes and consequences of complex system failures or accidents. FTA is adept at identifying potential faults, assessing their probabilities, and delineating critical factors contributing to hazardous events within refinery settings. Numerous references provide guidance on executing FTA tailored to the context of petroleum refineries: (JŻyżyński et al., 2019).

1. American Petroleum Institute (API):

API, a leading trade association in the petroleum industry, has disseminated recommended practices and standards concerning risk analysis and safety management. API RP 14C, titled "Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms," offers guidance on FTA, particularly for offshore facilities, but its principles are adaptable to petroleum refineries. It furnishes insights into applying FTA techniques and considerations germane to refinery safety (American Petroleum Institute (API), 2007).

2. Center for Chemical Process Safety (CCPS):

The CCPS, affiliated with the American Institute of Chemical Engineers (AIChE), has crafted comprehensive resources on process safety, including FTA. The publication "Guidelines for Hazard Evaluation Procedures" (2nd edition) from CCPS provides guidance on FTA and elucidates the steps involved in constructing fault trees. While not refinery-specific, these guidelines offer valuable insights applicable across diverse industries (Center for Chemical Process Safety (CCPS)., 1992).

3. Lees' Loss Prevention in the Process Industries:

Frank Lees' book, "Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control," spans a wide array of process safety topics, encompassing FTA. The book provides intricate explanations of FTA methodology, supplemented by case studies and examples pertinent to the petroleum industry.

4. International Electro technical Commission (IEC):

IEC has promulgated standards related to FTA, such as IEC 61025, specifically addressing Fault Tree Analysis. While not confined to petroleum refineries, these standards furnish general guidelines and best practices for executing FTA. They can be tailored to the refinery context to conduct effective risk assessment and management (IEC 61882, 2016).

5. Academic Research Papers:

Academic research papers serve as valuable resources exploring specific applications of FTA within the petroleum refinery industry. These papers offer insights derived from case studies, methodologies, and lessons gleaned from FTA analyses conducted in refinery settings. A comprehensive search across academic databases and journals dedicated to process safety engineering and refinery operations can yield pertinent references.

By leveraging these resources and adhering to industry standards, petroleum refinery operators and engineers can adeptly apply FTA. This application facilitates the identification of critical failure scenarios, comprehension of causative factors, and the formulation of targeted risk mitigation strategies. Ultimately, this contributes to accident prevention and ensures the safety of refinery operations (IEC 61882, 2016).

V. Event Tree Analysis (ETA) in the Petroleum Refinery Industry

Event Tree Analysis (ETA) stands as a valuable tool in the petroleum refinery sector, utilized for the assessment and analysis of potential outcomes and consequences arising from specific events or incidents. ETA, being a forward-looking technique, visually represents the plausible sequences of events that may unfold following a particular initiating event, ultimately leading to various outcomes. This method aids in comprehending the risks associated with refinery operations and supports decision-making for the formulation of risk mitigation strategies. Several references offer guidance on executing ETA within the context of petroleum refineries: (IEC 61882, 2016).

1. American Petroleum Institute (API):

API, a prominent trade association in the petroleum industry, has disseminated recommended practices and standards pertaining to risk analysis and safety management. API RP 14J, titled "Design and Hazards Analysis for Offshore Production Facilities," provides guidance on ETA for offshore facilities but holds relevance for petroleum refineries. It furnishes insights into the application of ETA techniques and considerations germane to refinery safety.

2. Center for Chemical Process Safety (CCPS):

The CCPS, affiliated with the American Institute of Chemical Engineers (AIChE), has developed comprehensive resources on process safety, including ETA. Their publication "Guidelines for Hazard Evaluation Procedures" (2nd edition) offers guidance on conducting ETA, elucidating the steps involved in developing event trees.

3. Lees' Loss Prevention in the Process Industries:

Frank Lees' book, "Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control," spans a wide array of process safety topics, including ETA. It provides detailed explanations of ETA methodology, supplemented by case studies and examples relevant to the petroleum industry.

4. Academic Research Papers:

Academic research papers delve into specific applications of ETA in the petroleum refinery industry, offering insights from case studies, methodologies, and lessons learned from ETA analyses in refinery settings. Exploring academic databases and journals related to process safety engineering and refinery operations can yield valuable references.

By leveraging these resources and adhering to industry standards, petroleum refinery operators and engineers can effectively apply ETA. This application enables the assessment of potential consequences associated with events, identification of critical paths leading to undesirable outcomes, and the development of targeted risk mitigation strategies to prevent or minimize the impact of incidents in refinery operations (Jalali et al., 2019).

VI. Bow-tie Analysis in the Petroleum Refinery Industry

Bow-tie Analysis stands out as a potent risk assessment and management tool widely employed in the petroleum refinery sector. Its primary purpose is to identify, analyze, and visually represent potential hazards, their causes, and the corresponding preventive and meditative barriers. This method offers a clear and concise depiction of the interrelationships between hazards, causes, consequences, and control measures, facilitating a comprehensive understanding and effective communication of risks. Various references provide guidance on conducting Bow-tie Analysis in the context of petroleum refineries (Emam, 2011).

1. Energy Institute (EI):

The EI, a prominent professional membership body in the energy sector, has issued guidelines on Bow-tie Analysis in their publication "Guidelines for Barrier Risk Management" (2nd edition). This resource furnishes detailed information on the application of Bow-tie Analysis, encompassing its implementation in petroleum refinery settings and the integration of barriers.

2. Center for Chemical Process Safety (CCPS):

The CCPS, affiliated with the American Institute of Chemical Engineers (AIChE), has produced comprehensive resources on process safety, incorporating Bow-tie Analysis. Their publication "Bow Ties in Risk Management: A Concept Book for Process Safety" provides an in-depth understanding of the Bow-tie Analysis methodology, its advantages, and practical applications in various industries, including petroleum refineries (Center for Chemical Process Safety, 2010).

3. Lees' Loss Prevention in the Process Industries:

Frank Lees' book, "Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control," covers an extensive range of process safety topics, including Bow-tie Analysis. It imparts insights into the application of Bow-tie Analysis in petroleum refineries, accompanied by case studies and examples specific to the industry (Lees, 2012).

4. Academic Research Papers:

Academic research papers frequently delve into the application of Bow-tie Analysis in the petroleum refinery industry. These papers offer insights into case studies, methodologies, and practical experiences of implementing Bow-tie Analysis for risk assessment and management in refinery operations. A thorough exploration of academic databases and journals related to process safety engineering and refinery operations can yield valuable references.

By consulting these resources and adhering to industry standards, petroleum refinery operators and engineers can proficiently apply Bow-tie Analysis. This application enables the identification of critical hazards, an understanding of their causes and consequences, and the development of targeted control measures and barriers to prevent or mitigate incidents in refinery operations (Matin et al., 2017).

2.7 Overview of Major Petroleum Refinery Accidents and the Lesson Learned

Major accidents in the petroleum refinery industry have highlighted the need for comprehensive understanding and lessons learned. These accidents, often resulting in fatalities, injuries, and asset damage, can occur due to complex interactions among subsystem failures, design errors, operational procedures, and safety-related issues.

Hazardous events that lead to accidents are typically beyond immediate control and are caused by the accumulation of failures related to technical risks, organizational risks, operational risks, inadequate knowledge for making risk-informed decisions, and external factors.

Valuable insights into the causes of accidents in the petroleum refining industry are derived from various sources, including institutions like the UK HSE, the Chemical Safety and Hazard Investigation Board (CSB) in the United States, Japan's science and technology agency, and journals focusing on petroleum, chemical, and petrochemical industry accidents. These reports and journals offer comprehensive knowledge regarding different accidents, their underlying causes, lessons learned, and proposed recommendations to prevent future occurrences.in additional sources by key personal interview with key persons in target refinery.

By analyzing information from these sources, a better understanding of common patterns and the sequence of events that lead to accidents can be obtained. Lessons learned from past petroleum refinery accidents provide valuable insights into recurrent issues that have contributed to these incidents. This knowledge allows for the identification of preventive measures and the implementation of effective safety practices to mitigate risks and avoid similar accidents in the future.

2.8 Challenges and Accidents that Occurred Inside and Outside Iraq in Petroleum Refinery

2.8.1 Chevron Richmond Refinery catastrophe

On August 6, 2012, a catastrophic incident unfolded at the Chevron Richmond refinery in California, USA, when a critical pipe in crude unit 4 experienced a catastrophic failure. Specifically, a 52-inch-long carbon steel component within the crude unit 4 pipeline ruptured, releasing flammable hydrocarbons. These hydrocarbons formed a substantial vapor cloud, which subsequently engulfed 19 Chevron employees and ignited. Fortunately, most of the employees narrowly escaped serious injuries. The continuous combustion of the ignited flammable hydrocarbons from the process led to the release of toxic particulates and vapors, which spread across Richmond, California. This incident had a profound impact on nearly 15,000 individuals residing and working in the surrounding area.

Several factors and circumstances contributed to the initiation of this accident, as documented by the Chemical Safety and Hazard Investigation Board (CSB) in 2015:

The rupture of the pipe in the refinery's crude unit was caused by sulfidation corrosion. This corrosive process was triggered by sulfur compounds naturally present in the crude oil. Under high temperatures ranging from approximately 450 to 800 degrees Fahrenheit (ºF), these compounds attacked the steel pipes, resulting in severe thinning of the pipe wall near the rupture site.

1. There was an absence of adequate inspection protocols to monitor and manage suffixation corrosion.

2. Chevron's technical team failed to conduct a thorough assessment of corrosion and damage mechanisms within the crude unit.

3. Inherent safety measures that could have identified sulfidation corrosion as a significant hazard were not effectively implemented.

4. Prior to the incident, Chevron's management failed to implement internal recommendations from technical staff to inspect and upgrade high-temperature carbon steel piping susceptible to sulfidation corrosion to 9-Chrome.

5. The process hazard analysis conducted by Chevron's Richmond refinery crude unit failed to identify sulfidation corrosion as a potential underlying cause of leaks or pipe ruptures.

6. Chevron's Management of Change (MOC) process did not encompass crucial aspects of employee recommendations, ultimately allowing the 52-inch component to remain in service.

7. The safety management system in place was ineffective in preventing the accident.

8. In summary, the Chevron Richmond refinery accident of August 6, 2012, was a result of multiple contributing factors, including sulfidation corrosion, inadequate inspection and safety measures, failure to implement recommendations, and deficiencies in the safety management system

2.8.2 Major Incidents at Tesoro Anacortes Refinery and McKee Refinery

On April 2, 2010, a significant incident occurred at the Tesoro Anacortes petroleum refinery during the start-up process aimed at restoring the operation of the A/B/C bank of heat exchangers. These heat exchangers had previously undergone cleaning to remove contaminants that had caused fouling, disrupting their normal operational conditions. The accident unfolded in the catalytic reformer/naphtha hydro-treated unit of the refinery, resulting in the catastrophic rupture of a heat exchanger. This rupture was attributed to High-Temperature Hydrogen Attack (HTHA), leading to the release of highly flammable hydrogen and naphtha at temperatures reaching 500 degrees Fahrenheit (ºF). The released gases ignited, causing a powerful explosion and a fierce fire that raged for three to four hours. Tragically, seven Tesoro employees working in close proximity to the heat exchanger during the start-up activity suffered fatal burns. Among the injured were a shift supervisor and six operators.

The Tesoro Anacortes Refinery's NHT (naphtha hydrotreater) unit comprised two sets of heat exchanger banks, labeled A/B/C and D/E/F. These heat exchangers played a crucial role in preheating process fluids before entering a reactor, where contaminants were treated for subsequent removal.

According to the report from the Chemical Safety and Hazard Investigation Board (CSB) in 2012, the heat exchanger that ruptured was Heat Exchanger E, situated within the operating bank of heat exchangers D/E/F. The events and conditions that led to this accident included:

1. Increased mechanical stress resulting from the start-up of the A/B/C heat exchangers, which temporarily raised the temperature. This increase in temperature exceeded the material strength of the critically weakened Heat Exchanger E, ultimately causing its rupture at its most vulnerable point.
2. Emergency, Response. Prevention, Office. (1998). EPA chemical accident investigation report:
3. Near the town of Sunray, Texas had severe consequences, according to the report from the Chemical Safety and Hazard Investigation Board (CSB). In this incident, liquid propane was unintentionally released from a control station located near the extraction tower within the Propane De-Asphalting (PDA) unit of the refinery. The released propane subsequently formed a vapor cloud that encountered a source of ignition as it migrated towards the boiler house, leading to a fire that inflicted serious injuries upon four refinery workers. The fire also resulted in damage to the unit's piping and equipment, as well as a major pipe rack. Furthermore, the fire extended to other units within the refinery, including the storage area for LPG (liquefied petroleum gas). As a consequence, the refinery remained shut down for nearly two months, and its operational capacity was reduced for nearly a year.
4. The sequence of events and conditions that precipitated this accident, as identified by the CSB in 2008, encompassed several key factors:
5. The root cause of the accident lay in adverse weather conditions that led to the freeze-related fracturing of high-pressure piping, specifically at an elbow situated within a propane mix control station. This control station had been out of service for approximately 15 years and allowed water to accumulate in the low point created by the station.
6. The McKee Refinery lacked established measures for the identification, evaluation, and protection against freezing of dormant or intermittently used piping and equipment, such as the propane mix control station.

7. Emergency isolation valve procedures were not adequately employed by the McKee Refinery when assessing risks within the PDA unit. This failure to ensure swift isolation of large quantities of flammable materials within the unit in case of an emergency was a critical oversight.
8. The process hazard analysis (PHA) conducted for the PDA unit failed to identify the specific hazards that ultimately contributed to the incident.
9. When the control station was taken out of active service, the McKee refinery did not conduct a thorough Management of Change (MOC) review. Consequently, the freeze-related hazards associated with the dormant control station's dead-leg were neither identified nor rectified.

2.8.3 Tragedy Unveiled: The BP Texas City Refinery Disaster of March 23, 2005

On March 23, 2005**,** a devastating incident occurred at the BP Texas City refinery, which at the time was the third-largest oil refinery in the United States. Prior to the incident, Amoco owned the refinery, but BP had merged with Amoco in 1999 and had taken over its operation. This tragic accident resulted in explosions and fires that claimed the lives of 15 individuals, injured 180 others, and incurred financial losses exceeding $1.5 billion. The incident transpired during the start-up of an isomerization (ISOM) unit when an overfilling of the raffinate splitter tower occurred. This overfilling caused pressure relief devices to activate, resulting in the release of a flammable liquid geyser from a blow down stack that lacked a flare. The released flammable substance found an ignition source in close proximity to office trailers near the blow down drum, leading to a catastrophic explosion and fire. All recorded fatalities took place within the office trailer area, and properties up to three-quarters of a mile away from the refinery were damaged.

This accident stands as one of the most severe industrial disasters in recent U.S. history.

The events and conditions that set the stage for this tragedy, as outlined in the Chemical Safety and Hazard Investigation Board (CSB) report in 2007, encompassed several critical factors:

Operational personnel deviated from the ISOM start-up procedure, resulting in the overfilling of the raffinate splitter tower with flammable liquid hydrocarbon.

Critical alarms and control instrumentation provided false indications that failed to alert operators to the high level of flammable liquid and elevated pressure within the tower.

The presence of occupied trailers in close proximity to the process unit where the start-up operation was initiated.

Inadequate supervision, insufficient staffing levels, and a lack of technically trained personnel during the start-up phase.

Poor communication of crucial information regarding the start-up process during shift turnovers among operators and supervisors.

Severe work fatigue experienced by ISOM operators who worked 12-hour shifts continuously for 29 days.An inadequate operator training program.

Outdated and ineffective procedures that failed to address recurring operational issues.A lack of effective key safety systems.

BP Texas City management's failure to implement an effective safety review policy before the start-up, BP's responsibility for mechanical integrity program deficiencies, which contributed to process equipment failures at the Texas City refinery. BP's poor management practices and insufficient safety monitoring and auditing efforts, which also played a role in the incident.

2.8.4 ISIS in Iraq

The conflict-ridden years of 2014 and 2015 in Iraq witnessed a dire incident that unfolded with devastating consequences. The ongoing battles against ISIS not only left a trail of destruction but also inflicted severe damage upon the infrastructure of several refineries. This incident, compounded by a series of other unfortunate factors, triggered a calamity of unimaginable proportions catastrophic environmental release of a multitude of hazardous chemicals, including the notorious polycyclic aromatic hydrocarbons (PAHs).

In response to this unprecedented disaster, an exhaustive six-month-long investigation was launched, marking a historic endeavor aimed at understanding the extent of the incident. The focal point of this investigation was the measurement of 16 distinct PAHs in the vicinity of the oil refineries located along the Tigris River and its estuaries.

The investigation delved deep into the heart of the incident, scrutinizing the concentrations of these 16 PAHs in both surface water and sediments near several oil refineries, including Baiji, Kirkuk, Al-Siniyah, Qayyarah, Al-Kasak, Daura, South Refineries Company, and Maysan. The outcome of this painstaking effort unveiled a grim reality the concentrations of these 16 PAHs exhibited a staggering variation. Water samples recorded levels ranging from 567.8 to an alarming 3750.7 ng/L, while sediment samples painted an even more ominous picture, with values spanning from 5619.2 to a terrifying 12795.0 ng/g.

The NORTH Refineries Company emerged as the epicenter of this environmental catastrophe, with the water samples collected from its vicinity showing the highest PAH concentrations. Meanwhile, Baiji oil refinery bore the weight of infamy, with sediment samples from its location exhibiting the most extreme PAH levels recorded.

What made this incident even more unsettling was the predominant presence of high molecular weight PAHs, characterized by 5 to 6 rings, in both water and sediment samples. These ominous compounds dominated the landscape, constituting a significant portion of the total PAH content—ranging from 49.41% to a chilling 81.67% for water samples and from 39.06% to a spine-chilling 89.39% for sediment samples. This revelation cast a haunting shadow over the incident, intensifying its severity.

As the investigation delved further into the heart of this environmental tragedy, it became apparent that the primary sources of these 16 PAHs in the Tigris River's water and sediment samples were pyrogenic in nature—a somber reminder of the fiery destruction that had unfolded.

The environmental repercussions of this incident were profound. An assessment based on sediment quality guidelines (SQGs) revealed that the majority of the sites fell within a potential effect range. Occasional biological effects stemming from elevated PAH concentrations haunted the sediment samples, further underscoring the gravity of the situation. To compound the tragedy, the calculated incremental lifetime cancer risk (ILCR) value pointed to an exceptionally high level of risk. The looming threat of adverse health effects, including the specter of cancer, loomed ominously over those who had been unwittingly exposed to these treacherous PAHs. This incident serves as a somber reminder of the enduring consequences of conflict, etching its tragic mark on the region's history (www.bbc.com., 21.12.2023).

Figure 2.2: Clarifying ISIS Control over the Baiji Refinery

Source: (www.Al-Jazeera.com., 22.2.2024)

2.8.5 Tragedy at Salahaddin 1 Refinery (in Baiji Refinery): A Fatal Mishap, operational lapses, and financial repercussions

In 2011, during maintenance work on the equipment (air fan) used for condensing and cooling petroleum products in the oil refining unit at Salahaddin 1 refinery in Baiji refinery, a technical malfunction occurred in the air fan. The following day, a team from the rotating equipment department arrived to check the cause of the malfunction without informing the operating team in the refining unit that they were conducting maintenance work. Meanwhile, the maintenance engineer was entering and climbing inside the fan. At the same time, the operating team inadvertently started the fan without knowledge of the maintenance engineer inside it, resulting in the engineer's death. This incident had a psychological impact on the operators of the refinery belonging to the refining unit, in addition to causing delays in maintenance work, which led to a failure to meet the technical specifications of the product. As a result, most of the products had to be transferred to the slop tank, causing significant financial losses to the Baiji refinery company.

The circumstances and causes that led to this accident were as follows:

Failure to fully comply with safety procedures.

1. Lack of coordination between the technical team (maintenance employee and operating staff).
2. Aging equipment in need of regular, scheduled, and planned maintenance rather than ad hoc maintenance.
3. Absence of effective management.
4. Operating conditions exceeding control limits.

2.8.6 Unforeseen Tragedy: The 2012 Liquid Gas Unit Incident at Baiji Refinery

The incident that occurred during the annual maintenance of the Liquid Gas Unit in Baiji refinery in 2012 had several contributing factors that led to the unfortunate outcome.

One of the main factors was the failure to properly manage the steam injection process. Due to time constraints, the required level of steam injection was not followed. This deviation from proper procedures and standards compromised the safety of the maintenance work and increased the risk of accidents.

Additionally, the person responsible for overseeing the unit lacked the necessary experience and technical knowledge. This deficiency in expertise likely led to poor decision-making and inadequate supervision during the maintenance activities. Lack of experience and knowledge can result in overlooking critical safety measures and failing to recognize potential hazards, which can have severe consequences.

It was an accident, the maintenance team begins the maintenance stages, which are emptying and then introducing steam at a pressure of 4.5 bar into the unit to expel the gases and remove them through the drainage and drainage valves. Welding works were performed, and it was found that the 12-Inch drain valve needed to be replaced. This is considered a push valve from the stabilization tower and pump to the furnace and then back to the stabilization tower to absorb the liquid gas with the saturated naphtha. After a week of maintenance work, one of the officials directed that steam be introduced into the furnace room, which led to the irritation of the hydrocarbon materials deposited inside the furnace tubes and led to the backfire to the pump and the occurrence of a large fire that led to the burning of the maintenance worker.

The accident caused significant material losses through damage to parts of the pump and the lower part of the tower, and confusion among workers due to the fire, which caused a delay in the production of liquid gas.

