DESIGN AND FABRICATION OF PET BOTTLE CRUSHER

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CERTIFICATION

This is to certify that the research project submitted to the Department of Mechanical Engineering was carried out by AIGBOVO OSAHENOMA FRIDAY, ERO ISIUWA MRORE DONALD OGHENERURO, OKPALA HILIARY CHIZOBA and OKPAKO OGHENEOCHUKO of the Department of Mechanical Engineering, University of Benin, Benin City, Edo State, Nigeria, under the supervision of Professor Godfrey O. Ariavie.

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DEDICATION

We dedicate this project to God almighty for all his mercies and grace upon us and to our loving parents and family for their love and care during our stay in the University of Benin.

ACKNOWLEDGEMENTS

We would like to express my sincere appreciation to all those who have supported me in completing this project. First and foremost, we want to thank God Almighty for watching over us and guiding us throughout our life.

Also, we are grateful to my supervisor, Prof. G.O. Ariavie, for his guidance, feedback, and encouragement throughout this project. We acknowledge the impact over the years of some of my lecturers and the influence these individuals have had in shaping my life as a mechanical engineering student in training, the person of Prof. Ebunilo, Engr. Peter Olagbegi, Dr. Kwasi, Engr G. Linus Dr. O. Ighodaro, Dr. H. Egware, and others, to name a few.

We also thank classmates for their valuable suggestions and constructive criticism. Finally, we want to thank my family and friends for their moral support and understanding during this challenging period. This project would not have been possible without the help of all these people.

ABSTRACT

The pipelines that transport petroleum products across Nigeria are vital for the country's economy and energy security. However, they are also exposed to various hazards and risks, such as theft, sabotage, corrosion, impact damage, fire, explosion, and environmental pollution. These risks can cause significant losses of life, property, and revenue, as well as damage the reputation and credibility of the pipeline operators. Therefore, it is essential to conduct a hazard and operability (HAZOP) study and a risk assessment of the pipelines to identify the potential causes and consequences of failure, and to propose appropriate mitigation measures.

A Hazard and Operability (HAZOP) analysis of pipelines is a systematic and structured process used to identify potential hazards, operability issues, and risks associated with the design, operation, and maintenance of pipeline systems.

This report presents the methodology and results of a HAZOP study and a risk assessment of the pipelines across Nigeria. The report also reviews the existing literature on the topic and compares the findings with the data collected around the pipelines observed in around Edo State. The report also went ahead to calculate the third party damage index for some selected pipelines and examines the pipeline right of way conditions in such locations.

The report aims to provide useful information and recommendations for the pipeline, regulators, stakeholders, and researchers who are involved or interested in the safety and reliability of the pipelines across the State.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

BACKGROUND TO THE STUDY

The transportation of natural gas is a critical aspect of the global energy industry, providing a reliable and efficient means of delivering this valuable resource from production centers to customers (Tseng, Y.Y et al. 2005). Central to this process are pipelines, which serve as the primary mode of transporting natural gas over long distances. However, the inherent nature of natural gas, with its flammability and potential for explosions, emphasizes the paramount importance of safety and risk management throughout the entire lifecycle of pipelines (Amyotte et al. 2021).

In Nigeria, there have been several series of pipeline incidents. Some notable situations and hazards that have occurred are the Jesse pipeline explosion 1998, Ijegun pipeline explosion 2008, the Arepo Pipeline Fire 2012, the Osisioma pipeline explosion 2018, Imo River Pipeline explosion 2019, Abule Egba pipeline explosion 2020, and several oil spillages in the Niger Delta region and in Lagos state. The various pipeline explosions have led to the loss of several lives and properties and environmental impacts. The various incidents and damages may have been caused by several factors such as leakages in the Pipeline, Design criteria and material of pipeline, inadequate ROW (Right of Way) distance, vandalism and third party effects (Omodanisi et.al 2014, Doherty and Otitoloju 2013, Fadeyibi et al. 2009, Eze A.U et al. 2022, Kadafa A.A 2012).

In light of the potential hazards and risks associated with the pipeline systems, there is increasing research in the Risk Assessment of pipelines. A systematic process of the study of potential hazards and the likelihood and consequences of potential adverse effects is what we call Risk Analysis or Risk Assessment. Pipeline Risk Analysis is therefore the study of the adverse effects of pipelines, the different types of pipelines and their failures, preventive maintenance of pipelines damages, etc. Risk Analysis of pipelines involves the assessment of the potential hazards associated with pipelines to identify, evaluate and mitigate risks in ensuring safety and reliability to the environment (Brito et al. 2009). There are several methods of Risk Assessment of pipelines, some of which include; Qualitative Risk Assessment, Semi-Qualitative Risk Assessment, Hazard Identification Workshops (HAZID), Hazard and Operational Analysis (HAZOP), Quantitative Risk Assessment, Fault Tree Analysis, Event Tree Analysis, Failure Modes and Effects Analysis (FMEA), etc (Pallavi et al. 2015, Clemens et al. 1998, Ferguson and Lu 2017, Hong et al. 2009, Shahriar et al. 2012). This project presents a comprehensive risk analysis focusing on pipeline installation and failures using an HAZOP Study.

The Hazards and Operational study is a widely recognized methodology used in the oil and gas industry to identify and assess potential hazards and operability issues in industrial processes, including oil pipeline systems (Marhavilas et al. 2019). A Hazard and Operability (HAZOP) analysis of pipelines is a systematic and structured process used to identify potential hazards, operability issues, and risks associated with the design, operation, and maintenance of pipeline systems (Chae et al. 1994).

It involves a multidisciplinary team of experts who systematically examine the pipeline's various components, processes, and operating conditions. The study prioritizes hazards and purpose effective risk mitigation measures by considering both severity and frequency assessments (Marhavilas et al. 2011).

STATEMENT OF PROBLEM

The installation, transportation and operation of natural gas pipelines present multifaceted challenges, including possible material defects, construction errors, corrosion, and third party interference. Failure in any of these phases can lead to catastrophic consequences, including environmental damage, loss of life and properties, pipeline vandalism, economic losses, etc. It is therefore imperative to conduct a thorough analysis and study on potential risks, deviations and operational inefficiencies on pipelines to enhance safety measures.

AIM AND OBJECTIVES

The aim of this project is to identify the potential hazards associated with pipeline installation, construction, operation and maintenance and third party effects in order to improve the reliability and integrity of pipelines.

This is to be achieved by meeting the following objectives:

1. To inspect some selected pipelines using Hazard and Operational study.
2. Inspection of the Pipeline right-of-way encroachment in the selected pipeline for case study.
3. To examined the third party damage using third party index variable.
4. Plotting of the right of way distance using python Matplotlib. .

SIGNIFICANCE OF STUDY

The significance of this project plays crucial role in ensuring the safety, reliability and environmental responsibility of pipeline systems. A successful risk assessment of pipeline can help identify hazards and recommend ways to mitigate such risks which would save lots of lives and properties and mitigate pipeline vandalism.

PROJECT SCOPE AND LIMITATIONS

The HAZOP study will encompass various aspects of natural gas pipeline installation, transportation and failure covering only onshore installations. The project will concentrate on the study of pipeline installation. It will involve the study of depth of pipeline in such locations, the right of way condition, the materials used in the pipelines, the third party effects, techniques used in the installation, analysis and detention of leakages and environmental effects. Furthermore, a node will be selected and several tests carried out to collect data to identify deviations and the preparation of the risk curve and design of risk reduction measures.

CHAPTER TWO

LITERATURE REVIEW

Pipeline is a connection of different pipes, with component such as valves, pumps, control and safety devices and others, used for the transportation of liquid from one location to a long distance destination (Pharris and Kolpa 2008). Transportation of crude via pipelines can be categorized into two; Crude Oil Pipelines and Product Pipeline. The former involve the transportation of crude (Oil, water and gas) from one location to refineries while the latter involves the transportation of the products (such as Gasoline, jet fuel, etc.) from the refineries (Frittelli et al. 2014). Pipelines can also be classified according to their lines and purpose. We have Gathering Pipeline, Feeder Pipeline, Transmission Pipeline, Distribution Pipeline, etc. (Shan K. and Shuai J. 2017).