Circumstances leading to the accident:

Inappropriate decision by the unit official regarding steam pumping due to a lack of sufficient experience

1. Inadequate warning signs indicating the danger of “ignition hazard of hydrocarbons.”
2. There are no barriers and appropriate safety distances.
3. The work and maintenance permit form does not mention the presence of hydrocarbon materials deposited in the furnace, and they thought they got rid of them during the unloading process.
4. Lack of guidance and training for personnel performing maintenance and operation near the liquid gas unit

2.8.7 Crisis Unleashed: The Catastrophic 2012 Incident at Baiji Refinery's Liquid Gas Unit

In 2012, at the Liquid Gas Unit in the north Refinery Sector of Baiji refinery, after the annual maintenance, the unit was immediately operated at a pressure of 15 bar through corroded and old pipelines. This led to the ignition of a flame that struck the butane vessel and caused it to explode. Despite the presence of protective layers in the vessel, the fire managed to penetrate through those layers due to the high pressure. The massive fire resulted in the death of one person and injured 30 others. To this day, the malfunction that caused the fire has not been repaired, leading to billions of dollars in losses for the company.

The circumstances that led to this incident include several factors. There was a lack of inspection by the maintenance team regarding the corroded condition of the pipeline, leading to its use without proper repair or replacement.

the steps and stages of operation were shortened from startup to stability state directly,

the safety valve should have had an arm, but it was armless in this case.

1. The management of the gas refining unit at that time failed to provide effective maintenance planning.
2. It also failed to formulate a plan to control known risks.
3. Lack of proper supervision of maintenance activities by the operations supervisor
4. Safety management failed to conduct documented audits.

3. METHODOLOGY

3.1 Summary

Outlining a conceptual framework designed to improve the safety of petroleum refinery operations. The chapter delves into the foundational principles of the methods employed at each stage within the conceptual framework.

This chapter delineates the fundamental methodology employed in this research. It establishes the philosophical underpinnings of the adopted research methodology within a novel conceptual framework. The research methodology serves as the blueprint for the entire investigation, outlining the researcher's intended strategy or plan of action from initiation to conclusion. In the context of this chapter, research is defined as a structured, systematic, data-based, critical, objective, and scientific inquiry aimed at addressing specific problems (Sekaran and Bougie, 2001). p.135, as cited in (Abubaker, 2013).

When undertaking research, three fundamental methods come into play: the quantitative research method, qualitative research method, or a combination of both. The qualitative research method places a strong emphasis on the phenomenological aspect of the study, involving a detailed description of a phenomenon or cultural study (Creswell, 2003). This approach to qualitative research entails discovering and understanding the meaning attributed to a problem based on individual or group judgments, perspectives, and perceptions. Qualitative research methods may be conducted through empirical study, material case study, personal experience, brainstorming sessions, historical information, interviews, and observation.

The qualitative research method is characterized by its constructive, interpretive, and inductive nature. On the other hand, quantitative research methods are identified as statistical studies, empirical studies, or hypothesis testing research. Various strategies are employed in quantitative research, such as self-administered questionnaires, experimental studies, quasi-experimental studies, pre-test and posttest designs, as well as structured interview and observation schedules (Polkinghorne, 2005).

Fundamentally, research methods encompass the procedures for data collection, analysis, and interpretation that a researcher employs throughout their research endeavors. In this particular study, the process of acquiring data is rooted in pertinent knowledge extracted from experts in the field of study. Consequently, this chapter is dedicated to detailing how the research was executed to fulfill its stated aims and objectives.

3.2 Research Design

The formulation of a fundamental research plan to address a research problem is crucial for ensuring the viability and validity of the research. The development of a systematic process to tackle significant research questions depends on the chosen research method. This research adopts a primary strategy centered on selecting and integrating the most effective qualitative and quantitative methods to address different facets of the research problem. A well-designed research plan establishes a close connection between research questions, methodology, data collection approach, the nature of data, and the data analysis process (Hox and Boeije, 2005).

The research design is characterized by the ideology of a conceptual framework, incorporating a specific theoretical perspective that accommodates both qualitative and quantitative data. Recognizing that no single method is universally applicable to all research questions, solving a research problem necessitates the incorporation of multiple methods, as various approaches are not mutually exclusive. The implementation of research methods and data collection techniques in this study entails the utilization of diverse theories and the gathering and integration of both qualitative and quantitative data within a unified research design. This approach aims to offset the limitations of one method by leveraging the strengths of the other. The data acquisition and its rationale in this research were determined through the employment of a questionnaire, literature survey, expert opinions, brainstorming/interviews, and case studies (Gill et al., 2008).

3.3 Population and Sampling Techniques

Once the primary research question is identified, a researcher can determine the type of informants or respondents to be involved in a research project. This decision-making process aids the researcher in shaping the questions posed to respondents in the research (Harrell and Bradley, 2009).

Given the elevated risk associated with operational activities in petroleum refineries, the selection of the right experts for investigating the risk of disruption in these operations is crucial for this research. Expertise is sought from individuals encompassing operators, managers, and consultants within the petroleum refining industry. The qualitative data collection in this study is guided by the careful selection of respondents from major crude oil-producing countries, possessing expertise in petroleum refinery operations. The process of random sampling involves consulting professionals and specialists distinguished by their extensive knowledge and experience in petroleum refinery operations. Therefore, the experts selected through random sampling are well-acquainted with the critical elements of risk inherent in their involvement. The capacity of each selected expert to articulate and assess which elements of risk have a greater impact on the disruption of petroleum refinery operations justifies their inclusion in this research. The criteria for randomly selecting these experts are grounded in their academic qualifications, skills, years of experience in the petroleum refining industry, and the positions they have attained.

The collection of valid data is facilitated for the purpose of risk assessment and decision support in the management of risks associated with petroleum refinery operations. In this thesis, the sample size ranges from 5 to 6 experts, comprising senior managers, process/mechanical/maintenance engineers, and consultants within the petroleum refining industry at Baiji Refinery. This sample size is deemed appropriate due to the expectation that specialists in the field share common values, justifying the use of a relatively smaller sample size (Saaty, 2001). as cited by (Mokthari, 2011). suggests that a small sample size (i.e., < 10 respondents) is sufficient when acquiring data from experts. In this research, these justifications provide the flexibility to effectively utilize the gathered data from the experts.

3.4 Data Collection Analysis

Selecting the most appropriate method for gathering data involves taking into account the inherent uncertainty associated with addressing research questions. Two prominent approaches to data collection are primary and secondary methods. Primary data collection involves obtaining fresh data tailored to a specific research objective, while secondary data collection entails using existing data for current research purposes (Harrell and Bradley, 2009). These methods are categorized as qualitative and quantitative research approaches.

Qualitative data collection methods have been widely employed in research to address diverse research questions, particularly when there is a need to comprehend complexity, interpretations, ideas, values, beliefs, and experiences. This approach contributes to making inferences in research. Qualitative data acquisition involves gathering evidence through document studies, literature reviews, case studies, interviews, brainstorming sessions, and expert judgments (Hox and Boeije, 2005). Conversely, quantitative data collection involves the gathering of numerical data.

For this research, primary data gathering involves a literature review, a questionnaire survey, brainstorming sessions with experts, and expert judgments. Data obtained through expert judgments are qualitative and come with a certain level of uncertainty, which is addressed using techniques such as fuzzy set theory. Additionally, qualitative data based on expert judgment can be converted into quantitative data for various stages of the research, such as risk/hazard identification and ranking, risk assessment, and risk mitigation. The credibility of this research is rooted in the systematic use of both qualitative and quantitative approaches to data collection, enhancing the accuracy, validity, and reliability of the research findings in a scientific and consistent manner (Sadiq and Tesfamariam, 2012).

In the pursuit of a comprehensive understanding of risk management within complex systems, this thesis employs the Fuzzy Failure Mode and Effects Analysis (Fuzzy FMEA) methodology as a pivotal analytical tool. The data collection design is strategically crafted to harness the capabilities of Fuzzy FMEA, which integrates fuzzy logic to handle uncertainties inherent in the assessment of failure modes and their potential impacts. To initiate the data collection process, a systematic approach is undertaken, beginning with a clear definition of research objectives and the identification of the specific Fuzzy FMEA tools to be utilized. The design involves a meticulous selection of linguistic variables, fuzzy numbers, and criteria for risk assessment within the defined system or process. Drawing insights from a thorough literature review on Fuzzy FMEA methodologies, this study establishes a robust framework for data collection, focusing on key variables and their interrelationships. The instruments for data collection, such as surveys and expert interviews, are tailored to capture imprecise information in alignment with Fuzzy FMEA principles. The sampling strategy is carefully devised to ensure a representative dataset, and the involvement of subject matter experts adds valuable insights to the fuzzy risk analysis. Ethical considerations are paramount in the design, and a rigorous validation process is implemented to maintain the integrity of the collected data. As a pivotal element of the research, this data collection design not only adheres to ethical standards but also lays the groundwork for a rigorous and nuanced analysis of risk within the chosen system or process (Mendel, 2001).

3.5 Data Analysis Techniques

When collecting data for research, the primary goal is typically either to formulate or refute a hypothesis, contributing to the development of a scientific theory that elucidates the observed behavior of the subject under investigation. Consequently, it is crucial to assess the quality and depth of the collected data to enhance the overall research findings. The thorough examination of data collected for research purposes should offer detailed insights into perceptions and experiences, serving as a valuable supplement to the data. In this study, data were acquired through expert judgment using survey questionnaires and brainstorming sessions with experts. Employing such a data acquisition approach presents challenges related to incomplete information, biased judgment, and uncertainties regarding the experts' knowledge availability for delivering quality responses. This research addresses these challenges by implementing strategies to mitigate incompleteness, bias, and uncertainties in the experts' knowledge.

In the pursuit of a meticulous and sophisticated data analysis for this thesis, MATLAB emerges as a potent ally, seamlessly integrated with the Fuzzy Failure Mode and Effects Analysis (Fuzzy FMEA) methodology. MATLAB, renowned for its robust analytical capabilities, serves as a powerful tool to unravel the complexities inherent in fuzzy data analysis. The Fuzzy FMEA approach demands a nuanced treatment of uncertainties, and MATLAB provides a versatile platform to implement intricate algorithms and models tailored to the specific requirements of fuzzy logic applications (Yuhua. and Datao, 2005). Through the utilization of MATLAB scripts, this research endeavors to conduct an in-depth examination of linguistic variables, fuzzy scales, and expert-derived fuzzy numbers, extracting meaningful insights into the intricate relationships among variables identified during the data collection phase. The synergy between MATLAB's computational prowess and Fuzzy FMEA's methodology is expected to yield a comprehensive analysis, elucidating the risk priorities within the studied system or process. This integration not only enhances the precision of the analysis but also empowers the exploration of intricate patterns and correlations that might elude traditional data analysis methods. By leveraging MATLAB in conjunction with Fuzzy FMEA, this research aspires to contribute to the cutting-edge advancements in risk management and underscore the efficacy of a multidimensional analytical approach in addressing the uncertainties inherent in complex systems (Amiri, 2010).

3.5.1 Analysis methods

3.5.1.1 FMEA failure mode and effect analysis

Petroleum refineries, serving as the backbone of the global energy sector, operate in an environment where safety is paramount. The complex processes involved, coupled with inherent hazards, demand rigorous risk management strategies. Among these strategies, Failure Mode and Effect Analysis (FMEA) has emerged as a crucial tool for identifying, assessing, and mitigating potential risks within petroleum refineries.

Understanding FMEA:

Failure Mode and Effect Analysis (FMEA) is a systematic and analytical methodology (Shafiee et al., 2019). employed to evaluate potential failure modes within a system. Its primary objectives are to comprehensively assess the consequences of these failure modes and prioritize them based on the. parameters of severity, occurrence, and detectability. In essence, FMEA allows refineries to take a proactive stance towards risk management by identifying vulnerabilities and mitigating potential risks before they manifest (Chen-qin and Yue, 2012).

Table 3.1: Rating and Interpretation for Severity S Occurrence O and Detection D

Description				
Rating	Meaning	Severity (S)	Occurrence (O)	No detection (D)
1	Al-most none	Failures and defects do not impact performance metrics.	The likelihood of a defect occurring is low. The likelihood is nearly negligible.	Detecting emerging failures is impossible due to a lack of access or opportunity for control.
1,2,3	Low	Defects are repairable and can be easily rectified.	Highly negligible likelihood.	Identifying emerging failures poses challenges, and technological checks prove ineffective.
4,5,6	Medium	Failures result in a gradual decline in structural safety and a reduction in performance indicators.	Moderate likelihood of a defect.	Detecting failures proves challenging during the control and testing phases.
7,8	High	Defects have the potential to lead to ruptures and accidents in pipelines.	The construction adheres to the plans, even in the face of numerous past failures.	Identifying failures is a straightforward process.
9,10	Very High	Failure poses a risk to safety (endangering life and health) and goes against legal regulations.	Defects are unavoidable.	If failures occur, they are readily identified, with a detection probability exceeding 95%.

Source: (Ahmed and Gu, 2020).

Mathematical Foundations:

At the core of FMEA lies a mathematical formula that calculates the Risk Priority Number (RPN) for each identified failure mode. This formula, expressed As

Severity× Occurrence× Detectability

RPN= Severity × Occurrence × Detectability (3.1)

Assigns numerical values to three critical parameters.

Severity (S): Severity ratings quantify the impact of each failure mode on safety, environmental integrity, and overall refinery operations. The higher the severity rating, the more critical the consequences.

Occurrence (O):

Occurrence ratings assess the likelihood of each failure mode happening. Historical data, industry benchmarks, and maintenance records contribute to this assessment.

Detectability (D):

Detectability ratings evaluate the effectiveness of existing monitoring and control systems in identifying a failure mode before severe consequences occur.

Multiplying these three ratings results in the RPN, a numerical indicator that guides refineries in prioritizing their efforts and resources toward the most critical areas of risk (Smith and Reliability, 1993).

Application in Petroleum Refineries:

The application of FMEA in petroleum refineries involves assembling cross-functional teams with expertise in process engineering, safety, maintenance, and operations. These teams systematically identify potential failure modes, assess their consequences, and assign severity, occurrence, and detectability ratings. The calculated RPN values offer a quantitative basis for prioritizing mitigation efforts, ensuring a targeted and effective approach to risk management (Mandal and Maiti, 2015).

Real-World Significance:

The real-world significance of FMEA in petroleum refineries is underscored by industry standards and guidelines. "Risk Management in Petroleum Refineries: A Comprehensive Guide" by J. Smith provides practical insights into the application of FMEA, offering a comprehensive understanding of risk management strategies tailored to the intricacies of refinery operations. Additionally, the "API Recommended Practice 571: Damage Mechanisms Affecting Fixed Equipment in the Refining Industry" published by the American Petroleum Institute outlines crucial considerations for identifying and managing potential failure modes in refinery equipment (Smith and Reliability, 1993).

Furthermore, "Failure Mode and Effect Analysis: A Practical Guide for Refinery Operations" by R. Paul delves into the practical aspects of implementing FMEA, providing real-world case studies and examples that enrich the understanding of how this methodology can be effectively applied in petroleum refining.

Risk Mitigation Strategies:

Once the FMEA analysis is complete, refineries can implement targeted mitigation strategies. These strategies may include upgrading equipment, enhancing monitoring systems, providing additional training, or revising standard operating procedures. The goal is to proactively eliminate or minimize the occurrence and impact of potential failures, thus enhancing overall safety (Stamatis, 2003).

In the dynamic and challenging landscape of petroleum refining, where safety is non-negotiable, Failure Mode and Effect Analysis (FMEA) stands as a beacon for risk management. Its mathematical foundation, particularly the RPN formula, offers a quantitative lens through which refineries can prioritize their efforts, ensuring a proactive and targeted approach to risk mitigation. As the energy industry continues to evolve, FMEA remains an indispensable tool, contributing significantly to the safety, sustainability, and operational excellence of petroleum refineries worldwide.

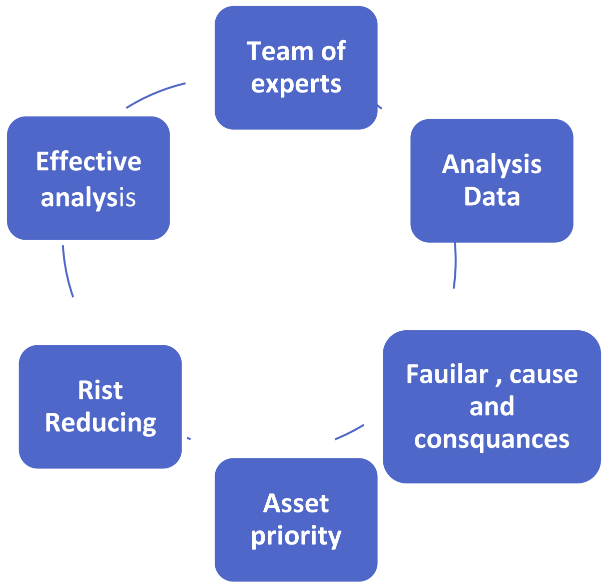


Figure 3.1: FMEA Analysis

Source: (www.swadesqms.com., 18.12.2023)

Conclusion, the adoption and implementation of FMEA in petroleum refineries represent a proactive and strategic approach to risk management. By leveraging its mathematical foundations and real-world applications, refineries can navigate the complexities of their operations with confidence, safeguarding both their personnel and the environment.

The drawbacks outlined above directly impact the Risk Priority Number (RPN), introducing several limitations in the conventional Failure Mode and Effect Analysis (FMEA) methodology (Yazdi et al., 2017).

These issues in the existing literature can be summarized as follows:

i. There is an underlying assumption that the parameters O, S, and D carry equal importance. However, in reality, the significance of risk parameters may vary based on the specific failure mode, leading to potential inaccuracies in real-life applications.

ii. Different combinations of risk parameters may yield the same RPN value, resulting in various outcomes for the system. This discrepancy can lead to inefficient allocation of resources and time, as well as a failure to prioritize high-risk failures promptly.

iii. The evaluations lack consideration of the relative importance assigned by experts, introducing a subjective bias into the assessments.

iv. Risk parameters are assessed independently for each failure mode, neglecting potential direct or indirect relationships between O, S, and D parameters.

v. RPN values exhibit high sensitivity to changes in risk parameters, emphasizing the need for experienced experts. Small alterations in O and S values can lead to substantial differences in the RPN value.

vi. Obtaining clear and precise ratings from experts for risk parameters is often challenging. Linguistic expressions are suggested as an alternative to convey more nuanced data.

vii. The numerical scale used to determine O, S, and D values is unspecified, leading to ambiguity. The use of a random numerical scale introduces complexities when combining factors, and the resulting numerical answer may lack clarity. To address these limitations and enhance the effectiveness of the FMEA process, various hybrid models have been developed in recent years. These models aim to overcome the constraints of traditional FMEA, especially considering the increasing complexity of the industrial landscape.

In this context, the application of fuzzy set theory has gained prominence as a method to eliminate the disadvantages associated with RPN calculation and to bolster the overall performance of FMEA. Fuzzy set theory provides a more flexible and adaptable framework, allowing for a nuanced representation of imprecise and uncertain information, which is particularly beneficial in the intricate domain of petroleum refineries. This approach contributes to a more accurate and realistic assessment of risks, thereby advancing the capabilities of FMEA in managing complex industrial processes (Cheng, 2010).

3.5.1.2 Fuzzy Logic

The term "fuzzy logic system" was coined by Lotfi A. Zadeh in the 1960s, representing an approach that moves beyond binary or opposing categories such as on/off, true/false, and one/zero. Instead, it embraces "shades of grey" and more diversified categories like large/very large. Fuzzy logic involves characterizing knowledge within rule bases and fuzzy sets, utilizing one or more "fuzzified" input values assessed by rule bases and then "defuzzied" for outputs (Khaleghi et al., 2013).

This sensitivity to imprecision and uncertainty enables the uniquely human ability to understand slightly noisy speech data, defects in natural language, interrupted or gapped texts, speech, summarizing, paraphrasing, as well as recognizing and grouping images. Fuzzy logic allows the specification of mapping rules in the form of vocabulary rather than numbers. This tool offers flexibility in decision-making, considering inaccuracy, subjectivity, uncertainty, and imprecision. Hence, it was applied to precisely determine S (Severity), O (Occurrence), and D (Detection) variables (Mendel, 2001).

The primary advantage of fuzzy theory applications in risk assessment lies in the qualitative and operational nature of the resulting system assessment, utilizing linguistic variables. Fuzzy logic effectively deals with subjective, incomplete, or unreliable knowledge bases, making it adept at establishing key points of any system with ease and precision. It concurrently evaluates risk factor levels, providing information on how they collectively contribute to risk indicators. This aids in establishing corrective measures and procedures to reduce risks. The Fuzzy Inference System (FIS) formulates input data to output data using fuzzy logic.

The Mamdani method is the most widespread Fuzzy Inference System (FIS) due to its simple structure, making it more intuitive and easier to understand. It is well-suited to expert system applications based on human expert knowledge, and it was chosen for this research for its compatibility with the research's purpose. The Mamdani FIS involves several steps.

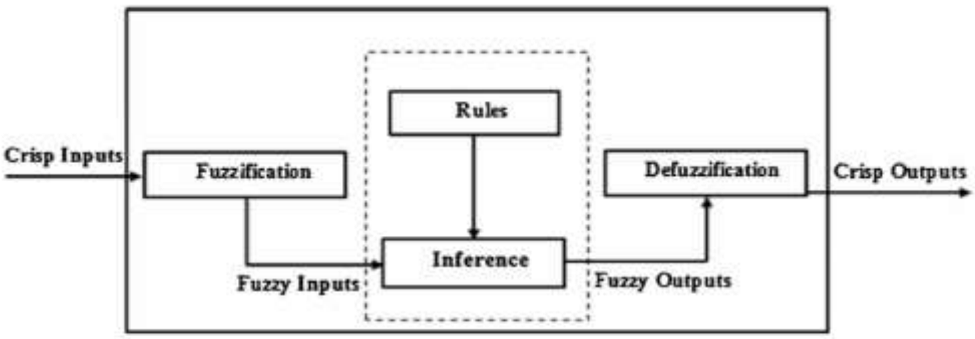


Figure 3.2: Fuzzy Logic System

Source: (Kumru, 2013).

Justification for the Utilization of Proposed Methodologies in This Study Anticipating the uncertain nature of acquiring historical failure data for modeling and analyzing complex risk scenarios within the Baiji Refinery, it is imperative to employ methodologies that exhibit flexibility and comprehensiveness. The inherent fuzziness of information regarding risk parameters calls for approaches that can efficiently handle uncertainty. The selection of methodologies in this research is justified based on the following reasons: (Mendel, 2001).

Flexibility in Expert Subjective Assessment: The methodologies integrated into the developed framework offer flexibility by allowing the use of experts' subjective assessments to quantify the criticality level of disruption risk elements and their attributes. This ensures an efficient assessment process without any loss of valuable information (Ross, 1995).

Handling Interactive Complexity: The methodologies are capable of coping with the growth of interactive complexity inherent in risk and decision modeling of complex scenarios. They facilitate hierarchical propagation of evidence between different levels in a model, addressing the challenge of incomplete knowledge about the relationship between variables within a given domain. These methodologies are chosen for their credibility, demonstrated in applications across various fields such as engineering and medical research, including medical prognosis, risk modeling for marine and offshore systems, and decision modeling for risk management criteria. They offer a practical and clear interpretation of uncertainty in the analysis of complex systems, particularly when relevant data is scarce (Anvaripour et al., 2014).

This chapter has provided a concise overview of the research methods adopted for each phase of the study. The conceptual framework, illustrating the research perspectives, aligns with the philosophy of the research. The research design, sampling frame, data collection method, data analysis, and data sources have been elucidated. The summary of the application of these research methods in each phase justifies the conceptual framework, emphasizing the appropriateness of the chosen methodologies to address the research objectives.

3.5.1.3 Fuzzy FMEA

Exploring Fuzzy FMEA: A Paradigm Shift in Risk Management for Enhanced Precision

In the realm of risk management, where uncertainties and complexities abound, traditional methodologies sometimes fall short in capturing the nuanced nature of real-world scenarios. Enter Fuzzy FMEA (Failure Mode and Effect Analysis), a dynamic approach that leverages fuzzy logic to address the imprecise and uncertain aspects inherent in risk assessments. This innovative paradigm offers a more flexible and adaptive framework, enhancing the precision and effectiveness of risk management strategies, particularly in industries like petroleum refineries (Tseng, 2005).

Understanding Fuzzy FMEA:

Fuzzy FMEA is an extension of the conventional FMEA methodology, introducing the principles of fuzzy logic to deal with imprecision, vagueness, and uncertainties in risk assessments. The core idea is to move beyond the binary nature of classical logic and embrace degrees of truth, allowing for a more realistic representation of risk factors and their interdependencies (Nasseri, 2008).

Categorizing Fuzzy FMEA Approaches:

In the literature, fuzzy FMEA approaches can be broadly categorized into two main groups: the fuzzy aggregation operator approach and the rule-based expert system approach. The former involves utilizing fuzzy aggregation operators to handle imprecise data, while the latter employs a rule-based system that mimics human decision-making processes, providing a more intuitive and context-aware analysis (Yousefi and Lajevardi, 2011).

Advantages of Rule-Based Fuzzy FMEA:

The rule based fuzzy FMEA, in particular, stands out as a powerful tool for risk management. This approach involves the creation of a rule-based expert system, which systematically models human knowledge and reasoning. By using if-then rules, this system can emulate expert decision-making, offering several advantages:

Data Interpretation: The rule based fuzzy FMEA system facilitates meaningful data interpretation by storing and processing information in a manner that aligns with human cognitive processes (Yousefi and Lajevardi, 2011).

Consistency: It enables the development of a more consistent risk management system compared to traditional methods, minimizing the impact of individual biases and variations.

Speed and Efficiency: The fuzzy rule-based system can generate solutions more rapidly, contributing to faster decision-making processes and response times in managing potential risks.

Overcoming Challenges with Fuzzy FMEA:

While Fuzzy FMEA brings a wealth of benefits, it is not without challenges. Building the entire rule base before initiating any inference process can be time-consuming and costly. However, this investment in the initial setup can lead to more accurate and adaptive risk assessments in the long run (Reis, 2005).

Fuzzy FMEA has found applications across various industries, including petroleum refineries. The complexities of refinery operations often involve uncertainties and dynamic interactions between different parameters. Fuzzy FMEA, with its ability to handle imprecise data and mimic human decision-making, proves invaluable in refining risk assessments and improving the overall safety of these critical facilities.

Fuzzy FMEA represents a paradigm shift in risk management, providing a more sophisticated and adaptive approach to deal with the uncertainties inherent in complex systems. The integration of fuzzy logic, particularly in rule-based systems, enhances the precision of risk assessments, offering a nuanced understanding of potential failure modes. As industries like petroleum refining continue to evolve, embracing Fuzzy FMEA can lead to more resilient risk management strategies, ultimately ensuring the safety, efficiency, and sustainability of critical processes.

In conclusion, the marriage of fuzzy logic and FMEA opens new avenues for refining risk management practices, offering a holistic and context-aware approach in an ever-changing industrial landscape.

In prior research, the FMEA method was utilized in combination with other quality tools to mitigate potential risks and instill confidence in the system. The assessment results from FMEA implementation were presented in terms of the Risk Priority Number (RPN), indicating problem severity. Correctly evaluating the RPN served as an indicator for taking corrective actions to minimize or eliminate potential risks. However, when the FMEA method was employed, certain drawbacks were identified. Consequently, various studies have proposed the implementation of FMEA to enhance process efficiency and address the mentioned drawbacks effectively in practical applications (Tseng, 2005).

A new technique was introduced in Reference, utilizing severity, occurrence, and detection in failure assessment. These parameters represented members of a fuzzy set to combine results through rule-based evaluation, employing min-max inference and subsequent defuzzification for risk assessment of failure. This approach prioritizes failures for corrective actions within the Failure Mode, Effects, and Criticality Analysis (FMECA) based on fuzzy logic. Another method, proposed in Reference, aimed to reduce rules and simplify the fuzzy logic based FMEA methodology by eliminating unnecessary rules in semiconductor manufacturing processes. Wang et al. demonstrated that distinguishing between two different failure modes proved challenging. Inconsistent verdicts arose due to varying levels of knowledge and judgment among different experts. Additionally, including or eliminating rules was not feasible if not reduced from a complete "if-then" rule base.

Therefore, deserving rule reduction was not accomplished comprehensively (Tay and Lime, 2006).

The application of a fuzzy-based FMEA to enhance Improved Analysis Precision: This approach effectively solved problems, explicitly identified potential failure modes and effects, and instilled confidence in the process.

An influential fuzzy rule-based method, proposed, offered specific advantages over traditional FMEA methods. These advantages included the ability to use linguistic terms in criticality assessment directly, the incorporation of ambiguity, qualitative and quantitative data in a consistent manner, and a more flexible structure for combining severity (S), occurrence (O), and detection (D) parameters (Lago, 2014).

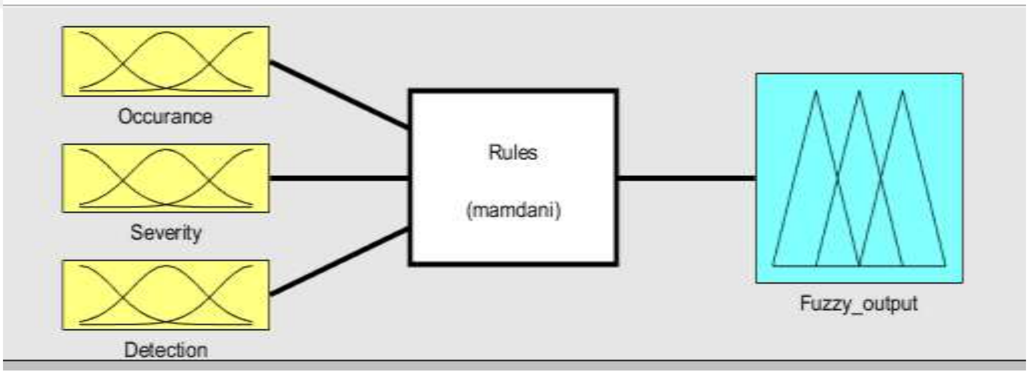


Figure 3.3: Fuzzy FMEA Model by MATLAB

Source: Prepared by the Researcher Based on Fuzzy logic Toolbox in MATLAB

The fuzzy logic system was grounded in the understanding that some problems did not necessitate precise values but could be solved based on prior expertise or knowledge. It leveraged probability theory in transferring crisp input to fuzzy input, processed through a fuzzy rule base created by experts. The resulting fuzzy output could be reverted to crisp output, making fuzzy logic a decision-making tool under conditions of uncertainty by allowing flexibility. Fuzzy logic, with its characteristics extending beyond Boolean logic, provided a more nuanced representation of partially true concepts, embracing values between completely true and false.

The algorithm for fuzzy logic involved defining linguistic variables and terms, constructing membership functions, building the rule base, fuzzification of crisp input data, rule evaluation, combining results, and defuzzification of output data. In the first stage, precise input data undergo a transformation into fuzzy values through a process known as fuzzification. Subsequently, the core of the inference processing involves considering rules within the fuzzy logic system. The evaluation of these rules and the combination of decision results form the basis for inference. Finally, a defuzzification step converts the fuzzy output into a crisp output corresponding to the system.

The linguistic variables' analysis data were utilized to elucidate the severity, occurrence, and detection of failures. These data served as inputs for fuzzification, determining the degree of membership in each input. The fuzzy inputs underwent evaluation using the rule base and fuzzy logic operations to identify the risk of failure modes and their associated degrees of membership in the risk category. Following defuzzification, the fuzzy output was transformed into a crisp output for prioritizing failure modes (Garcia, 2005).

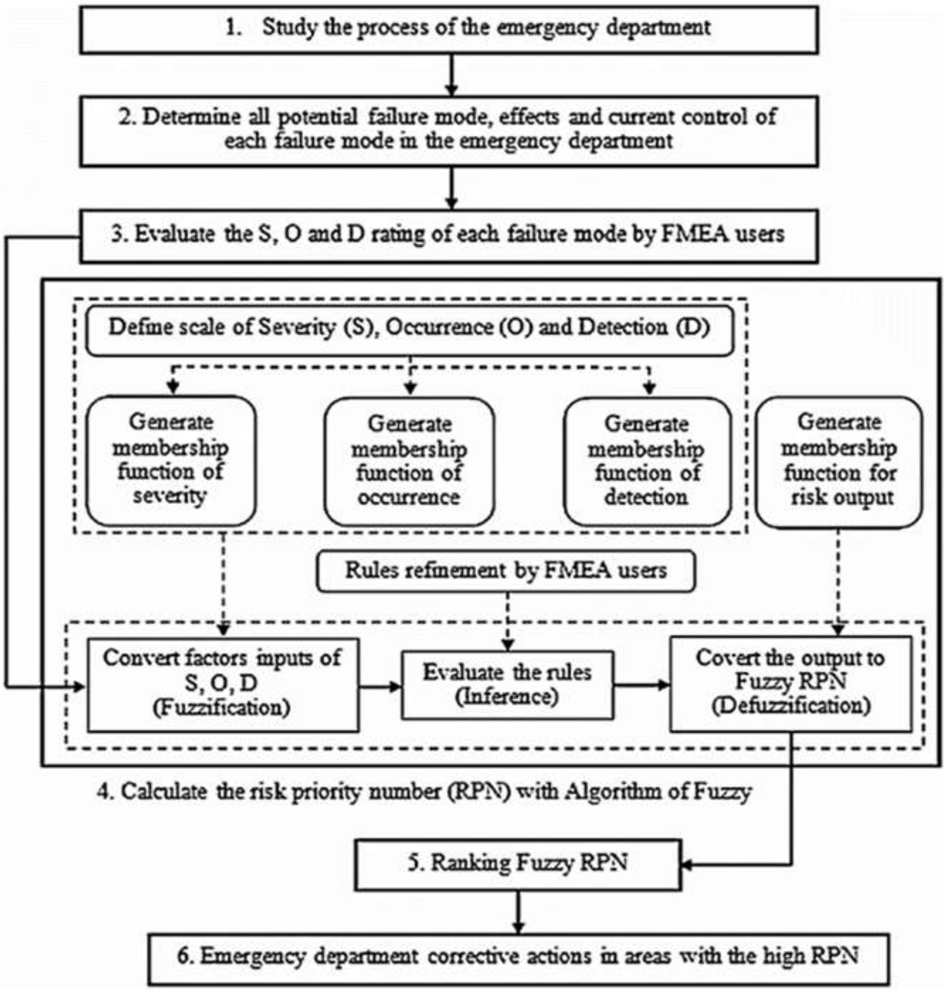


Figure 3.4: Fuzzy FMEA Steps

Source: (Nalinee Chanamool, 2015).

Fuzzification, as illustrated, involved converting crisp inputs to ascertain the degree of membership through the membership function, considered a viable solution under defined linguistic conditions. The rule base, established for controlling the output variable in the fuzzy logic system through if-then rules with provision and summing, played a crucial role. To yield results, the evaluation of each rule was combined in a process called fuzzy inference, allowing the calculation of rules based on the input. The widely adopted "min-max" inference technique, setting the true value of the rule as the minimum value, was prevalent. In instances where the output of a fuzzy set involved more than one rule, the subset was defined as the maximum real value. The Mamdani (max-min) method was commonly employed in the inference.

Following the evaluation of a rule, the overall result was a fuzzy value. This value underwent defuzzification to convert the fuzzy output into a crisp output. A function was constructed based on the membership function of the output variable, with the center of gravity (COG) method being a popular choice in this process.

$$COG = \frac{\sum_i^n xi.\mu i}{\sum_i^n \mu i} \tag{3.2}$$

COG is the center of gravity (COG) of the fuzzy output set.

- xi is the center point of the i- sub-interval in the output space.
- μi is the degree of membership of the output fuzzy set in the i- sub-interval.

Step.1. involves examining the Refinery units to understand the implementation process and develop a data collection form for analysis. Data for this study were gathered through observations and completed by Engineers, informed, and relevant authorities associated.

Step.2. the goal is to identify all potential failure modes, their effects, and the existing control measures for each failure mode within the Refinery units.

Step.3. involves evaluating the Severity (S), Occurrence (O), and Detection (D) ratings for each failure mode by the FMEA users. According to Wang et al, the implementation of a fuzzy logic approach in FMEA doesn't necessitate expert knowledge, and the number of people involved in the process doesn't limit the assessment. Previous studies have indicated that involving three to six individuals with sufficient knowledge enhances the suitability and ease of operation.

Step.4. Entails computing the Risk Priority Number (RPN) using the fuzzy algorithm. Initially, a function was developed to implement fuzzy logic, as depicted in Fig.2.4 . The primary step involves establishing a scoring scale for each factor to create a membership function for input variables. Following this, the next step is to formulate the membership function for the output variable. The final step involves specifying rules to govern the output.

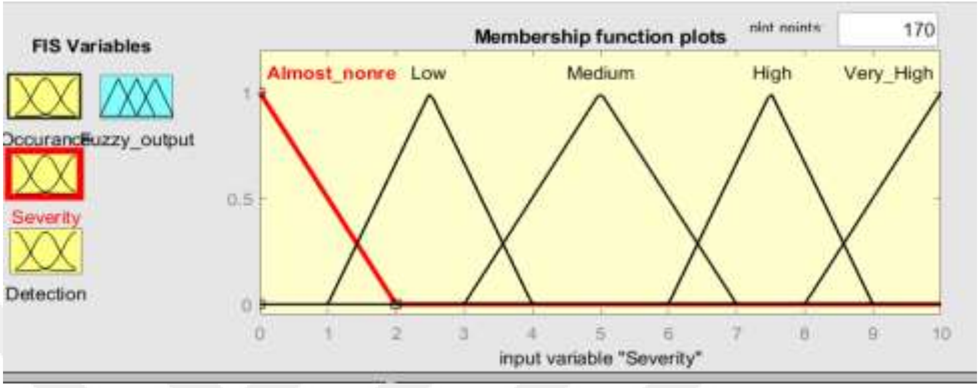


Figure 3.5: Input Variable Severity

Source: Prepared by the Researcher Based on Fuzzy logic Toolbox in MATLAB

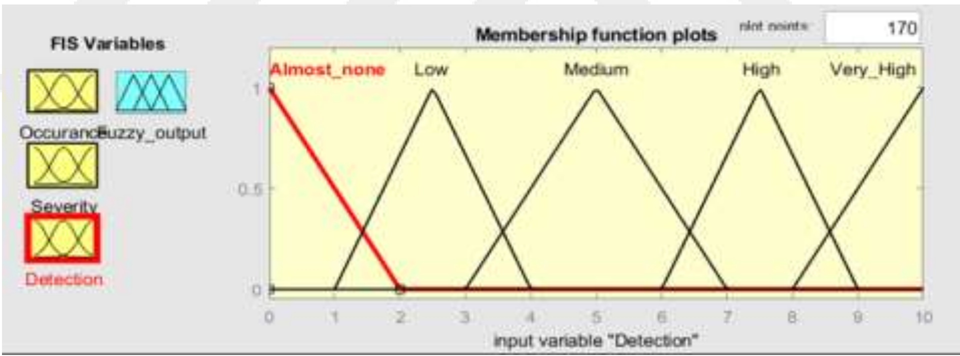


Figure 3.6: Input Variable Detection

Source: Prepared by the Researcher Based on Fuzzy logic Toolbox in MATLAB

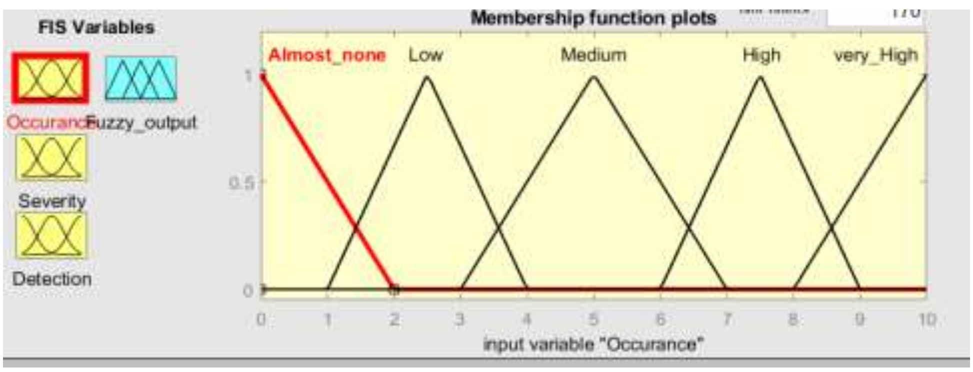


Figure 3.7: Input Variable Occurrence

Source: Prepared by the Researcher Based on Fuzzy logic Toolbox in MATLAB

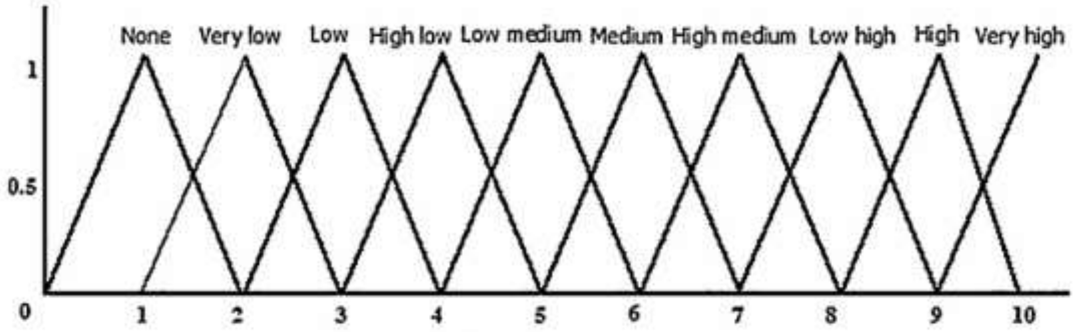


Figure 3.8: Output Variable

Source: Prepared by the Researcher Based on Fuzzy logic Toolbox in MATLAB

3.5.1.4 If Then Rules

In Fuzzy FMEA (Failure Mode and Effect Analysis), IF-THEN rules play a crucial role in defining the logic for evaluating the risk associated with various failure modes. These rules are based on fuzzy logic principles and are formulated to capture the uncertainty and imprecision inherent in the assessment process. Here's a simplified explanation of how IF-THEN rules are typically structured in Fuzzy FME

IF-THEN Structure:

Each rule in Fuzzy FMEA follows a basic IF-THEN structure. It consists of an antecedent (IF) and a consequent (THEN) part.

Antecedent (IF):

This part of the rule specifies the conditions or criteria based on which the evaluation is made. It involves linguistic variables and membership functions related to the input parameters of the system.

Consequent (THEN):

The consequent part determines the output or decision based on the conditions specified in the antecedent. It involves linguistic variables and membership functions related to the output parameters, representing the degree of risk associated with a particular failure mode.

Linguistic Variables and Membership Functions:

Linguistic variables represent qualitative terms such as "low," "medium," or "high" that describe the degree of a certain parameter (e.g., severity, occurrence, detection). Membership functions define the degree of membership of a value to a linguistic variable.

Rule Base:

The collection of all IF-THEN rules forms the rule base of the Fuzzy FMEA system. These rules are usually derived from expert knowledge, historical data, or a combination of both.

Inference Engine:

The inference engine in a Fuzzy FMEA system evaluates the rules based on the input values and determines the degree of membership for each linguistic variable in the consequent part.

Aggregation and Defuzzification:

The system aggregates the outputs from multiple rules to obtain a comprehensive risk assessment. Defuzzification is then applied to convert the fuzzy output into a crisp output that represents the overall risk level.

Here's a simple illustrative example:

IF Severity is High AND Occurrence is High THEN Risk is Very High.

This rule indicates that if both severity and occurrence are assessed as high, then the overall risk is categorized as very high.

It's important to note that the actual formulation of IF-THEN rules depends on the specific context, variables, and expert knowledge involved in a particular Fuzzy FMEA application. The goal is to model the decision-making process under uncertainty and imprecision to provide a more nuanced risk assessment (Chanamool and Neanna, 2016).