Risk is the measure or rate of the frequency and severity of an adverse effect (Dan Williams, P.Eng, and Pipeline Risk Assessment Fundamentals). Risks could be divided into two categories; Individual Risk and Societal Risks.

Individual Risk: This can be defined as the probability by which a person or an individual has the likelihood of experiencing an adverse effect or undesirable outcome. It is a type of risk which takes into account when a plant employee is exposed to plant hazards (Dziubinski et al. 2006).

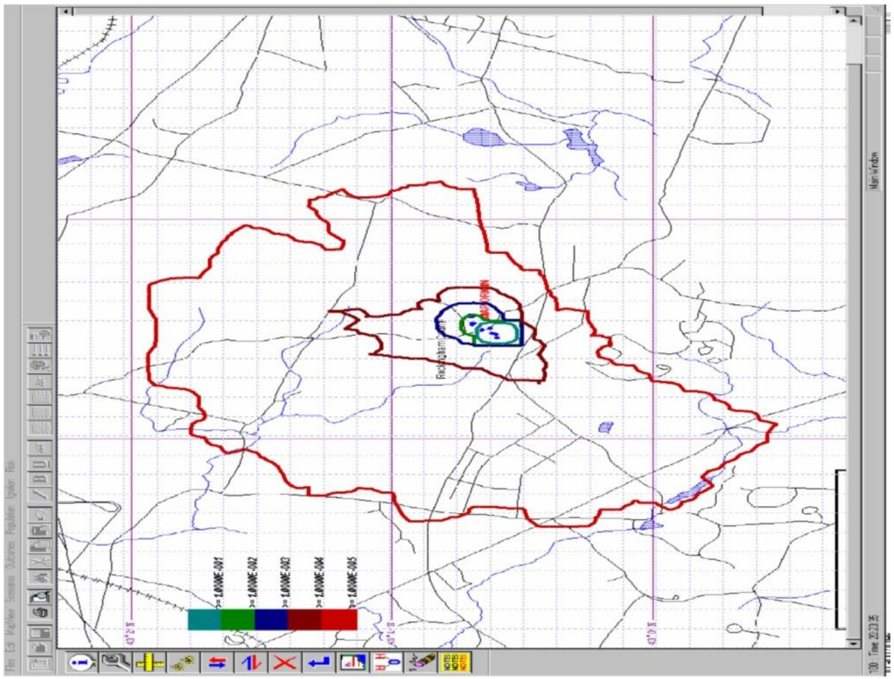


Figure 2.1 Individual Risk Contour plot generated using SuperChems (Pierre et al.)

Societal Risk: This is the probability of the likelihood of a group of persons or people experienced to potential hazards or an adverse effect. It is termed as a risk of widespread or large scale detriment from the realization of a potential hazard (HSE, 1995, Henselwood and Phillips 2006). Some characteristics of this risk include:

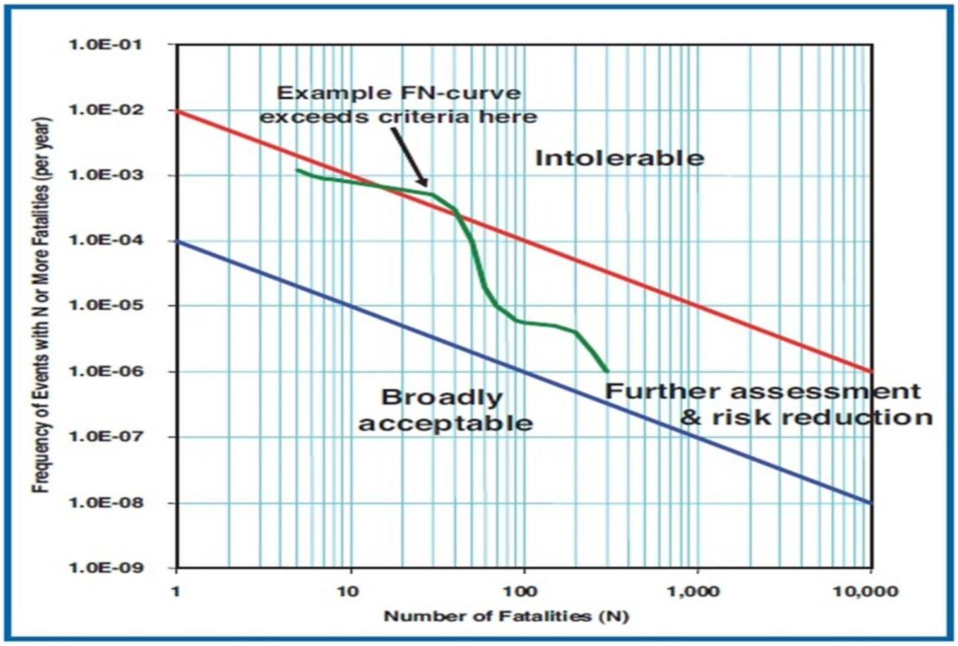


Figure 2.2 Societal Risk Plot using F-N Criteria (Risktec TuvRheinland).

Most pipeline operators control the risks by complying with the government regulatory measures and undergo maintenance whenever there is any perceived need or where past experience or analysis shows it's prone to risks (Hopkins A, 2011). Regulatory authorities in USA, Canada and in the UK are moving away from these perspective approaches to "risk management" as the safest and most cost effective means of maintaining and improving safety levels in pipelines. A systematic process of the study of potential hazards and the likelihood and consequences of potential adverse effects is what we call Risk Analysis or Risk Assessment. Pipeline Risk Analysis is therefore the study of the adverse effects of pipelines, the different types of pipelines and their failures, preventive maintenance of pipelines damages, etc. (Shahriar et al. 2012).Risk Analysis of pipelines involves the assessment of the potential hazards associated with pipelines to identify, evaluate and mitigate risks in ensuring safety and reliability to the environment (Kishawy and Gabbar 2010).

Definition of some terms:

Hazard: The term hazard is coined from the Arabic word "*al zahr*" which means "dice" and was an ancient game (Stahel et al. 2017). A hazard is any characteristic or group of characteristics which refers to damage or has the potential of causing a damage or loss (Ciurean et al. 2013).

Risk Analysis: A systematic assessment of hazards, their potential damages and consequences to estimate the risk.

Risk Management: This is a process whereby the risks evaluated are mitigated and control to reduce its drastic effects on lives and environment.

Failure: A material is said to undergo failure when it cannot serve the purpose for which it is intended for. Pipeline Failure refers to any pipeline which has been disturbed or deviated from transporting fluids from one location to another.

Depth of Cover: This refers to the depth by which a pipeline is buried under the earth crust and they serve to protect the pipeline from third party effects and environmental effects.

Activity Level: This is usually used to describe the level of activity, events, buildings and structure, population density, etc. of the environment surrounding the pipeline (Muhlbauer, 2004).

Right of Way: This is a piece of land and distance from the pipeline location to a particular distance where the company has been given approval to carry out pipelines operations without any obstruction or building of houses, shops, etc. over the land (Muhlbauer, 2004).

Patrol Frequency: This is the rate at which the pipeline operators are to inspect the surface of the pipeline route to observe the conditions on or within the pipeline right of way distance (Muhlbauer, 2004).

HAZARD IDENTIFCATION

Hazard Identification can be defined as systematical process of analyzing potential hazards such as the causes and consequences of the various hazards (Khan and Abassi 1998). Hazard identification involves various key steps and techniques, some of which include: Gathering of Information, Selection of Multidisciplinary team, Define the scope of the hazard identification, identify sources, causes and consequences of the hazards, and ways to mitigate and manage risks (Hou and Dong 2020).

TYPES OF HAZARDS:

Oil and gas pipelines are associated with specific types of hazards due to the nature of fluid that passed through the pipelines. Gas being easily flammable poised a lot of risks when they are disrupted by vandalism or other means.

FLAMMABLE HAZARDS: These include BLEVE (Boiling Liquid Expanding VaporExplosion) Jet Fire, Pool Fire and Flash Fire (Pula et al. 2006).