In a Mamdani-type fuzzy inference system, fuzzy rules are defined to map inputs to outputs. Each rule consists of an antecedent (input conditions) and a consequent (output action)

In a Mamdani-type fuzzy inference system, fuzzy rules are defined to map inputs to outputs. Each rule consists of an antecedent (input conditions) and a consequent (output action)

Table 3.2: Fuzzy Rules Output

No.	Occurrence	Severity	No detection	Risk (Fuzzy output)
1	Almost none	Almost none	Almost none	None
2	Almost none	Almost none	Low	None
3	Almost none	Almost none	Medium	Very low
4	Almost none	Almost none	High	Low
5	Almost none	Almost none	Very high	Low
6	Almost none	Low	Almost none	Very low
7	Almost none	Low	Low	Low
8	Almost none	Low	Medium	Low
9	Almost none	Low	High	High low
10	Almost none	Low	Very high	Low medium
11	Almost none	Medium	Almost none	Very low
12	Almost none	Medium	Low	Low
13	Almost none	Medium	Medium	Low
14	Almost none	Medium	High	High low
15	Almost none	Medium	Very high	High low
16	Almost none	High	Almost none	Low
17	Almost none	High	Low	High low
18	Almost none	High	Medium	Low medium
19	Almost none	High	High	Medium
20	Almost none	High	Very high	High medium
21	Almost none	Very high	Almost none	High low
22	Almost none	Very high	Low	Low medium
23	Almost none	Very high	Medium	Medium
24	Almost none	Very high	High	High medium
25	Almost none	Very high	Very high	High
26	Low	Almost none	Almost none	None
27	Low	Almost none	Low	None
28	Low	Almost none	Medium	Very low
29	Low	Almost none	High	Low
30	Low	Almost none	Very high	Low
31	Low	Low	Almost none	Very low
32	Low	Low	Low	Low
33	Low	Low	Medium	High low
34	Low	Low	High	Low medium
35	Low	Low	Very high	Medium
36	Low	Medium	Almost none	High low
37	Low	Medium	Low	Low medium
38	Low	Medium	Medium	Medium
39	Low	Medium	High	High medium
40	Low	Medium	Very high	Low high
41	Low	High	Almost none	Low medium
42	Low	High	Low	Medium
43	Low	High	Medium	High medium
44	Low	High	High	Low high
45	Low	High	Very high	High

Table 3.2: (Cont.) Fuzzy Rules Output

No.	Occurrence	Severity	No detection	Risk (Fuzzy output)
46	Low	Very high	Almost none	Low medium
47	Low	Very high	Low	Low medium
48	Low	Very high	Medium	Medium
49	Low	Very high	High	High
50	Low	Very high	Very high	High
51	Medium	Almost none	Almost none	Very low
52	Medium	Almost none	Low	Very low
53	Medium	Almost none	Medium	Low
54	Medium	Almost none	High	High low
55	Medium	Almost none	Very high	Low medium
56	Medium	Low	Almost none	Low
57	Medium	Low	Low	High low
58	Medium	Low	Medium	Low medium
59	Medium	Low	High	Medium
60	Medium	Low	Very high	High medium
61	Medium	Medium	Almost none	Low medium
62	Medium	Medium	Low	Medium
63	Medium	Medium	Medium	High medium
64	Medium	Medium	High	Low high
65	Medium	Medium	Very high	High
66	Medium	High	Almost none	Low
67	Medium	High	Low	High low
68	Medium	High	Medium	Low medium
69	Medium	High	High	High medium
70	Medium	High	Very high	Low high
71	Medium	Very high	Almost none	Low high
72	Medium	Very high	Low	Medium
73	Medium	Very high	Medium	High medium
74	Medium	Very high	High	Low high
75	Medium	Very high	Very high	High
76	High	Almost none	Almost none	None
77	High	Almost none	Low	Very low
78	High	Almost none	Medium	Low
79	High	Almost none	High	Low
80	High	Almost none	Very high	High low
81	High	Low	Almost none	Very low
82	High	Low	Low	Low
83	High	Low	Medium	High low
84	High	Low	High	Low medium
85	High	Low	Very high	Medium
86	High	Medium	Almost none	Low
87	High	Medium	Low	High low
88	High	Medium	Medium	Low medium
89	High	Medium	High	Medium
90	High	Medium	Very high	High medium

Table 3.2: (Cont.) Fuzzy Rules Output

No.	Occurrence	Severity	No detection	Risk (Fuzzy output)
91	High	High	Almost none	Low medium
92	High	High	Low	Medium
93	High	High	Medium	High medium
94	High	High	High	Low high
95	High	High	Very high	High
96	High	Very high	Almost none	Medium
97	High	Very high	Low	High medium
98	High	Very high	Medium	Low high
99	High	Very high	High	High
100	High	Very high	Very high	Very high
101	Very high	Almost none	Almost none	Very low
102	Very high	Almost none	Low	Very low
103	Very high	Almost none	Medium	Low
104	Very high	Almost none	High	Low
105	Very high	Almost none	Very high	High low
106	Very high	Low	Almost none	Low
107	Very high	Low	Low	High low
108	Very high	Low	Medium	High low
109	Very high	Low	High	Low medium
110	Very high	Low	Very high	Medium
111	Very high	Medium	Almost none	High low
112	Very high	Medium	Low	High low
113	Very high	Medium	Medium	Low medium
114	Very high	Medium	High	Medium
115	Very high	Medium	Very high	High medium
116	Very high	High	Almost none	Low medium
117	Very high	High	Low	Medium
118	Very high	High	Medium	High medium
119	Very high	High	High	Low high
120	Very high	High	Very high	High
121	Very high	Very high	Almost none	High medium
122	Very high	Very high	Low	Low high
123	Very high	Very high	Medium	High
124	Very high	Very high	High	Very high
125	Very high	Very high	Very high	Very high

Source: (Chanamool and Neanna, 2016)

In this study, 125 rules were used, defining the rule for controlling the output value by creating the rule using the **MATLAB program,** which used the conjunction "and" to link each factor to the output value for controlling the value of FRPN that received any important level of risk, as shown in Fig 2.9 This procedure is implemented in the inference process to evaluate the rules and combine the results.

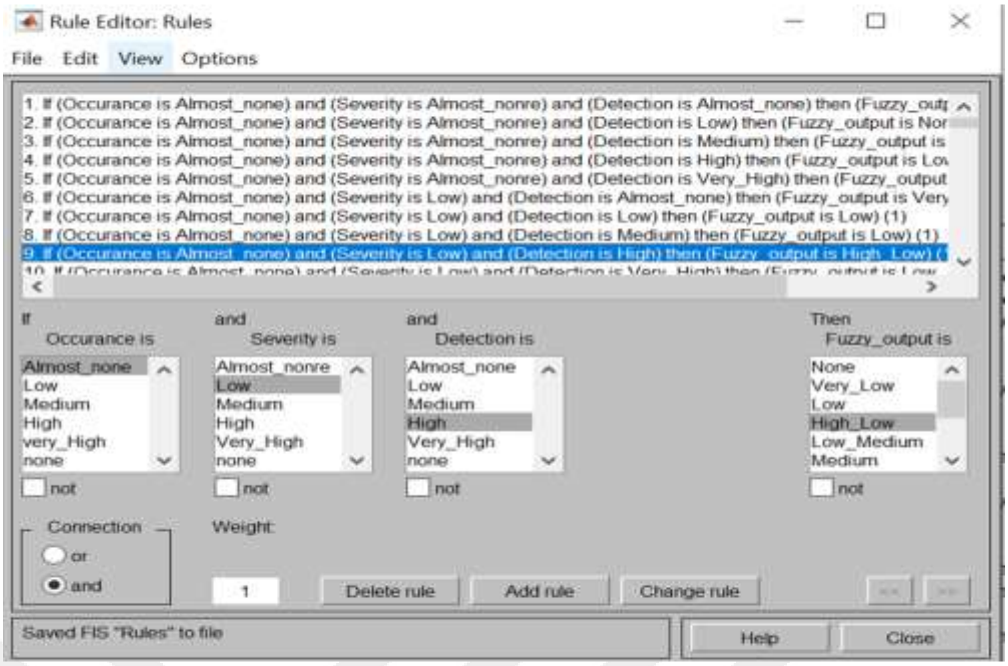


Figure 3.9: IF THEN Rules in MATLAB

Source : Prepared by the Researcher Based on Fuzzy logic Toolbox in MATLAB

4. RESULT AND DISSCUSION

The primary outcomes of the FMEA were condensed in the summary table. The authors suggested preliminary defect control measures derived from the FMEA analysis, and these are detailed in the same table. The subsequent section provides a discussion on the acquired results.

Based on the gathered data, it is noteworthy that the most critical equipment failures in the oil and gas industry encompass:

Corrosion and stress-corrosion damage, including pitting, corrosion, and erosion. Failures arising from faults in the technological processes applied to this equipment, during operation, the technical condition of components of the process equipment undergoes continuous detrimental impacts. When the damage reaches a critical level, accumulated over time in operation, it leads to the deterioration of the equipment's working condition and subsequently results in failure, accompanied by other consequences.

The primary criterion for evaluating equipment reliability lies in ensuring its operational safety, which involves preventing sudden failures of its components. The quantification of risk parameters, indicating the probability of failure, serves as a crucial measure of safety. The Failure Modes and Effects Analysis (FMEA) tool proves to be an effective method for assessing and mitigating the probability of risk.

The establishment of a ranked list of failure causes for oil refinery equipment is instrumental in devising effective measures to enhance reliability.

Table 4.1: Data Collection for FMEA Elements

Failure	Head Engineer in LPG UNIT (3 persons)			Safety and Fire Departmen (4 Persons)			Northern Refinery Department (4 Persons)			Technician Has 15 years experinces (3 persons)			Hydrocracking Department Manager (2 persons)			Occurance =Sum (occurace)/5	Severity=Sum (Severity)/5	Severity =Sum (Severity)/5
	Occurance	Severity	Detection	Occurance	Severity	Detection	Occurance	Severity	Detection	Occurance	Severity	Detection	Occurance	Severity	Detection			
Corrosion	5	5	6	5	6	7	5	5	8	5	4	8	5	5	6	5	5	7
Pressure Vessel Failures in liquid gas unit	3	9	5	4	10	5	3	9	7	2	8	8	3	9	5	3	9	6
Inadequate Emergency Shutdown Systems in liqued gas unit	5	10	5.5	5	10	7	4	10	6	6	10	7	5	10	7	5	10	6.5
Increase in temperatures	3	9	3	5	10	4	4	10	5	3	9.5	3	5	9	5	4	9.5	4
Human Factors	4	10	4	3	10	6	3	10	4	5	10	5	5	10	6	4	10	5
Contamination of the catalyst co-agent with impurities.	4	9	3	5	9	5	5	8	6	5	10	3	6	9	3	5	9	4
Pipeline Failures:	6	5	4	6	4.5	4	5	6	5	6	7	3	7	5	4	6	5.5	4
Fatigue Failure	5	5	6	6	3	6	3	5	5	6	3	7	5	4	6	5	4	6
Increase in pressure	5	8	4	4	10	2	5	10	4	3	9	3	3	8	2	4	9	3
Leakage of sulfur-containing gases in production pipelines	3.25	9.5	3.5	5	9.5	4	3.5	10	3	2.75	8.5	4	4.25	10	3	3.75	9.5	3.5
Cavitation in Pumps in liqud gas unit	6	6	3	7	5	3	6	8	4	5	6	2	6	5	3	6	6	3
structures are corroded																3.5	5.5	3
Leakage	5	7	5	6	7	4	5	6	6	4	9	4	5	6	6	5	8	5
Erosion and Abrasion	6	8	6	5	8	5	7	6	7	6	7	5	6	6	7	6	7	6
Freeze-up or Solidification:	3	7	4	4	8	4	5	6	5.5	5	7.5	5	3	9	4	4	7.5	4.5
Cracking	5	7	2	6	9	2	4	7	2	5	6	3	5	6	1	5	7	2
Seismic Vulnerability	1	5	10		5	10	1	4	10	1	6	10	1	5	10	1	5	10
Defects of isolation and prodtective covers peeling, variation of cover thickness, breaks cuts and tears	7	3	2	7	4	3	8	5	4	6	3	3	7	5	3	7	4	3

Source: Prepared by Researcher through collecting Data (FMEA elements Severity, Occurrence and Detection)

(From the specialists and experienced in Baiji Refinery)

Table 4.2: Analysis of the Structure through FMEA: Examining the Equipment within the Baiji oil-Refinery

#	Failure mode	Couse	Consequences	Occurrence	Severity	Detection	RPN
13	Inadequate Emergency Shutdown Systems in liquid gas unit	failure or malfunction of emergency shutdown systems	Delayed response to emergencies, increased risks during abnormal situations, and potential for severe accidents.	**5**	**10**	**6.5**	**325**
6	Erosion and Abrasion	Impact of solid particles carried by fluids, such as sand or catalysts.	Thinning of metal surfaces, increased roughness, and compromised structural integrity.	**6**	**7**	**6**	**252**
9	Human Factors	Operator errors, inadequate training, or miscommunication	Equipment damage, operational inefficiencies, and safety incidents	**4**	**10**	**5**	**200**
10	Leakage	Faulty seals, gaskets, or welds, corrosion, or equipment malfunction.	Environmental pollution, safety risks, and loss of valuable resources.	**5**	**8**	**5**	**200**
4	Contamination of the catalyst co-agent with impurities.	Crude Oil Quality Operational Processes Catalyst Supply System Poor Temperature and pressure Control Catalyst Quality	Deterioration of Catalyst Effectiveness Reduction in Catalyst Lifespan Impact on Product Quality Increase in Maintenance Costs Production Shutdowns	**5**	**9**	**4**	**180**
5	Corrosion	Exposure to corrosive substances in the processed fluids, high temperatures, and humidity.	Weakening of metal structures, reduced equipment lifespan, and potential leaks leading to environmental damage.	**5**	**5**	**7**	**175**
16	Pressure Vessel Failures in liquid gas unit	Overpressure due to process upsets, equipment malfunction, or failure of pressure relief systems.	Rupture of vessels, release of hazardous gases, and potential for fires or explosions.	**3**	**9**	**6**	**162**
3	Increase in temperatures	Operating equipment in high-temperature conditions without effectively cooling the engines failure in fire suppression systems	Equipment Damage Loss of Heat Efficiency Impact on Product Quality Maintenance Costs Increase in Water Consumption Impact on Workers	**4**	**9.5**	**4**	**152**
15	Freeze-up or Solidification	Exposure to low temperatures causing liquid gases to freeze or solidify.	Blockages in pipelines, equipment malfunction, and potential safety risks.	**4**	**7.5**	**4.5**	**135**

Table 4.2: (Cont.) Analysis of the Structure through FMEA: Examining the Equipment within the Baiji oil-Refinery

#	Failure mode	Couse	Consequences	Occurrence	Severity	Detection	RPN
11	Pipeline Failures:	Corrosion, external damage, or welding defects in pipelines	Oil spills, environmental contamination, and disruption of transportation.	**6**	**5.5**	**4**	**132**
1	Leakage of sulfur-containing gases in production pipelines	Pipe Corrosion High Pressure Temperature Fluctuations Poor Maintenance Design Issues Natural Disasters Valve and Fitting Failures	Health Impacts Environmental Effects Accidents and Explosions Production Shutdown Repair Costs Economic Impact	**3.75**	**9.5**	**3.5**	**124.6875**
7	Fatigue Failure	Cyclical loading and unloading, often due to operational fluctuations.	Microcracks, eventual component failure, and potential safety hazards.	**5**	**4**	**6**	**120**
2	Increase in pressure	Increased Production Volume Changes in Oil Properties Faulty Pressure Equipment Gas Leakage Temperature Changes Operation of High-Pressure Systems ot conducting regular pressure inspection	Gas Leaks Equipment Failure Performance Deterioration	**4**	**9**	**3**	**108**
12	Cavitation in Pumps in liqud gas unit	Rapid changes in pressure leading to the formation and collapse of vapor bubbles in pumps.	Erosion of pump components, reduced efficiency, and potential for pump failure.	**6**	**6**	**3**	**108**
17	Defects of isolation and protective covers peeling, variation of cover thickness, breaks cuts and tears	Reduced Insulation Performance Exposure to Environmental Elements Safety Hazards Equipment Malfunction Corrosion and Wear	Material Quality and Aging Mechanical Damage Improper Installation Environmental Factors Operational Stresses	**7**	**4**	**3**	**84**
8	Cracking	Stress corrosion, hydrogen-induced cracking, or metallurgical issues.	Structural instability, leaks, and potential catastrophic failures.	**5**	**7**	**2**	**70**

Source: Prepared by Researcher

Table 4.3: Analysis of the Structure Through Fuzzy FMEA: Examining the Equipment within the Baiji Oil-Refinery

#	Failure mode	Couse	Consequences	occurrence	severity	Detection	FRPN
5	Corrosion	Exposure to corrosive substances in the processed fluids, high temperatures, and humidity.	Weakening of metal structures, reduced equipment lifespan, and potential leaks leading to environmental damage.	5	5	7	8
16	Pressure Vessel Failures in liquid gas unit	Overpressure due to process upsets, equipment malfunction, or failure of pressure relief systems.	Rupture of vessels, release of hazardous gases, and potential for fires or explosions.	3	9	6	8
13	Inadequate Emergency Shutdown Systems in liqued gas unit	ailure or malfunction of emergency shutdown systems	Delayed response to emergencies, increased risks during abnormal situations, and potential for severe accidents.	5	10	6.5	7.57
3	Increase in temperatures	Operating equipment in high-temperature conditions without effectively cooling the engines failure in fire suppression systems	Equipment Damage Loss of Heat Efficiency Impact on Product Quality Maintenance Costs Increase in Water Consumption Impact on Workers	4	9.5	4	7.1
9	Human Factors	Operator errors, inadequate training, or miscommunication	Equipment damage, operational inefficiencies, and safety incidents	4	10	5	7
4	Contamination of the catalyst co-agent with impurities.	Crude Oil Quality Operational Processes Catalyst Supply System Poor Temperature and pressure Control Catalyst Quality	Deterioration of Catalyst Effectiveness Reduction in Catalyst Lifespan Impact on Product Quality Increase in Maintenance Costs Production Shutdowns	5	9	4	7
11	Pipeline Failures:	Corrosion, external damage, or welding defects in pipelines	Oil spills, environmental contamination, and disruption of transportation.	6	5.5	4	7

Table 4.3: (Cont.) Analysis of the Structure Through Fuzzy FMEA: Examining the Equipment within the Baiji Oil-Refinery

#	Failure mode	Couse	Consequences	occurrence	severity	Detection	FRPN
7	Fatigue Failure	Cyclical loading and unloading, often due to operational fluctuations.	Microcracks, eventual component failure, and potential safety hazards.	5	4	6	7
2	Increase in pressure	Increased Production Volume Changes in Oil Properties Faulty Pressure Equipment Gas Leakage Temperature Changes Operation of High-Pressure Systems ot conducting regular pressure inspections	Gas Leaks Equipment Failure Performance Deterioration	4	9	3	6.43
1	Leakage of sulfur-containing gases in production pipelines	Pipe Corrosion High Pressure Temperature Fluctuations Poor Maintenance Design Issues Natural Disasters Valve and Fitting Failures	Health Impacts Environmental Effects Accidents and Explosions Production Shutdown Repair Costs Economic Impact	3.75	9.5	3.5	6.11
12	Cavitation in Pumps in liqud gas unit	Rapid changes in pressure leading to the formation and collapse of vapor bubbles in pumps.	Erosion of pump components, reduced efficiency, and potential for pump failure.	6	6	3	6
1	Metal structures are corroded	The continuous exposure to harsh chemical environments And the long lifespan of metal structures. The lack of regular preventive maintenance implementation Not using corrosion-resistant materials and fuel or product contamination."	Decreased load-bearing strength and structural corrosion Performance Deterioration iquid Leakage Increased Maintenance Costs Shutdowns	3.5	5.5	3	5.43
10	Leakage	Faulty seals, gaskets, or welds, corrosion, or equipment malfunction.	Environmental pollution, safety risks, and loss of valuable resources.	5	8	5	5.25

Table 4.3: (Cont.) Analysis of the Structure Through Fuzzy FMEA: Examining the Equipment within the Baiji Oil-Refinery

#	Failure mode	Couse	Consequences	occurrence	severity	Detection	FRPN
6	Erosion and Abrasion	impact of solid particles carried by fluids, such as sand or catalysts.	Thinning of metal surfaces, increased roughness, and compromised structural integrity.	6	7	6	5
15	Freeze-up or Solidification:	Exposure to low temperatures causing liquid gases to freeze or solidify.	Blockages in pipelines, equipment malfunction, and potential safety risks.	4	7.5	4.5	5
8	Cracking	Stress corrosion, hydrogen-induced cracking, or metallurgical issues.	Structural instability, leaks, and potential catastrophic failures.	5	7	2	4
14	Seismic Vulnerability	Inadequate design considerations for seismic events	Structural damage, equipment misalignment, and potential for leaks or failures during earthquakes.	1	5	10	4
17	Defects of isolation and prodtective covers peeling, variation of cover thickness, breaks cuts and tears	Reduced Insulation Performance Exposure to Environmental Elements Safety Hazards Equipment Malfunction Corrosion and Wear	Material Quality and Aging Mechanical Damage Improper Installation Environmental Factors Operational Stresses	7	4	3	3.5

Source: Prepared by Researcher

Table 4.4: Examining the RPN Value and Prioritized Differences between Conventional FMEA and the FUZZY Method

#	Failure mode	Couse	Consequences	RPN	Priority as traditional FMEA	FRPN	Priority as FUZZY FMEA
13	Inadequate Emergency Shutdown Systems in liqued gas unit	failure or malfunction of emergency shutdown systems	Delayed response to emergencies, increased risks during abnormal situations, and potential for severe accidents.	**325**	**1**	**7.57**	2
6	Erosion and Abrasion	impact of solid particles carried by fluids, such as sand or catalysts.	Thinning of metal surfaces, increased roughness, and compromised structural integrity.	**252**	**2**	**5**	10
9	Human Factors	Operator errors, inadequate training, or miscommunicatio n	Equipment damage, operational inefficiencies, and safety incidents	**200**	**3**	**7**	4
10	Leakage	Faulty seals, gaskets, or welds, corrosion, or equipment malfunction.	Environmental pollution, safety risks, and loss of valuable resources.	**200**	**4**	**5.25**	9
4	Contaminatio n of the catalyst co-agent with impurities.	Crude Oil Quality Operational Processes Catalyst Supply System Poor Temperature and pressure Control Catalyst Quality	Deterioration of Catalyst Effectiveness Reduction in Catalyst Lifespan Impact on Product Quality Increase in Maintenance Costs Production Shutdowns	**180**	**5**	**7**	4
5	Corrosion	Exposure to corrosive substances in the processed fluids, high temperatures, and humidity.	Weakening of metal structures, reduced equipment lifespan, and potential leaks leading to environmental damage.	**175**	**6**	**8**	1
16	Pressure Vessel Failures in liquid gas unit	Overpressure due to process upsets, equipment malfunction, or failure of pressure relief systems.	Rupture of vessels, release of hazardous gases, and potential for fires or explosions.	**162**	**7**	**8**	1

Table 4.4: (Cont.) Examining the RPN Value and Prioritized Differences between Conventional FMEA and the FUZZY Method

#	Failure mode	Couse	Consequences	RPN	Priority as traditional FMEA	FRPN	Priority as FUZZY FMEA
3	Increase in temperatures	Operating equipment in high-temperature conditions without effectively cooling the engines failure in fire suppression systems	Equipment Damage Loss of Heat Efficiency Impact on Product Quality Maintenance Costs Increase in Water Consumption Impact on Workers	**152**	**8**	**7.1**	3
15	Freeze-up or Solidification :	Exposure to low temperatures causing liquid gases to freeze or solidify.	Blockages in pipelines, equipment malfunction, and potential safety risks.	**135**	**9**	**5**	10
11	Pipeline Failures:	Corrosion, external damage, or welding defects in pipelines	Oil spills, environmental contamination, and disruption of transportation.	**132**	**10**	**7**	4
1	Leakage of sulfur-containing gases in production pipelines	Pipe Corrosion High Pressure Temperature Fluctuations Poor Maintenance Design Issues Natural Disasters Valve and Fitting Failures	Health Impacts Environmental Effects Accidents and Explosions Production Shutdown Repair Costs Economic Impact	**124.6875**	**11**	**6.11**	6
7	Fatigue Failure	Cyclical loading and unloading, often due to operational fluctuations.	Microcracks, eventual component failure, and potential safety hazards.	**120**	**12**	**7**	4

Table 4.4: (Cont.) Examining the RPN Value and Prioritized Differences between Conventional FMEA and the FUZZY Method

#	Failure mode	Couse	Consequences	RPN	Priority as traditional FMEA	FRPN	Priority as FUZZY FMEA
2	Increase in pressure	Increased Production Volume Changes in Oil Properties Faulty Pressure Equipment Gas Leakage Temperature Changes Operation of High-Pressure Systems ot conducting regular pressure inspections	Gas Leaks Equipment Failure Performance Deterioration	**108**	**13**	**6.43**	5
12	Cavitation in Pumps in liqud gas unit	Rapid changes in pressure leading to the formation and collapse of vapor bubbles in pumps.	Erosion of pump components, reduced efficiency, and potential for pump failure.	**108**	**14**	**6**	7
17	Defects of isolation and prodtective covers peeling, variation of cover thickness, breaks cuts and tears	Reduced Insulation Performance Exposure to Environmental Elements Safety Hazards Equipment Malfunction Corrosion and Wear	Material Quality and Aging Mechanical Damage Improper Installation Environmental Factors Operational Stresses	**84**	**15**	**3.5**	12
8	Cracking	Stress corrosion, hydrogen-induced cracking, or metallurgical issues.	Structural instability, leaks, and potential catastrophic failures.	**70**	**16**	**4**	11

Table 4.4: (Cont.) Examining the RPN Value and Prioritized Differences between Conventional FMEA and the FUZZY Method

#	Failure mode	Couse	Consequences	RPN	Priority as traditional FMEA	FRPN	Priority as FUZZY FMEA
1	Metal structures are corroded	The continuous exposure to harsh chemical environments And the long lifespan of metal structures. The lack of regular preventive maintenance implementation Not using corrosion-resistant materials and fuel or product contamination."	Decreased load-bearing strength and structural corrosion Performance Deterioration liquid Leakage Increased Maintenance Costs Shutdowns	**57.75**	**17**	**5.43**	8
14	Seismic Vulnerability	Inadequate design considerations for seismic events	Structural damage, equipment misalignment, and potential for leaks or failures during earthquakes.	**50**	**18**	**4**	11

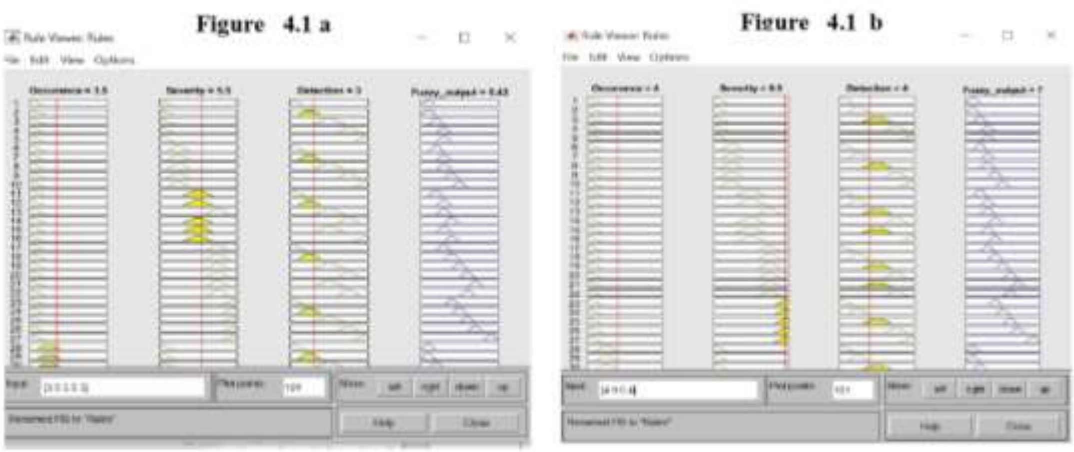


Figure 4.1: Group (a, b, c, d, e, f, g, h, i, j, k, l, m, n) Fuzzy Out Put Based on Rules in MATLAB

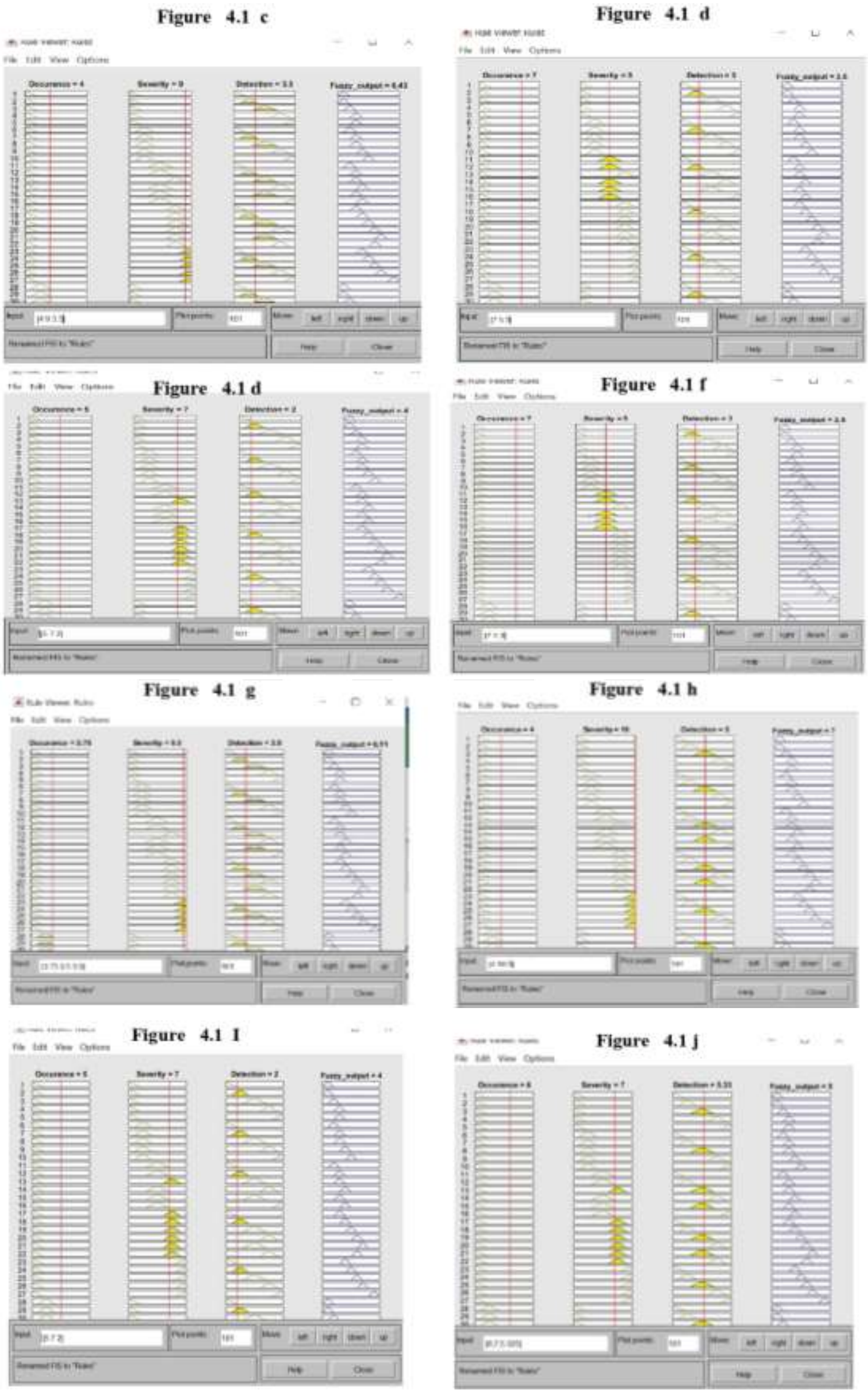
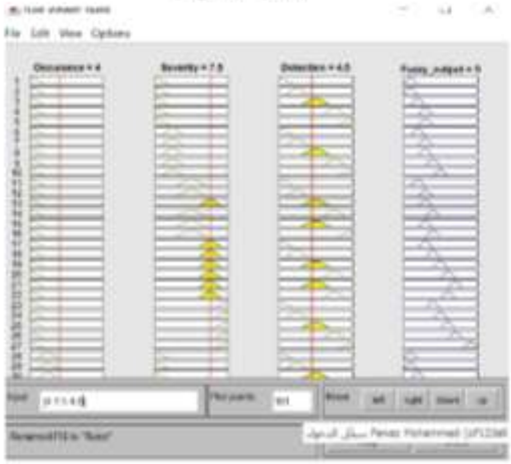


Figure 4.1: (Cont.) Group (a, b, c, d, e, f, g, h, i, j, k, l, m, n) Fuzzy Out Put Based on Rules in MATLAB

Figure 4.1 k

Figure 4.1 l



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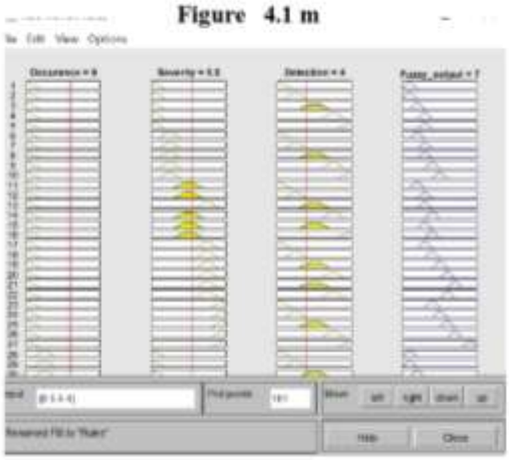

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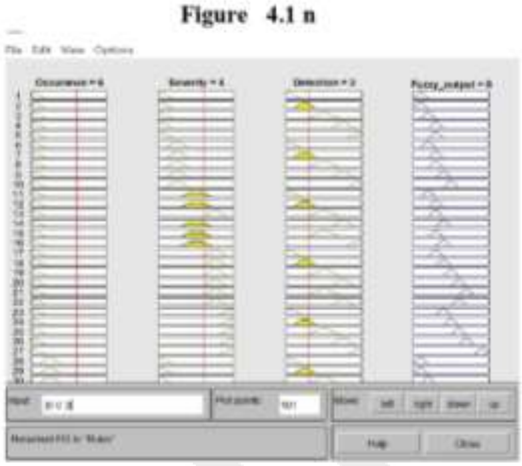
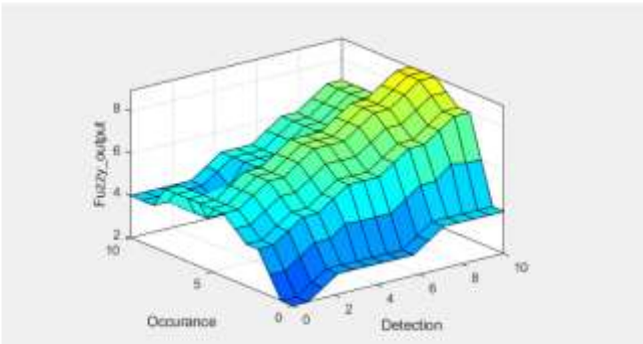
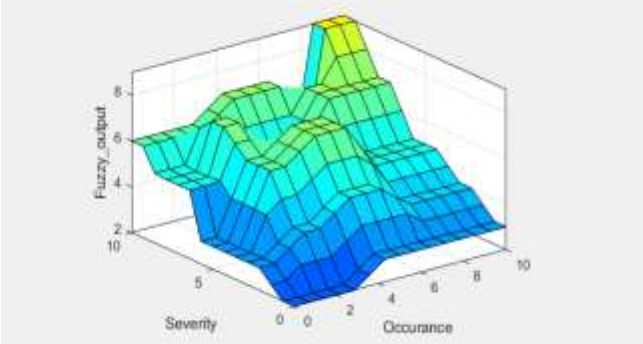


Figure 4.1: (Cont.) Group (a, b, c, d, e, f, g, h, i, j, k, l, m, n) Fuzzy Out Put Based on Rules in MATLAB



(a)



(b)

Figure 4.2: Chart 3D for Severity, Occurrence and Detection

Table 4.5: Result of Rules IF THEN

Failure	Occurrence	Severity	Detection	Fuzzy Output
Corrosion	Medium	Medium	High	Low High
Pressure Vessel Failures in liquid gas unit	Low	Very High	Medium	Medium
Inadequate Emergency Shutdown Systems in liqued gas unit	Medium	Very High	Medium	High Medium
Increase in temperatures	Medium	Very High	Medium	High Medium
Human Factors	Medium	Very High	Medium	High Medium
Contamination of the catalyst co-agent with impurities.	Medium	Very High	Medium	High Medium
Pipeline Failures:	Medium	Medium	Medium	High Medium
Fatigue Failure	Medium	Medium	Medium	High Medium
Increase in pressure	Medium	Very High	Low	Medium
Leakage of sulfur-containing gases in production pipelines	Low	Very High	Low	Low Medium
Cavitation in Pumps in liqud gas unit	Medium	Medium	Low	Medium
Metal structures are corroded	Low	Medium	Low	Low Medium
Leakage	Medium	High	Medium	Low Medium
Erosion and Abrasion	Medium	High	Medium	Low Medium
Freeze-up or Solidification:	Medium	High	Medium	Low Medium
Cracking	Medium	High	Low	High Medium
Seismic Vulnerability	Al-most none	Medium	Very High	High Low
Defects of isolation and prodtective covers peeling, variation of cover thickness, breaks cuts and tears	High	Medium	Low	High Low

Source: prepared by Researcher

Table 4.6: Action for Corrective Failure

Failure mode	**Couse**	**Consequences**	**Recommendation**	**FRPN**	**Priority**
Corrosion	Exposure to corrosive substances in the processed fluids, high temperatures, and humidity.	Weakening of metal structures, reduced equipment lifespan, and potential leaks leading to environmental damage.	• Regular Inspections: Check for corrosion regularly. • Corrosion-resistant Materials: Use resistant materials. • Coatings and Linings: Apply protective coatings. • Catholic Protection: Implement protection systems. • Corrosion Inhibitors: Use inhibitors. • Material Selection: Choose compatible materials. • Environmental Monitoring: Monitor conditions. • Regular Cleaning: Clean equipment routinely. • Risk Assessments: Assess and control risks. • Proper Ventilation: Ensure good ventilation. • Education and Training: Train personnel. • Emergency Response Plan	**8**	1
Inadequate Emergency Shutdown Systems in liqued gas unit	failure or malfunction of emergency shutdown systems	Delayed response to emergencies, increased risks during abnormal situations, and potential for severe accidents.	• System Redundancy: Implement redundant shutdown systems for fail-safe operation. • Regular Testing and Maintenance: Conduct routine testing and maintenance to ensure system functionality. • Failure Mode Analysis: Prioritize corrective actions based on failure mode analysis. • Instrumentation Reliability: Maintain reliable instrumentation through calibration and testing. • Staff Training: Train personnel on emergency shutdown protocols. • Communication Systems: Install reliable communication for swift response. • Remote Shutdown Capability: Consider centralized shutdown capabilities. • Alarm Systems: Deploy effective alarms for timely alerts. • Emergency Response Drills: Conduct regular drills for preparedness. • Regulatory Compliance: Ensure systems meet industry standards. • Continuous Improvement: Pursue ongoing performance evaluation.	**7.57**	2
Increase in temperatures	Operating equipment in high-temperature conditions without effectively cooling the engines failure in fire suppression systems	Equipment Damage Loss of Heat Efficiency Impact on Product Quality Maintenance Costs Increase in Water Consumption Impact on Workers	• Temperature Monitoring: Implement continuous monitoring for prompt detection of abnormal increases. • Thermal Insulation: Apply effective insulation to minimize heat transfer and prevent unintended temperature rises. • Regular Inspections: Conduct routine inspections to identify potential issues leading to temperature increases. • Heat Exchanger Maintenance: Establish proactive maintenance for efficient heat transfer and prevention of overheating. • Process Control Systems: Use advanced controls to maintain optimal temperatures and prevent spikes. • Emergency Shutdown Systems: Install systems triggered by abnormal temperatures to isolate affected areas quickly. • Cooling Systems: Ensure properly designed and maintained cooling systems can handle required loads. • Temperature Alarms: Install alarms for early warnings and automatic interventions. • Ventilation Systems: Optimize ventilation to control ambient temperatures and prevent heat buildup. • Training and Procedures: Provide comprehensive training on temperature control and emergency response. • Risk Assessments: Regularly assess temperature-related hazards and implement control measures. • Materials Selection: Use heat-resistant materials to minimize structural failures in high-temperature areas.	**7.1**	3

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Contamination of the catalyst co-agent with impurities.	Crude Oil Quality Operational Processes Catalyst Supply System Poor Temperature and pressure Control Catalyst Quality	Deterioration of Catalyst Effectiveness Reduction in Catalyst Lifespan Impact on Product Quality Increase in Maintenance Costs Production Shutdowns	• Quality Control Measures: Enforce strict quality standards for catalyst co-agents. • Supplier Evaluation: Assess suppliers based on reputation and adherence to standards. • Storage and Handling Practices: Implement proper storage and handling to prevent contamination. • Contamination Monitoring: Regularly test for impurities to detect contamination early. • Material Compatibility: Ensure equipment compatibility to prevent contamination. • Segregation of Materials: Keep co-agents separate to avoid cross-contamination. • Proper Sampling Procedures: Enforce correct sampling for accurate analysis. • Training and Awareness: Educate staff on contamination prevention. • Contingency Plans: Develop plans for swift contamination response. • Regular Audits: Audit facilities to ensure compliance. • Collaboration with Suppliers: Work closely with suppliers to address issues. • Documentation and Record-Keeping: Maintain records for traceability.	**7**	4
Fatigue Failure	Cyclical loading and unloading, often due to operational fluctuations.	Microcracks, eventual component failure, and potential safety hazards.	• Material Selection: Opt for fatigue-resistant materials for critical components. • Regular Inspections: Conduct routine checks for signs of fatigue, like cracks or structural changes. • Risk Assessments: Regularly evaluate areas prone to fatigue and prioritize preventive measures. • Monitoring Systems: Employ structural health monitoring for early fatigue detection. • Load Analysis: Thoroughly analyze loads to ensure equipment can handle them without fatigue. • Operational Monitoring: Monitor factors contributing to fatigue, such as vibration and temperature. • Proper Design and Engineering: Design equipment to mitigate fatigue, including stress concentrations. • Maintenance Practices: Establish proactive maintenance, including fatigue-specific checks and repairs. • Education and Training: Train staff on fatigue awareness and reporting procedures. • Cyclic Loading Management: Control cyclic loading and implement load-reducing measures. • Fail-Safe Design: Design with fail-safe principles to lessen the impact of fatigue failures. • Lifecycle Planning: Plan for equipment lifespan, considering fatigue and scheduling timely replacements or upgrades.	**7**	4

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Human Factors	Operator errors, inadequate training, or miscommunication	Equipment damage, operational inefficiencies, and safety incidents	• Training and Education: Provide comprehensive safety training for personnel, covering emergency procedures and task specifics. • Human-System Interface Design: Design user-friendly interfaces to minimize errors caused by poor design. • Fatigue Management: Implement strategies like regular breaks and limiting overtime to mitigate worker fatigue. • Effective Communication: Establish clear communication channels to ensure accurate and timely information flow. • Risk Awareness and Reporting: Encourage a culture of risk reporting without fear of reprisal. • Human Reliability Analysis: Analyze tasks for potential failure points or errors in human performance. • Task Design and Automation: Design tasks to reduce cognitive load and consider appropriate automation levels. • Continuous Training and Evaluation: Conduct regular training and evaluations to keep personnel updated on safety protocols. • Emergency Response Training: Ensure thorough emergency response training and conduct regular drills. • Safety Culture Promotion: Foster a strong safety culture, recognizing and rewarding safe behavior. • Human Factors Engineering: Incorporate human factors principles into equipment and facility design. • Workload Management: Manage workload effectively to prevent errors due to excessive demands on personnel.	**7**	4
Pipeline Failures:	Corrosion, external damage, or welding defects in pipelines	Oil spills, environmental contamination, and disruption of transportation.	• Integrity Management Program: Establish a comprehensive program for pipeline integrity, including inspections and maintenance. • Risk Assessments: Regularly assess risks to prioritize preventive measures based on severity. • Corrosion Prevention: Implement measures like coatings and cathodic protection to prevent corrosion. • Regular Inspections and Monitoring: Conduct frequent inspections to detect deterioration. • Emergency Shutdown Systems: Install systems to isolate sections in case of abnormal conditions. • Leak Detection Systems: Implement advanced systems to quickly detect and respond to leaks.	**7**	4