BLEVE: A BLEVE happens when a container that is holding a volatile liquid under pressure ruptures or catastrophically collapses, such as a pressurized tank or vessel. Due to the fast pressure decrease that results from the container failing, the liquid within quickly vaporizes, producing a sizable vapor cloud. This vapor cloud's potential for igniting can result in a huge explosion that frequently has disastrous effects. In businesses where flammable or poisonous substances are kept or transported, BLEVEs are especially dangerous (Abbasi and Abassi 2007).

Figure 2.3 BLEVE Fire (ioMasaic and Pantektor AB)

Jet Fire: A pressured discharge of combustible liquids or gases through a tiny hole or nozzle causes a fire known as a jet fire (Palacios and Casal, 2011). High material velocity produces a turbulent jet that interacts with the surrounding air to make a flame. In industrial settings, jet fires are frequent, particularly in oil and gas installations where pressurized hydrocarbons might leak from pipelines, valves, or machinery (Tong et al. 2013).

Figure 2.4 Jet Fire (ioMasaic and Pantektor AB)

Pool Fire: When a flammable liquid, such gasoline, oil, or alcohol, spreads and pools on the ground or other surfaces, it starts a pool fire (Liu et al 2021). Above the surface of the pool, the liquid evaporates and creates a flammable vapor cloud that may catch fire if it comes in contact with an ignition source (Verfondern and Dienhart 2007). Pool fires may be dangerous and difficult to put out, especially in settings where hazardous materials are stored or where there is considerable visibility and heat production (Chatris et al. 2001).

Figure 2.5 Pool Fire (ioMasaic and Pantektor AB)

EXPLOSIVE HAZARDS:

Explosive hazards are threats that might be present from things like chemicals, materials, or equipment that can react violently and quickly, releasing a lot of energy in the form of pressure, heat, and shockwaves**.** This includes Vapor Cloud and dust explosions (Abbasi and Abbasi 2007).

Figure 2.6 Explosive Hazard Release (ioMasaic and Pantektor AB)

TOXIC CONSEQUENCES

Pipeline dangers can have a variety of hazardous effects that pose serious concerns to both human health and the environment. Pipelines are used to move a variety of goods, including potentially dangerous ones like chemicals, gases, and petroleum products. Accidents involving pipelines, leaks, or breakdowns may result in hazardous exposure and have serious repercussions.

PIPELINE FAILURE

Pipeline Failure is a termed used to describe a situation where there is disruption, damage and malfunction of a pipeline system (Ariman and Muleski 1981). Pipeline failures have adverse effects to the environment through which it passes. They can be caused due to a lot of factors such as Third Party Damage, Corrosion, Mechanical Failure, Natural Hazards, Operational fault, equipment failures and others (Andersen and Misund 1983).

THIRD PARTY DAMAGE

The oil and gas sector is very concerned about third-party damage to pipelines since it can result in failures, spills, and possibly disastrous occurrences. Any harm caused to a pipeline by people or organizations unrelated to its operation is referred to as third-party damage. Various activities, such as building, excavation, or vandalism, may cause this damage (Guo et al. 2018). Third party damage may be caused as a result of encroachment into the pipeline route and vandalism by individuals (Ambituuni et al. 2015).

CORROSION

One of the most prevalent and important reasons for pipeline failure in the oil and gas sector is corrosion (Makhlouf et al. 2018). It describes the slow deterioration and corrosion of pipeline materials brought on by chemical interactions with the environment. The pipeline's structural integrity may be compromised by corrosion, which might result in leaks, ruptures, and other types of failure (Ossai et al. 2015). There are various types of corrosion which can affect the pipeline industry, some of which include Uniform Corrosion, Pitting Corrosion, Galvanic Corrosion, etc (Jambekar et al. 2021). Corrosion of pipeline can be monitored by using Intelligent PIGs (Pipeline Inspection Gauge) to detect corrosion cracks and faults in the pipeline (Zelmati et al. 2020).

MECHANICAL FAILURE

In the oil and gas sector, mechanical failure accounts for a sizable portion of pipeline failures and accidents (Siler-Evans et al. 2014). Mechanical failures, which can cause leaks, ruptures, or other types of failure, refer to structural faults or problems with the physical components of the pipeline (Dundulis et al. 2016). These failures might happen for a number of causes. Pipeline operators must follow rigorous guidelines, conduct routine inspections and maintenance, and place a high priority on the security and dependability of their pipes in order to avoid and reduce mechanical failures (Hussain and Seema 2023).