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Increase in pressure	Increased Production Volume Changes in Oil Properties Faulty Pressure Equipment Gas Leakage Temperature Changes Operation of High-Pressure Systems ot conducting regular pressure inspections	Gas Leaks Equipment Failure Performance Deterioration	• Pressure Relief Systems: Install and maintain systems to prevent excessive pressure buildup. • Regular Inspections: Conduct routine checks to identify issues leading to pressure increases. • Pressure Monitoring: Implement continuous monitoring to detect abnormal pressure increases promptly. • Safety Valves: Ensure correct sizing, installation, and testing of relief valves. • Process Control Systems: Use advanced controls to maintain optimal conditions and prevent pressure spikes. • Emergency Shutdown Systems: Install systems to isolate affected areas during abnormal pressure conditions. • Training and Procedures: Provide comprehensive training on pressure control and emergency response. • Pressure Release Venting: Design controlled venting systems for emergency pressure release. • Pressure Gauges: Install and calibrate gauges for accurate pressure monitoring. • Engineering Safeguards: Implement devices like rupture discs and pressure-limiting devices. • Regular Maintenance: Establish proactive maintenance to prevent pressure-related failures. • Risk Assessments: Conduct regular assessments to identify pressure-related hazards and implement control measures.	**6.43**	5
Leakage of sulfur-containing gases in production pipelines	Pipe Corrosion High Pressure Temperature Fluctuations Poor Maintenance Design Issues Natural Disasters Valve and Fitting Failures	Health Impacts Environmental Effects Accidents and Explosions Production Shutdown Repair Costs Economic Impact	• Monitoring Systems: Implement continuous sulfur-containing gas monitoring to detect leaks promptly. • Regular Inspections: Conduct frequent pipeline inspections to identify potential failure points and corrosion. • Corrosion-resistant Materials: Use corrosion-resistant materials in pipelines to reduce leak risks from corrosion. • Integrity Management Program: Establish a program for regular assessments and maintenance of pipelines. • Emergency Shutdown Systems: Install shutdown systems to quickly isolate pipeline sections in case of leaks. • Leak Detection Technologies: Utilize advanced technologies like acoustic sensors for enhanced leak detection. • Personnel Training: Train staff to recognize sulfur-containing gas leak signs and emergency response protocols. • Corrosion Inhibitors: Use inhibitors in pipelines to protect against corrosion and reduce leak risks. • Isolation Valves: Install valves along the pipeline for rapid shutdown during emergencies. • Pressure Monitoring: Implement systems to detect abnormal pressure changes signaling potential leaks. • Emergency Response Plan: Develop and review a plan for handling gas leaks, including procedures and protocols. • Public Awareness: Communicate risks and emergency procedures to nearby communities.	**6.11**	6

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Cavitation in Pumps in liqud gas unit	Rapid changes in pressure leading to the formation and collapse of vapor bubbles in pumps.	Erosion of pump components, reduced efficiency, and potential for pump failure.	• Proper Pump Sizing: Ensure pumps are sized correctly for intended flow rates and pressure conditions. • Throttling Control: Use throttling or variable speed drives to regulate flow and prevent cavitation. • NPSH Margin: Maintain adequate Net Positive Suction Head to prevent cavitation. • Proper System Design: Design the entire system to minimize pressure drops and enhance pump performance. • Cavitation-resistant Materials: Select materials resistant to cavitation erosion. • Regular Inspections: Conduct routine inspections to detect cavitation signs and address issues promptly. • NPSH Analysis: Perform detailed NPSH analysis during design and periodically during operation. • Education and Training: Provide training on cavitation causes, symptoms, and mitigation strategies. • Vibration Monitoring: Implement vibration monitoring to detect cavitation or other issues. • Efficient Pump Operation: Operate pumps at their most efficient point to reduce cavitation risk. • Regular Maintenance: Establish proactive maintenance to prevent cavitation-related failures.	**6**	7
Metal structures are corroded	The continuous exposure to harsh chemical environments And the long lifespan of metal structures. The lack of regular preventive maintenance implementation Not using corrosion-resistant materials and fuel or product contamination."	Decreased load-bearing strength and structural corrosion Performance Deterioration iquid Leakage Increased Maintenance Costs Shutdowns	• Regular Inspections: Conduct routine visual and non-destructive testing inspections. • Corrosion Protection Coatings: Apply high-quality coatings to shield against corrosive substances. • Catholic Protection: Install catholic protection systems to control corrosion on metal structures. • Material Selection: Use corrosion-resistant materials during design and construction phases. • Environmental Monitoring: Monitor environmental conditions and adjust preventive measures accordingly. • Regular Cleaning: Implement routine cleaning to remove corrosive deposits from metal surfaces. • Corrosion Inhibitors: Add inhibitors to process fluids to mitigate corrosive effects. • Localized Protection: Focus on vulnerable areas like joints, welds, and high-stress points. • Education and Training: Train personnel on corrosion prevention and prompt reporting procedures. • Emergency Response Plan: Develop a plan for system shutdown and repairs in case of severe corrosion. • Lifecycle Planning: Plan for maintenance, rehabilitation, or replacement based on expected lifespan. • Documentation and Record-Keeping: Maintain detailed records of inspections and mitigation measures for tracking.	**5.43**	8

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Leakage	Faulty seals, gaskets, or welds, corrosion, or equipment malfunction.	Environmental pollution, safety risks, and loss of valuable resources.	• Regular Inspections: Conduct frequent inspections of seals, gaskets, welds, and equipment to identify and address potential issues early. • Seal and Gasket Integrity: Ensure proper installation and maintenance, replacing worn or damaged seals and gaskets promptly. • Corrosion Prevention: Implement measures to prevent corrosion in equipment and pipelines, reducing the risk of leaks. • Welding Quality Assurance: Enforce strict protocols to ensure welding integrity and minimize leak risks. • Materials Compatibility: Select materials compatible with substances they encounter to prevent chemical reactions and leaks. • Proactive Maintenance: Establish a program for regular checks and preventive maintenance to address potential sources of leakage. • Leak Detection Systems: Implement advanced systems for quick leak identification and response. • Emergency Shutdown Systems: Install systems to promptly isolate affected areas upon leak detection. • Training and Awareness: Provide comprehensive training on leak prevention, detection, and reporting procedures. • Pressure Relief Systems: Ensure proper design and maintenance of relief systems to prevent over-pressurization and leaks. • Regular Testing and Monitoring: Conduct regular tests and monitor equipment performance and environmental conditions for potential leak contributors. • Contingency Plans: Develop and review plans outlining procedures for addressing leaks, including shutdown and emergency response protocols.	**5.25**	9

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Erosion and Abrasion	mpact of solid particles carried by fluids, such as sand or catalysts.	Thinning of metal surfaces, increased roughness, and compromised structural integrity.	• Material Selection: Opt for erosion and abrasion-resistant materials for components exposed to high-velocity flows or abrasive particles. • Coatings and Linings: Apply protective coatings or linings to vulnerable surfaces to minimize wear and erosion. • Regular Inspections: Conduct frequent inspections to detect wear and erosion early on in equipment and piping exposed to abrasive conditions. • Flow Control Measures: Implement measures like reducing flow velocities to minimize the impact of abrasive particles on equipment. • Proper Equipment Sizing: Ensure equipment is correctly sized to handle expected flow rates and pressures without excessive wear. • Particle Filtration: Install effective filtration systems to remove abrasive particles from the fluid stream. • Velocity Control: Manage fluid velocities within pipelines to reduce erosive effects of high-speed flows. • Regular Cleaning: Implement routine cleaning procedures to remove accumulated abrasive particles from equipment surfaces. • Education and Training: Train personnel on recognizing signs of erosion and abrasion and reporting issues promptly. • Monitoring Systems: Utilize monitoring systems like vibration sensors to detect early signs of equipment wear. • Proper Maintenance: Establish a proactive maintenance program to promptly address wear and erosion issues and prevent failures. • Emergency Response Plan: Develop a plan outlining procedures for addressing erosion and abrasion-related incidents, including shutdown protocols if necessary.	**5**	10
Freeze-up or Solidification:	Exposure to low temperatures causing liquid gases to freeze or solidify.	Blockages in pipelines, equipment malfunction, and potential safety risks.	• Process Heating Systems: Implement effective systems to maintain temperatures above freezing levels in critical components and pipelines. • Insulation and Heat Tracing: Apply insulation and heat tracing to prevent ice formation or solid deposits. • Temperature Monitoring: Install monitoring systems to track temperatures and provide early warnings. • Process Optimization: Optimize processes to minimize stagnant or low-flow areas prone to freezing. • Use of Antifreeze Agents: Consider antifreeze agents to lower freezing points of fluids. • Regular Inspections: Conduct inspections to identify signs of freezing or solidification. • Emergency Shutdown Systems: Install systems to isolate affected sections during abnormal temperature conditions. • Weather Monitoring: Monitor weather to anticipate temperature drops and take preventive measures. • Flow Control: Implement measures to maintain consistent fluid movement, reducing freeze-ups. • Proper Drainage: Ensure proper drainage to prevent ice formation. • Emergency Response Plan: Develop a plan for personnel safety, shutdown protocols, and post-event assessments. • Training and Awareness: Provide comprehensive training on freeze-up prevention, detection, and response.	**5**	10

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Cracking	Stress corrosion, hydrogen-induced cracking, or metallurgical issues.	Structural instability, leaks, and potential catastrophic failures.	• Stress Analysis: Conduct stress analysis during design and operation to ensure components stay within safe limits, reducing cracking risk. • Corrosion Prevention: Implement measures to reduce corrosion and associated cracking risks. • Temperature Control: Manage temperatures within equipment's operating range to prevent thermal stress-induced cracking. • Operational Monitoring: Monitor conditions like pressure fluctuations and temperature changes contributing to cracking. • Proper Welding Practices: Employ correct welding techniques, including preheating and post-weld heat treatment, to minimize cracking in welded components. • Materials Testing: Assess component susceptibility to cracking types, including stress corrosion cracking, through materials testing.	**4**	11
Seismic Vulnerability	Inadequate design considerations for seismic events	Structural damage, equipment misalignment, and potential for leaks or failures during earthquakes.	• Seismic Hazard Assessment: Conduct a thorough assessment to understand earthquake risks at the refinery's location. • Site Selection and Design: Ensure new facilities adhere to modern seismic design codes, considering seismic factors. • Retrofitting Existing Structures: Reinforce vulnerable structures and equipment, especially critical infrastructure. • Foundation Design: Design foundations to withstand seismic forces, accounting for soil conditions and hazards. • Emergency Shutdown Systems: Enhance systems to automatically isolate critical processes during earthquakes. • Tank Anchoring: Securely anchor storage tanks to prevent movement during seismic events. • Pipeline Integrity: Implement seismic-resistant design features and conduct regular inspections on pipelines. • Equipment Restraints: Install restraints to prevent equipment movement and minimize damage during earthquakes. • Seismic Isolation Devices: Consider using devices to absorb and dissipate seismic energy in critical infrastructure. • Emergency Response Plan: Develop and review a plan for personnel safety and post-event assessments. • Training and Drills: Train staff on seismic safety and conduct drills to ensure familiarity with emergency protocols. • Regulatory Compliance: Stay compliant with seismic design codes, standards, and regulations applicable to the region.	**4**	11

Table 4.6: (Cont.) Action for Corrective Failure

Failure mode	Couse	Consequences	Recommendation	FRPN	Priority
Defects of isolation and prodtective covers peeling, variation of cover thickness, breaks cuts and tears	Reduced Insulation Performance Exposure to Environmental Elements Safety Hazards Equipment Malfunction Corrosion and Wear	Material Quality and Aging Mechanical Damage Improper Installation Environmental Factors Operational Stresses	• Regular Maintenance: Establish proactive maintenance, including cleaning, inspections, and timely repairs or replacements of covers. • Emergency Response Plan: Develop and review a plan outlining procedures for cover-related incidents, including shutdown protocols. • Training and Awareness: Provide comprehensive training for personnel involved in cover installation, maintenance, and inspection, emphasizing defect detection. • Documentation and Record-Keeping: Maintain detailed records of cover type, location, and condition for tracking and trend analysis. • Collaboration with Suppliers: Work closely with cover suppliers to stay informed about best practices and material advancements. • Thickness Monitoring: Implement regular thickness monitoring to identify variations and address weaknesses. • Use of Resilient Materials: Choose durable materials to minimize risks of peeling, breaks, and tears in covers over time.	**3.5**	18

Source: Prepared by Researcher

Mitigating Risks in Petroleum Refinery Operations: Strategies for Supply Chain, Social, and Environmental Challenges"

A. Mitigating Risks in Petroleum Refinery Environmental Challenges

1. Comprehensive Risk Assessment: Conduct a thorough assessment to identify environmental hazards

2. Implement Safety Protocols: Develop and enforce safety measures to prevent accidents and spills

3. Monitoring and Surveillance: Establish continuous monitoring systems for emissions and effluents

4. Waste Management: Manage waste effectively to minimize environmental impact

5. Environmental Impact Assessment (EIA): Periodically assess the environmental impact of operations.

6. Invest in Clean Technologies: Adopt cleaner technologies to reduce emissions.

7. Regulatory Compliance: Ensure compliance with environmental regulations.

B. Mitigating Risks in Petroleum Refinery Operations Social challenges

1. Community Engagement and Communication: Establish transparent and ongoing communication channels with local communities to address concerns, share information about refinery operations, and solicit feedback. This can help build trust and foster positive relationships.

2. Employment and Labor Practices: Implement fair labor practices and prioritize the safety and well-being of refinery workers. Provide adequate training, ensure safe working conditions, and offer competitive wages and benefits to attract and retain skilled employees.

3. Health and Safety Measures: Prioritize the health and safety of workers and nearby residents by implementing robust safety protocols, emergency response plans, and regular health monitoring programs. Address any health concerns promptly and transparently.

4. Environmental Justice: Ensure that environmental impacts and risks are not disproportionately borne by vulnerable or marginalized communities. Conduct environmental justice assessments to identify and mitigate any potential inequities.

5. Stakeholder Engagement and Consultation: Engage with a wide range of stakeholders, including local residents, environmental organizations, government agencies, and indigenous communities, to understand their perspectives and incorporate their input into decision-making processes.

6. Community Investment and Development: Support local community development initiatives through investments in education, healthcare, infrastructure, and economic development programs. Partner with local organizations to address community needs and contribute to sustainable development.

7. Crisis Management and Conflict Resolution: Develop robust crisis management plans to address any social conflicts or emergencies that may arise. Proactively identify and address potential sources of tension and work towards mutually beneficial solutions.

8. Adherence to Human Rights Standards: Ensure compliance with international human rights standards, including the United Nations Guiding

Principles on Business and Human Rights. Respect the rights of indigenous peoples, landowners, and other stakeholders affected by refinery operations.

9. Transparency and Accountability: Maintain transparency in decision-making processes, disclose relevant information about risks and impacts, and hold the refinery accountable for its social performance through regular reporting and independent audits.

10. Continuous Improvement: Continuously monitor and evaluate social performance indicators, solicit feedback from stakeholders, and strive for continuous improvement in social risk management practices.

Managing supply chain risks in petroleum refineries is crucial for ensuring smooth operations, maintaining product quality, and mitigating potential disruptions.

C. Mitigating Risks in Petroleum Refinery Operations: Strategies for Supply Chain Challenges

1. Diversification of Suppliers: Avoid over-reliance on a single supplier by diversifying the supply base. Establish relationships with multiple suppliers for critical materials and components to reduce the risk of supply chain disruptions.

2. Supplier Evaluation and Qualification: Implement robust supplier evaluation and qualification processes to assess the financial stability, reliability, and quality of potential suppliers. Consider factors such as performance history, certifications, and compliance with industry standards.

3. Supply Chain Visibility and Transparency: Enhance visibility and transparency across the supply chain by leveraging technology such as supply chain management software and real-time tracking systems. Monitor key performance indicators (KPIs) and collaborate closely with suppliers to identify and address potential risks proactively.

4. Inventory Management: Maintain adequate inventory levels of essential materials and spare parts to buffer against supply chain disruptions. Implement inventory optimization techniques to balance the cost of holding inventory with the risk of stockouts.

5. Contingency Planning and Risk Mitigation: Develop contingency plans and alternative sourcing strategies to mitigate supply chain risks. Identify potential sources of disruption, such as geopolitical instability, natural disasters, or transportation bottlenecks, and develop response plans to minimize their impact.

6. Collaborative Relationships with Suppliers: Foster collaborative relationships with key suppliers based on trust, communication, and mutual understanding. Work closely with suppliers to identify potential risks and develop joint mitigation strategies.

7. Contractual Agreements and Risk Allocation: Establish clear contractual agreements with suppliers that outline responsibilities, performance expectations, and mechanisms for addressing disruptions. Consider incorporating clauses related to force majeure, supply chain interruptions, and dispute resolution into supplier contracts.

8. Supply Chain Resilience Assessment: Conduct periodic assessments of supply chain resilience to identify vulnerabilities and areas for improvement. Analyze the impact of potential disruptions on refinery operations and develop strategies to enhance resilience.

9. Continuous Monitoring and Improvement: Monitor supply chain performance continuously and adapt risk management strategies as needed based on changing market conditions, regulatory requirements, or emerging threats.

10. Investment in Technology and Innovation: Invest in technology and innovation to enhance supply chain agility, visibility, and efficiency. Explore emerging technologies such as blockchain, artificial intelligence, and predictive analytics to improve supply chain risk management capabilities.

4.1 Finding of Discussion

The initial intention behind applying FMEA was to identify previously unknown failures within refinery systems comprehensively. In essence, this method involves a systematic analysis of system components to pinpoint major failure modes and assess their significance in the overall system performance. FMEA's primary strength lies in providing a systematic overview of major system failures, prompting management or relevant authorities to reevaluate the reliability of the entire product unit system. Additionally, FMEA serves as a robust foundation for subsequent comprehensive quantitative analyses, such as fault tree analysis, event tree analysis, root cause analysis, etc.

Currently, prioritizing and analyzing risks using the FMEA technique has gained increased significance, as evident in studies attempting to overcome its inherent limitations. Various approaches to risk assessment systems have been proposed in the literature, with the fuzzy approach being among the most widely utilized. Integrating fuzzy logic with other techniques has led to the development of innovative tools. In this study, a fuzzy system was created for assessing failure modes, providing a robust tool that replicates the evaluation of risks by experts in a specific field. The assessment system adopts a Mamdani-type model, where the inference rules facilitate the translation of expert knowledge into a mathematical model, thereby enhancing decision-making processes.

In the evaluation of all three forms, the first approach allows each member of the FMEA team to assess individual opinions by assigning priorities to each failure without considering specific criteria, factors, or scores in the assessment. In the second approach, FMEA team members engage in brainstorming to evaluate failures, followed by the application of the traditional FMEA method to calculate the Risk Priority Number (RPN). In the third approach, each member in the FMEA team assesses individual opinions and then utilizes the fuzzy method to calculate the RPN.

The study's findings indicate that the advantages of this assessment lie in the independent evaluation of different opinions, and the prioritization of failures can be summarized by counting duplicated assessment data. Conversely, the first form's assessment involves each FMEA team member evaluating the priorities of all 17 failures without considering specific criteria, factors, or scores used in the assessment. Due to the inability to count the frequency of duplicated data, the assessment does not prioritize failures and is deemed inappropriate for implementation in emergency rooms. The non-unique data cannot lead to conclusive results, and the assessments lack criteria or guidelines for the decision-making process, potentially introducing errors and inaccuracies.

Applying FUZZY Failure Modes and Effects Analysis (FMEA) in assessing risk and failure impact in the context of Baiji refinery yielded significant insights and enhancements over traditional FMEA methodologies.

In the traditional FMEA method, three factors are computed through multiplication, each with different scores, leading to varying RPN values. The wide range and inconsistency in scores may result in some failures being overlooked without updates. Notably, only two failures have RPN values exceeding 100, indicating a very low risk of failure, and corrective actions may not be necessary for most failures. The limitation of a brainstorming session for rating evaluation lies in the inability of members to express their opinions freely, potentially causing biases in the assessment that cannot be accurately gauged based on actual circumstances.

Comparing received and numeric FRPNs yields continuous data values within the score range of 1–10. This format is user-friendly, allowing easy consideration and identification of rule settings for effective operational control. The unique evaluation format of Fuzzy FMEA with individual scores ensures unbiased representation, showcasing ideas and assessments without the influence of team scores. Implementing the Fuzzy FMEA methodology on 17identified problems revealed that 10 issues required high-priority resolution, as their FRPN exceeded the average FRPN (4.68), notably problems 20, 21, and 2, each with an FRPN ≈ 7.

The study's findings underscore the effectiveness of the Fuzzy FMEA method in identifying failures within an emergency department, demonstrating its potential impact on improving operational outcomes

The following discussion outlines key findings, implications, and recommendations derived from the research.

1. Identification and Prioritization of Failure Modes:

FUZZY FMEA demonstrated an improved capability to identify and prioritize failure modes in comparison to conventional FMEA. The incorporation of fuzzy logic allowed for a more nuanced consideration of uncertainties and imprecise information, leading to a more comprehensive understanding of potential failure scenarios.

2. Modeling Uncertainties with Fuzzy Logic:

The integration of fuzzy logic successfully addressed the inherent uncertainties in the oil refinery environment. Linguistic variables, such as "high," "medium," and "low," provided a more flexible and realistic representation of uncertainty, enabling a more accurate assessment of the associated risks.

3. Enhanced Risk Analysis:

FUZZY FMEA facilitated a more robust risk analysis by accounting for the dynamic and complex nature of the oil refining process. The fuzzy risk matrices provided a clearer picture of the interdependencies and interactions among various failure modes, contributing to a more accurate determination of criticality.

4. Comparative Analysis with Traditional FMEA:

A comparative analysis between FUZZY FMEA and traditional FMEA revealed the superiority of the fuzzy logic approach in capturing uncertainties. Traditional FMEA tended to oversimplify risk assessments, potentially leading to an underestimation of the true risk associated with certain failure modes.

5. Operational Implications:

The findings have operational implications for oil refineries, emphasizing the need for a more adaptive and flexible risk management approach. The incorporation of fuzzy logic in risk assessments allows for real-time adjustments to account for changing conditions, contributing to a more resilient and proactive.

4.2 Comparison of findings with literature review

The findings of this research in applying FUZZY FMEA in oil refineries were compared and contrasted with the existing literature on risk assessment methodologies, particularly within the oil and gas industry. The literature review provided a foundation for understanding the traditional FMEA methods and the challenges they face in addressing uncertainties. Below is a comprehensive comparison of the research findings with the insights derived from the literature.

1. Identification and Prioritization of Failure Modes:

Literature Review: Previous studies acknowledged the limitations of traditional FMEA in capturing uncertainties and emphasized the need for more sophisticated approaches.

Findings: FUZZY FMEA demonstrated a notable improvement in identifying and prioritizing failure modes, aligning with the literature's call for enhanced methodologies.

2. Modeling Uncertainties with Fuzzy Logic:

Literature Review: The literature highlighted the significance of fuzzy logic in dealing with imprecise information and uncertainties within complex systems.

Findings: The integration of fuzzy logic in FUZZY FMEA effectively addressed uncertainties, providing a more realistic representation of the dynamic nature of oil refinery operations.

3. Enhanced Risk Analysis with Fuzzy Matrices:

Literature Review: Existing literature suggested that traditional FMEA matrices might oversimplify the relationships among failure modes.

Findings: FUZZY FMEA, through the application of fuzzy matrices, offered a more nuanced and comprehensive risk analysis, aligning with the literature's recommendations for improved modeling.

4. Comparative Analysis with Traditional FMEA:

Literature Review: Prior research acknowledged the limitations of traditional FMEA in capturing uncertainties and advocated for more advanced risk assessment methods.

Findings: A comparative analysis between FUZZY FMEA and traditional FMEA confirmed the superiority of fuzzy logic in addressing uncertainties, validating the literature's assertions.

5. Operational Implications for Oil Refineries:

Literature Review: The literature emphasized the importance of adaptive and flexible risk management strategies in dynamic industries like oil refining.

Findings: FUZZY FMEA demonstrated operational implications by allowing real-time adjustments to risk assessments, aligning with the literature's recommendations for adaptability.

5. CONCLUSION AND RECOMEDATION

5.1 Summary of Findings

The research findings on the application of FUZZY Failure Modes and Effects Analysis (FMEA) in oil refineries can be summarized as follows:

The use of FUZZY FMEA demonstrated an improved ability to recognize and prioritize failure modes in comparison to traditional FMEA methods, with fuzzy logic providing a more refined analysis that effectively addresses uncertainties.

Fuzzy logic was effective in managing the inherent uncertainties within the oil refining process, employing linguistic variables to portray imprecise data more authentically and leading to a more precise evaluation of associated risks.

FUZZY FMEA, particularly through the use of fuzzy matrices, delivered a more thorough and nuanced risk analysis. This method enhanced comprehension of the relationships among failure modes, offering valuable insights for prioritizing risks.

Comparative assessment with traditional FMEA confirmed the superiority of FUZZY FMEA in capturing uncertainties. The fuzzy logic approach demonstrated greater adaptability and realism, aligning with the demand for advanced risk assessment in intricate industries.

Operational implications were evident as FUZZY FMEA allowed for real-time adjustments to risk assessments, aligning with the literature's emphasis on flexible risk management strategies in dynamic industries.

Challenges in defining fuzzy linguistic variables and achieving consensus in applying fuzzy logic were recognized, emphasizing the need for awareness of these challenges for successful implementation.

Future research recommendations included ongoing refinement of fuzzy logic parameters, improved data collection methods, and exploration of advanced technologies for more accurate risk predictions, aligning with the literature's proposals for future research.

In conclusion, the research affirms that FUZZY FMEA holds promise for enhancing risk assessment in oil refineries, addressing constraints of traditional methods and aligning with suggestions discussed in the existing literature. The study contributes valuable insights to ongoing discussions on risk assessment methodologies within the oil and gas industry.

5.2 Conclusion

In conclusion, the thesis on the assessment of the effectiveness of risk management strategies in petrol production, with a specific focus on the case study of Baiji Refinery in Iraq, provides valuable insights into the practical implementation of risk management protocols within the oil and gas industry. The research sheds light on the unique challenges faced by petrol production facilities and explores the efficacy of risk management strategies in mitigating potential threats and enhancing operational resilience.

The findings of the study reveal the complexity of risk factors inherent in the petrol production process and underscore the importance of a comprehensive risk management framework. The utilization of a case study approach, focusing on Baiji Refinery in Iraq, allows for a nuanced understanding of the real-world challenges and the application of risk management strategies within a specific operational context.

Effectiveness in risk management strategies is demonstrated through the analysis of the refinery's response to potential risks, including preventive measures, incident response protocols, and recovery mechanisms. The thesis highlights the significance of proactive risk identification, assessment, and mitigation in ensuring the continuity and safety of petrol production operations.

Furthermore, the research contributes to the ongoing discourse on risk management in the oil and gas sector by providing practical insights that can be applicable not only to Baiji Refinery but also to similar facilities globally. The case study serves as a valuable reference for industry practitioners, offering lessons learned and best practices in the implementation of risk management strategies.

The thesis acknowledges the dynamic nature of the oil and gas industry and emphasizes the need for continuous improvement in risk management practices. Recommendations for refining risk management strategies, based on the findings, provide a roadmap for Baiji Refinery and similar facilities to enhance their resilience against potential threats.

In summary, the assessment of the effectiveness of risk management strategies in petrol production, using Baiji Refinery in Iraq as a case study, contributes to the field by offering practical insights into the challenges and successes of risk management in a real-world operational setting. The research underscores the importance of a proactive and adaptive approach to risk management, emphasizing the continuous improvement of strategies to ensure the safety, reliability, and sustainability of petrol production operations.

The use of fuzzy FMEA in risk management in the oil refinery industry has shown promising results. The fuzzy FMEA approach aims to improve the conventional FMEA method by addressing its drawbacks and providing a better prioritization of risks. It has been applied in various areas such as the ranking and prioritization of risk factors on reinforced concrete structural systems in the oil and gas industry, the identification and management of health, safety, and environment (HSE) risks in the oil industry , and the assessment of the criticality of risks of external corrosion failures in offshore installations . The comparison between traditional FMEA and fuzzy FMEA has shown a high correlation, indicating that fuzzy FMEA can be used as an alternative when evaluations are subjective or incomplete. Overall, the use of fuzzy FMEA in risk management in the oil refinery industry has the potential to improve the identification, prioritization, and mitigation of risks.

In conclusion, the thesis on risk management in oil refineries utilizing the FUZZY Failure Modes and Effects Analysis (FMEA) approach has provided valuable insights into enhancing the robustness of risk assessment methodologies within this critical industry. The research findings underscore the efficacy of FUZZY FMEA in addressing the limitations of traditional methods, particularly in dealing with uncertainties inherent in oil refinery processes.

The application of FUZZY FMEA demonstrated a significant improvement in the identification and prioritization of failure modes. The integration of fuzzy logic proved to be a crucial element, allowing for a more nuanced analysis that captures the dynamic nature of the oil refining environment. By providing a systematic overview of major failures and offering a comprehensive risk analysis, FUZZY FMEA emerged as a powerful tool for guiding management decisions and prompting a reevaluation of the reliability of the entire product unit system.

The comparative analysis with traditional FMEA confirmed the superiority of FUZZY FMEA, particularly in its ability to address uncertainties. This aligns with the broader industry demand for advanced risk assessment methodologies that can adapt to the complex and evolving nature of oil refinery operations.

The operational implications of using FUZZY FMEA were evident, as it allowed for real-time adjustments to risk assessments. This adaptability is crucial in an industry where conditions are subject to frequent changes, contributing to a more resilient and proactive risk management strategy.

While the research highlighted the successes of FUZZY FMEA, it also acknowledged challenges in defining fuzzy linguistic variables and achieving consensus. The awareness of these challenges is crucial for refining the implementation of FUZZY FMEA in practical refinery scenarios.

Looking forward, the recommendations for future research, including the ongoing refinement of fuzzy logic parameters and exploration of advanced technologies, provide a roadmap for continuous improvement in risk assessment methodologies. This thesis contributes not only to the academic understanding of risk management but also offers practical implications for improving the safety and reliability of oil refinery operations.

In essence, the thesis on risk management in oil refineries through the application of FUZZY FMEA serves as a valuable addition to the body of knowledge in the field. It reflects a proactive and adaptive approach to addressing the complex challenges posed by the dynamic and uncertain nature of the oil and gas industry, ultimately contributing to safer and more reliable operations within oil refineries.

5.3 Implications of the Study

The implications of the study on the assessment of the effectiveness of risk management strategies in petrol production, particularly using tools like FUZZY

Failure Modes and Effects Analysis (FMEA) and focusing on the case study of Baiji Refinery in Iraq, are significant and extend to various dimensions within the oil and gas industry:

Enhanced Risk Identification and Mitigation:

The application of FUZZY FMEA facilitates a more nuanced and flexible approach to risk identification. The fuzzy logic allows for the incorporation of imprecise information and uncertainties, leading to a more comprehensive understanding of potential risks in petrol production at Baiji Refinery.

The study implies that using FUZZY FMEA enhances the refinery's ability to identify and mitigate risks, especially those associated with the dynamic and complex nature of petrol production processes.

Operational Resilience and Continuity:

The study suggests that the implementation of FUZZY FMEA contributes to operational resilience by providing a systematic overview of major failures and offering a more comprehensive risk analysis.

Improved risk management strategies, informed by FUZZY FMEA, can enhance the refinery's ability to ensure operational continuity, minimizing disruptions and downtime due to unforeseen events.

Proactive Decision-Making:

The findings imply that using FUZZY FMEA supports proactive decision-making within Baiji Refinery. The ability to assess risks with a more adaptable and realistic approach allows for timely adjustments to risk assessments, contributing to a more resilient risk management strategy.

Proactive decision-making, informed by FUZZY FMEA, can lead to a more agile response to potential risks, preventing incidents and reducing the impact of unexpected events.

Continuous Improvement in Risk Management:

The study highlights the importance of continuous improvement in risk management practices. Recommendations derived from the findings suggest that Baiji Refinery and similar facilities should consistently refine their risk management strategies based on insights gained from tools like FUZZY FMEA.

Continuous improvement is essential for adapting to evolving risks, technological advancements, and changes in the operational environment.

Industry Best Practices and Knowledge Sharing:

FMEA can contribute to the development of industry benchmarks and standards. The case study provides valuable insights into best practices for risk management in petrol production, particularly within the context of Baiji Refinery. The implications extend to the broader oil and gas industry, offering lessons learned that can be shared to enhance industry-wide risk management practices.

The study suggests that the knowledge gained from assessing risk management effectiveness using FUZZY.

Regulatory Compliance and Stakeholder Assurance:

Implementation of effective risk management strategies, as assessed by tools like FUZZY FMEA, contributes to regulatory compliance and assurance to stakeholders. The study implies that a robust risk management framework enhances the refinery's ability to meet industry regulations and standards.

Stakeholders, including regulatory bodies, investors, and the local community, can have increased confidence in the refinery's operations when effective risk management practices are in place.

In summary, the implications of the study emphasize the practical benefits of employing tools like FUZZY FMEA in assessing the effectiveness of risk management strategies in petrol production. The findings extend beyond Baiji Refinery, offering insights that can inform industry practices, enhance operational resilience, and contribute to a safer and more sustainable oil and gas sector.

Based on the findings and implications of the study on the assessment of the effectiveness of risk management strategies in petrol production, particularly using

FUZZY Failure Modes and Effects Analysis (FMEA) at Baiji Refinery in Iraq, several recommendations for future research emerge:

5.4 Recommendation for Future Research

Future research in the assessment of the effectiveness of risk management strategies in petroleum production could explore various avenues. One direction is to investigate the integration of advanced technologies, such as artificial intelligence and machine learning, in enhancing real-time risk monitoring and decision support systems. Additionally, there is a need to focus on the role of human factors and organizational culture in the successful implementation of risk management strategies. Exploring the environmental and social dimensions of risk, as well as assessing the resilience and adaptability of risk management approaches, could provide valuable insights. Researchers may also delve into the impact of regulatory frameworks, industry standards, and economic factors on the effectiveness of risk management strategies. Studying interconnected risks across the entire petroleum production supply chain and evaluating strategies to address cybersecurity threats are essential considerations. Furthermore, examining the influence of climate change on risk profiles and understanding cross-cultural perspectives in risk perception and management could contribute significantly to advancing the field there is a need to explore the application of risk-based approaches in steel structure corrosion management in oil and gas facilities, Additionally, emphasize the importance of accurately assessing the effectiveness of controls developed to manage risks in pipeline operations. Another area of research could involve identifying and modeling the risk factors that negatively impact the success of construction projects in the oil and gas industry. Furthermore, the establishment of a comprehensive risk management system and risk control mechanism in oil and gas companies, as discussed by the author of Context_4, could be explored further. Lastly, the adoption and implementation of enterprise risk management (ERM) practices in the oil and gas industry, as examined by the study, could be further investigated to identify critical success factors and the impact of external factors such as the COVID-19 pandemic.

Advanced Fuzzy Logic Applications:

Investigate further applications of fuzzy logic in risk management within the oil and gas industry. Explore advanced fuzzy logic models and algorithms to enhance the precision and adaptability of risk assessments in different operational contexts.

Integration of Emerging Technologies:

Explore the integration of emerging technologies such as artificial intelligence (AI), machine learning, and data analytics in conjunction with FUZZY FMEA. Assess how these technologies can further refine risk predictions, improve decision-making, and contribute to proactive risk management strategies.

Cross-Industry Comparative Studies:

Conduct comparative studies across different industries to evaluate the transferability and effectiveness of FUZZY FMEA. Investigate how the application of fuzzy logic in risk management may vary across sectors and identify industry-specific best practices.

Longitudinal Studies on Risk Mitigation:

Undertake longitudinal studies to assess the long-term effectiveness of risk mitigation strategies identified through FUZZY FMEA. This could provide insights into the sustained impact of risk management practices on operational resilience and safety.

Cultural and Organizational Impact:

Explore the cultural and organizational factors that influence the successful implementation of risk management strategies. Investigate how organizational culture and structure impact the adoption of FUZZY FMEA and its effectiveness in managing risks.

Human Factors in Risk Management:

Investing regulatory environments and operational conditions. This could provide a more comprehensive understanding of the applicability of FUZZY FMEA on a global scale.

Scenario-Based Risk Assessments:

Develop and implement scenario-based risk assessments using FUZZY FMEA to simulate potential crisis situations. Evaluate the effectiveness of risk management strategies under different scenarios to enhance preparedness and response capabilities.

Community and Environmental Impact Studies:

Expand research focus to include the impact of risk management strategies on local communities and the environment. Investigate how the application of FUZZY FMEA contributes to minimizing environmental risks and enhancing community safety.

Regulatory Compliance Frameworks:

Research the devel ate the role of human factors in risk management within the context of petrol production. Explore how human decision-making, training programs, and safety culture influence the success of risk management strategies identified through FUZZY FMEA.

Global Case Studies:

Extend the geographical scope of case studies to include refineries in different regions with varying opment of regulatory compliance frameworks based on the findings of risk management effectiveness using FUZZY FMEA. Assess how regulatory bodies can incorporate advanced risk assessment methodologies into industry standards.

These recommendations aim to guide future research endeavors, providing avenues for further exploration and refinement of risk management strategies in the context of petrol production and beyond.

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APPENDICES

Appendix-A:

PART 1

Survey template for evaluating risk culture or risk assessment has been crafted to gather insights from Baiji Refinery employees regarding their comprehension of the refinery's tolerance for risk. The questionnaire aims to gauge the extent to which employees grasp the various risks faced by the refinery. This survey template has been expertly devised. The questionnaire was in Arabic because it is the employees' primary language for ease of filling out the questionnaire.

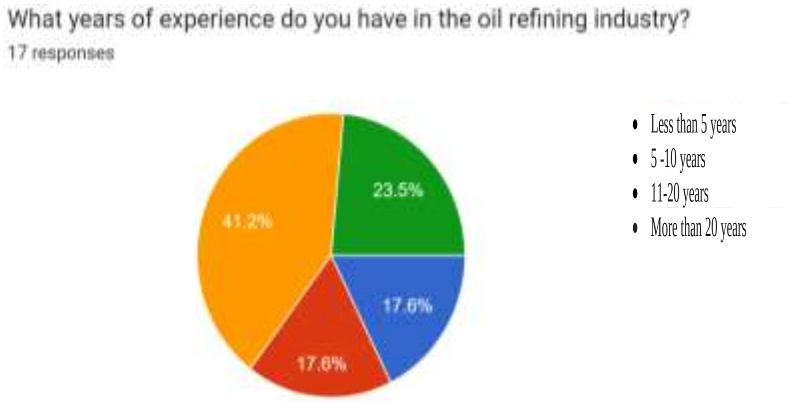
Questionnaire on risk management assessment at Baiji Refinery

This survey is being conducted as part of a thesis on risk management at Baiji Refinery. Your valuable input will help us understand current practices and challenges related to risk management at the refinery. Please answer the following questions based on your experience and knowledge. All responses will be kept confidential and used for academic purposes only.

*Indications required question

What years of experience do you have in the oil refining industry? *

- Less than 5 years
- 5 -10 years
- 11-20 years
- More than 20 years



How is risk management currently implemented at Baiji Refinery?

Formal risk assessment procedures

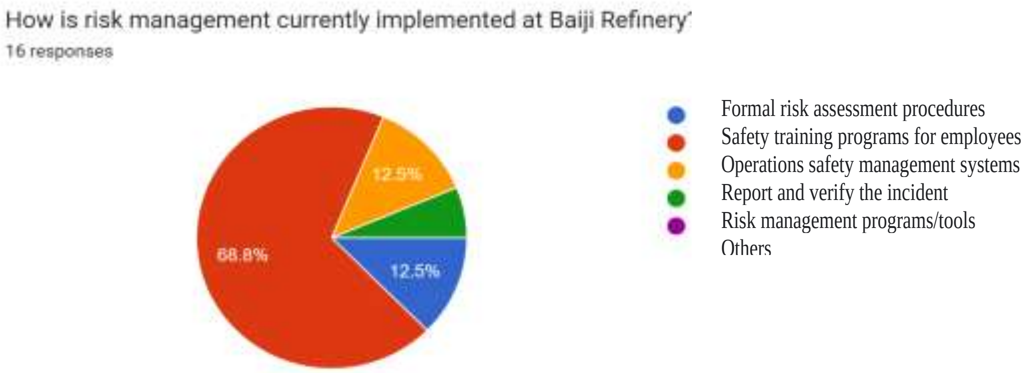
Safety training programs for employees

Operations safety management systems

Report and verify the incident

Risk management programs/tools

Others



How are potential risks identified within Baiji Refinery?

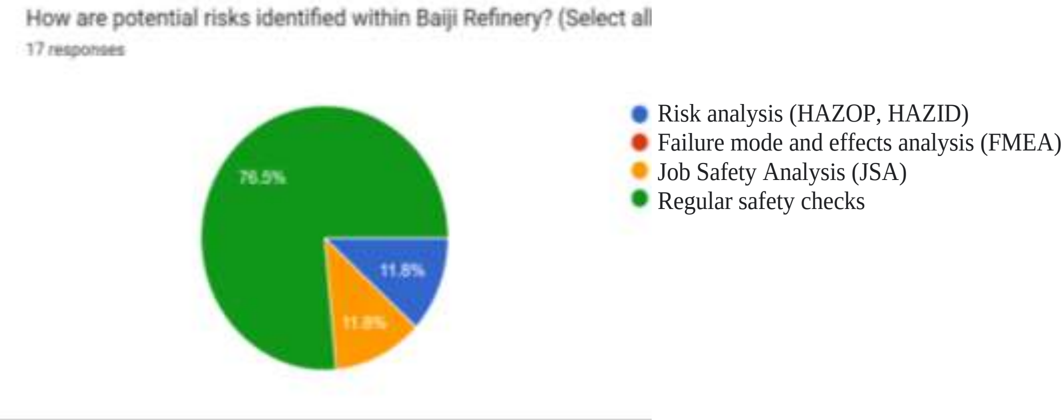
(Select all that apply)

Risk analysis (HAZOP, HAZID)

Failure mode and effects analysis (FMEA)

Job Safety Analysis (JSA)

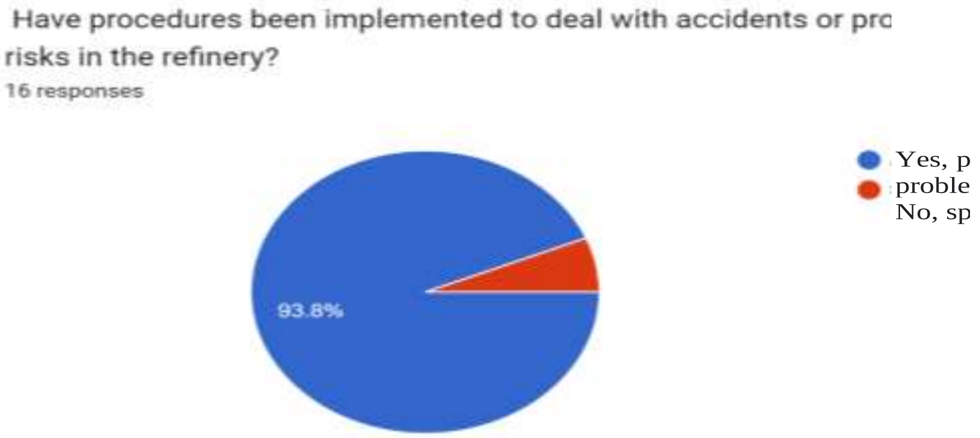
Regular safety checks



Have procedures been implemented to deal with accidents or problems resulting from production risks in the refinery?

Yes, procedures have been implemented to deal with incidents and problems

No, specific handling procedures are not implemented



How often are risk assessments conducted at Baiji Refinery?

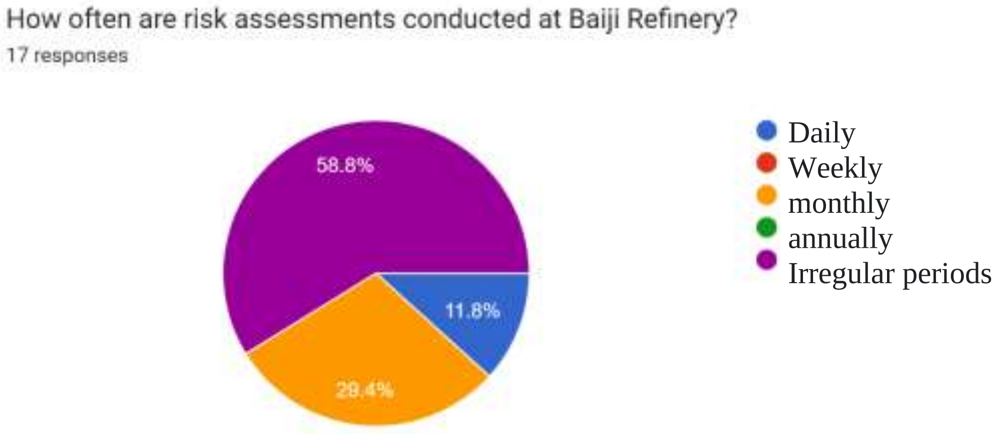
Daily

Weekly

monthly

annually

Irregular periods



What are the common risk mitigation measures used in the refinery?

Engineering controls

Administrative oversight

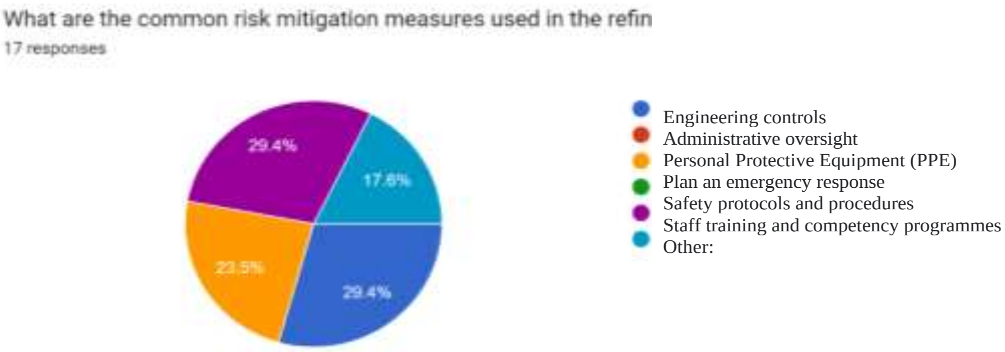
Personal Protective Equipment (PPE)

Plan an emergency response

Safety protocols and procedures

Staff training and competency programmes

Other:



In your opinion, what are the most important risks in Baiji Refinery?

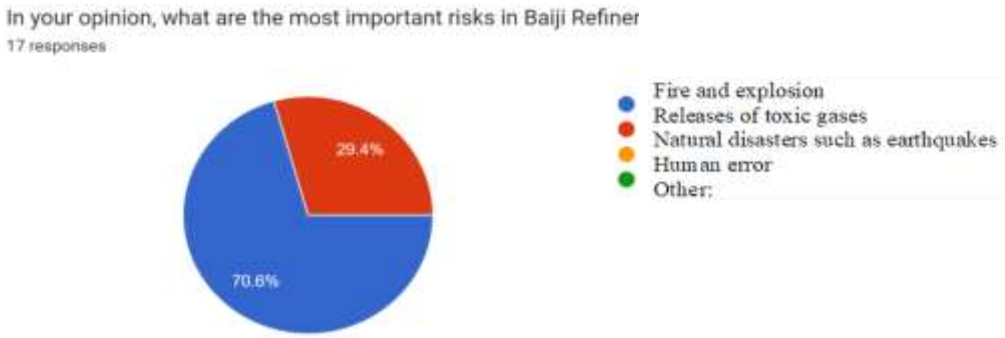
Fire and explosion

Releases of toxic gases

Natural disasters such as earthquakes and hurricanes

Human error

Other:



How are toxic gas emissions usually managed and controlled?

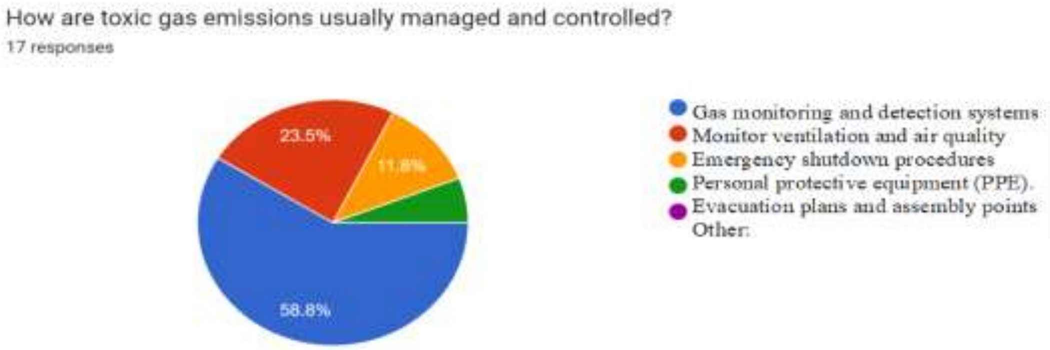
Gas monitoring and detection systems

Monitor ventilation and air quality

Emergency shutdown procedures

Personal protective equipment (PPE).

Evacuation plans and assembly points



How frequently is the risk management plan reviewed and updated?

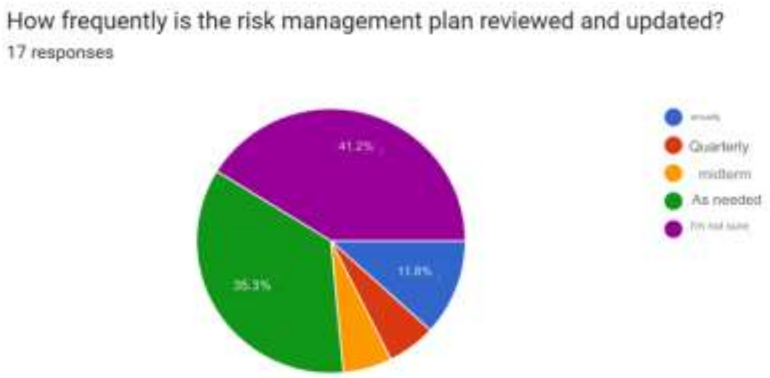
annually

quarterly

Mid-term

as it is required

I'm not sure



How do you evaluate the refinery's general safety culture and commitment to risk management?

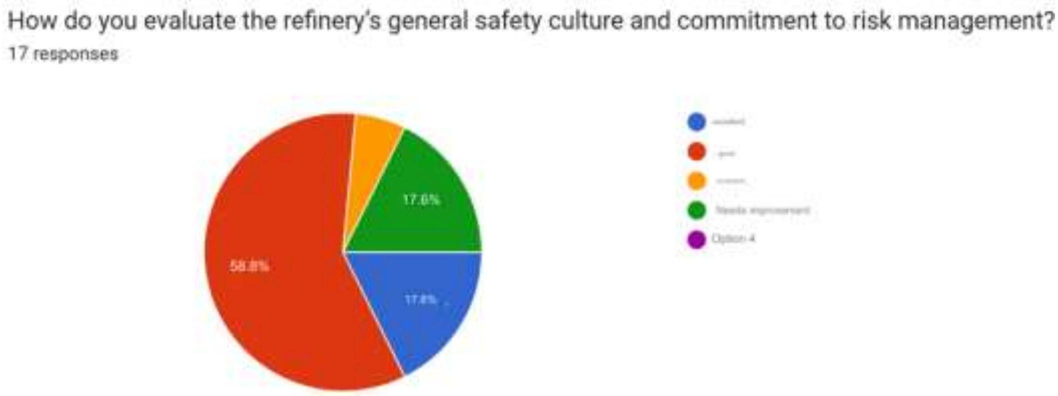
excellent

good

acceptable

Needs Improvement

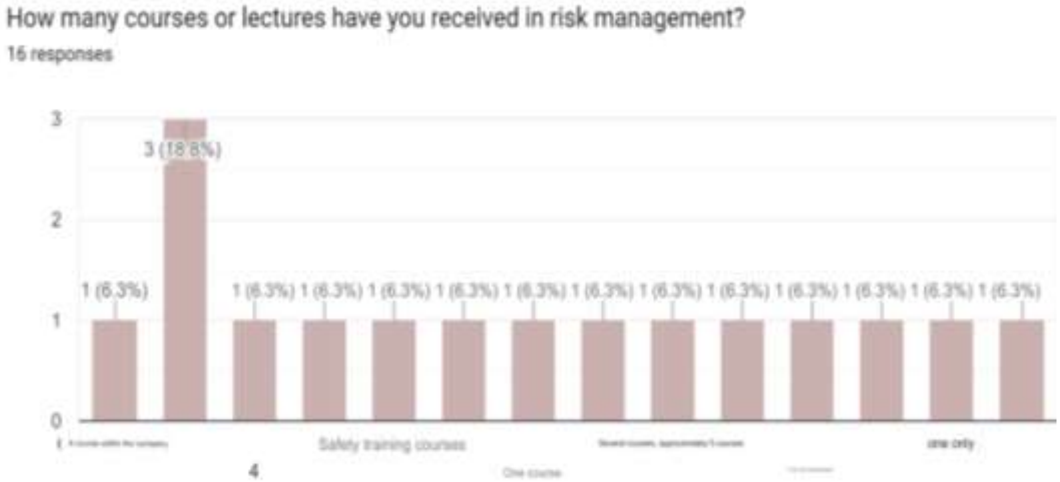
Option 4



How many courses or lectures have you received in risk management? 16 responses

0 courses within the compan4 training courses in safety courses One, several courses, approximately 5 courses, I do not remember. Only one01231 (6.3%)1 (6.3%)3 (18.8%)3 (18.8%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3) %)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%) %)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)

Value	Count
0 course within the company	1
2	3
4	1
Four courses	1
Safety training courses	1
Two courses	1
One course	1
Several courses, more than four courses	1
Several courses, approximately 5 courses	1
a lot	1
I don't remember.	1
One	1
one only	1
2	1



Are there risks surrounding you in your work environment? 16 responses

Gas emissions Gases Emission of toxic gases All No Fire hazards and YesYes High percentage of gases... Yes Conclusion We work in... sort of Somewhat 012341(6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)1 (6.3%)2 (12.5%)2 (12.5) %)1 (6.3%)1 (6.3%)4(25%)1

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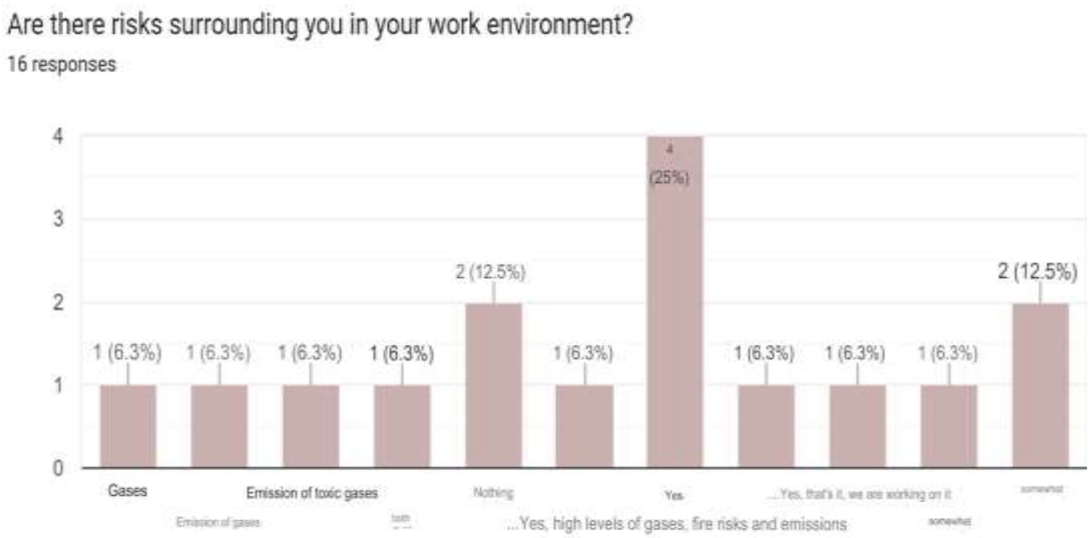


Value	Count
Gasses	1
Emission of gases	1
Emission of toxic gases	1
Both _	1
Nothing	2
Fire risks and emissions	1
Yes	4
Yes, there is an increase in the percentage of gases emitted as a result of refining operations in the operational units.	1
Yes, we are working in a dangerous location, the liquid gas unit	1
Somewhat	1
Somewhat	2

What are the main challenges you face in implementing effective risk management? 16 responses

- Failure to comply with safety instructions
- Nothing
- Lack of menstruation
- The working mechanisms are old, and must be improved in line with the development taking place

- Fire at the top of the towers
- Nothing
- There are no challenges
- Adequate training
- Awareness among employees
- Increasing employee awareness, full commitment to personal protective equipment by employees, and continuous follow-up of the implementation of safety plans to reduce environmental risks.
- Lack of tools
- Lack of capabilities
- Lack of commitment of employees
- Everything is within the responsibility

Have you encountered any major incidents related to risks in the past years? If the answer is yes, how were they dealt with and what were the lessons learned? 16 responses

- both
- no
- Yes, the incidents have been benefited from and the necessary measures have been taken
- Yes, a fire was extinguished and the cause was treated
- Yes/it was taken very seriously
- Yes, a fire was extinguished, it was controlled, and the defect causing it was addressed
- Yes, hydrogen gas emission occurred from a pressure of 30 bar to zero, and it was controlled by isolating the source
- no.

- The type of fabric is cotton fabric chosen for sewing work suits, which causes sparks
- Yes, a gas pipe explosion can be dealt with through insulation and ventilation
- Yes, fires / fires are dealt with quickly before it is too late due to the presence of hydrogen and gasoline using CO2 powder.

Your opinion on the level of risk management within the refinery

weak

1

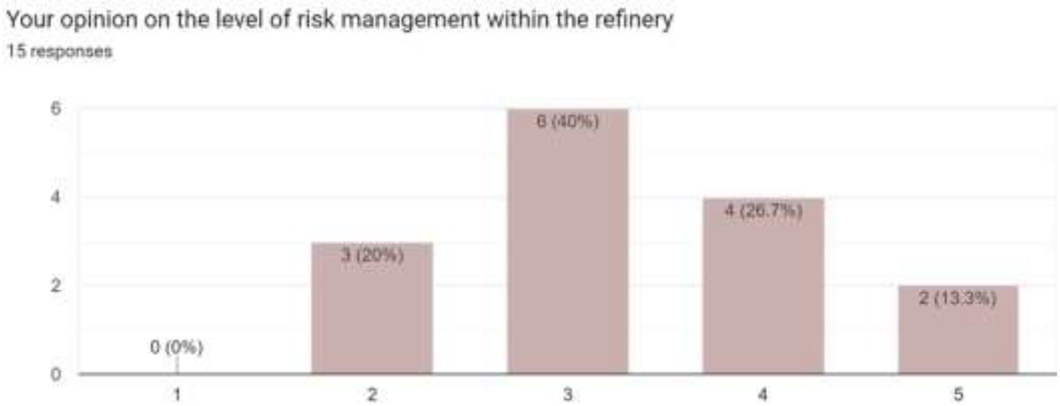
2

3

4

5

High



Are any specific risk categories given greater emphasis in the risk identification process? (eg process safety, environment, operation, finance, etc.) 14 responses

- All categories in which there are risks are emphasized without limitation
- Process safety, environment and operation
- Operations safety
- Safety of people and equipment

- Yes No
- Operational risks
- Operation, process safety and environment
- Yes
- Operation and environment
- Operations safety and environmental torches.
- Operations safety
- Yes
- Employment
- the environment

PART 2

Collecting information about previous incidents through interviews. Interviews provide an opportunity to obtain accurate and comprehensive details about incidents and their impact. The table below represents the details taken when conducting the interviews:

With the liquefied gas unit official and his agent, the director of the North Refinery Department, the director of the safety department, and some engineers at the refinery

Date of accident	Details	No. of victims	Faction of equipment	Losses caused by the accident	Circumstances that led to the occurrence of accidents

PART 3

Collecting information about the most prominent technical risks occurring at the Baiji refinery through interviews with a group of engineers and technicians

Faluier	Head Engineer in LPG UNIT			Head of Safety and Fire Departmen			Northern Refinery Department (Ph.D. in Chemical Engineering)			Technician Has 15 years experinces			Hydrocracking Department Manager			Occurance =Sum (occurace)/5	Severity =Sum (Severity)/5	Severity =Sum (Severity)/5
	Occurance	Severity	Detection	Occurance	Severity	Detection	Occurance	Severity	Detection	Occurance	Severity	Detection	Occurance	Severity	Detection			
Corrosion																		
Pressure Vessel Failures in liquid gas unit																		
Inadequate Emergency Shutdown Systems in liqued gas unit																		
Increase in temperatures																		
Human Factors																		
Contamination of the catalyst co-agent with impurities.																		
Pipeline Failures:																		
Fatigue Failure																		
Increase in pressure																		
Leakage of sulfur-containing gases in production pipelines																		
Cavitation in Pumps in liqud gas unit																		
structures are corroded																		
Leakage																		
Erosion and Abrasion																		
Freeze-up or Solidification:																		
Cracking																		
Seismic Vulnerability																		
Defects of isolation and prodtective covers peeling, variation of cover thickness, breaks cuts and tears																		

PART 4

Formulate the rules within each consequence

a. Occurrence - Almost none

S		D: Almost none	D: Low	D: Medium	D: High	D: Very high
S	**Almost none**	None	None	Very low	Low	Low
	Low	Very low	Low	Low	High low	Low medium
	Medium	Very low	Low	Low	High low	High low
	High	Low	High low	Low medium	Medium	High medium
	Very high	High low	Low medium	Medium	High medium	High

b. Occurrence - Low

S		D: Almost none	D: Low	D: Medium	D: High	D: Very high
S	**Almost none**	None	None	Very low	Low	Low
	Low	Very low	Low	High low	Low medium	Medium
	Medium	High low	Low medium	Medium	High medium	Low High
	High	Low medium	Medium	High medium	Low High	High
	Very high	Low medium	Low medium	Medium	High	High

c. Occurrence = Medium

	D: Almost none	D: Low	D: Medium	D: High	D: Very high
Low	Low	High low	Low medium	Medium	High medium
Medium	Low medium	Medium	High medium	Low High	High
High	Low	High low	Low medium	High medium	Low High
Very high	Low High	Medium	High medium	Low high	High

d. Consequence

Occurrence = High

	D: Almost none	D: Low	D: Medium	D: High	D: Very high
Low	Very low	Low	High low	Low medium	Medium
Medium	Low	High low	Low medium	Medium	High medium
High	Low medium	Medium	High medium	Low High	High
Very high	Medium	High medium	Low high	High	Very High

Fuzzy output

None	1	
Very low	2	
Low	3	
High low	4	
Low medium	5	
Medium	6	
High medium	7	
Low High	8	
High	9	
Very high	10	

PART 5

These accidents serve as stark reminders of the potential dangers associated with oil refining operations and underscore the importance of rigorous safety protocols and risk management practices in the industry.

1. **Texas City Refinery Explosion (2005)* *:

- Location: Texas City, Texas, USA.

- Date: March 23, 2005.

- Casualties: 15 workers were killed and more than 170 others were injured when an explosion occurred at the BP Texas City refinery. It was one of the deadliest refinery accidents in recent history.

2. **Pemex Gas Plant Explosion (2012)* *:

- Location: Reynosa, Mexico.

- Date: September 18, 2012.

- Casualties: 30 people were killed and more than 40 others were injured in a fire and explosion at a natural gas facility by Mexico's state oil company, Pemex.

3. **Grozny Refinery Fire (1999)* *:

- Location: Grozny, Chechnya, Russia.

- Date: November 3, 1999.

- Casualties: The fire at the Grozny oil refinery caused extensive damage and resulted in several deaths and injuries, although specific casualty figures are not readily available.

4. **Abadan Refinery Explosion (1974)* *:

- Location: Abadan, Iran.

- Date: August 19, 1974.

- Casualties: An explosion and fire at the Abadan oil refinery, one of the largest in the world at the time, resulted in numerous fatalities and injuries. Exact casualty figures vary in different sources.

5. **Nanjing Refinery Pipeline Explosion (2010)* *:

- Location: Nanjing, Jiangsu Province, China.

- Date: July 16, 2010.

- Casualties: At least 13 people were killed and many others were injured when a pipeline exploded at the Nanjing Refinery operated by Sinopec. The explosion also caused significant property damage.

RESUME

EXAMPLE

Haneen Mohammed Mahdi AL-SHANDAH

EDUCATION:

- 2018 Bachelor in Business Administration studies, Africa University, Libya
- 2024 Master degree (with thesis) in International Relations with excellent rate, Istanbul Gedik University, Istanbul, Turkey

WORK EXPERIENCE:

- Entrepreneur and free commerce. Since 2018 till 2021.
- Employee at the Ministry of Education, Libya June 2023 till now

SKILLS:

- Language: (excellent English, Arabic,).(French and Turkish basics)
- Managerial skills: analysis, market research, team Leadership, strategic management, Decision
- making, Adaptability, Relationship building, Strategic Thinking and Planning, Critical and
- Creative Thinking, Resistance to change and research

IT PROGRAM:

- Word, Excel, Access, PowerPoint, Business Intelligence.