NATURAL HAZARDS

Pipelines are susceptible to severe risks from natural disasters, which can result in failures and possibly disastrous events. Pipelines can sustain damage, leakage, or rupture as a result of a variety of natural disasters. Some of the natural hazards that can cause pipeline failure include wildfires, tornadoes, earthquake, floods, etc. These natural hazards cannot be controlled but good facilities and design of pipelines can be used to reduce the effects of the occurrence (Girgin and Krausmann 2016).

OPERATIONAL FAULT

Operational errors can play a key role in pipeline failures, posing a number of safety risks, causing environmental harm, and interfering with the flow of chemicals via the pipeline. These operational flaws may be the consequence of mistakes made by people, poor maintenance, or breakdowns in the operational procedures.

RISK ASSESSMENT METHODS

There are several other types of risk assessments used in various industries to evaluate and mitigate different types of risks. Here are some common ones:

Fault Tree Analysis (FTA):

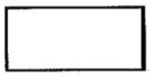
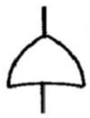
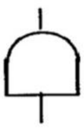
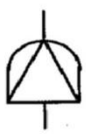
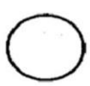
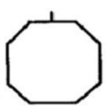
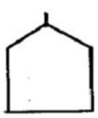
In many cases there are multiple causes for an accident or other loss-making event. Fault tree analysis is one analytical technique for tracing the events which could contribute [Toroody et al., 2016]. It can be used in accident investigation and in a detailed hazard assessment. The fault tree is a logic diagram based on the principle of multi-causality, which traces all branches of events which could contribute to an accident or failure.

Fault tree analysis is a failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events [Javadi et al., 2011] . This analysis method is mainly used in the field of safety engineering to quantitatively determine the probability of a safety hazard.

FTA was originally developed in 1962 at Bell Laboratories by H.A Watson, under a U.S Air Force Ballistics Systems Division contract to evaluate the Minuteman I Intercontinental Ballistic Missile (ICBM) Launch Control System [Pallavi et al., 2015].

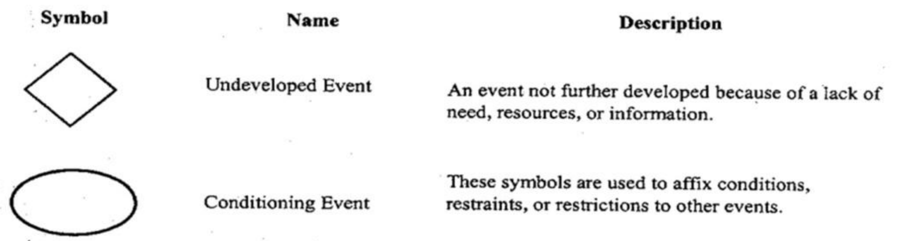
Fault trees are constructed with various event and gate logic symbols. These symbols are defined in figure..1 below. Although many event and gate symbols exist, most fault trees can be constructed with the following four symbols: (1) TOP or intermediate event, (2) inclusive OR gate, (3) AND gate, and (4) basic event. Figure.2 illustrates the procedures to construct a fault tree [Clemens et al., 1998].

Fault tree construction symbols

Symbol	Name	Description
	Event (TOP or Intermediate) *	TOP Event- This is the conceivable, undesired event to which failure paths of lower level events lead. Intermediate Event- This event describes a system condition produced by preceding events.
	Inclusive OR Gate *	An output occurs if one or more inputs exist. Any single input is necessary and sufficient to cause the output event to occur. Refer to Table VII-3 for additional information.
	Exclusive OR Gate	An output occurs if one, but only one input exists. Any single input is necessary and sufficient to cause the output event to occur. Refer to Table VII-3 for additional information.
	Mutually Exclusive OR Gate	An output occurs if one or more inputs exist. However, all other inputs are then precluded. Any single input is necessary and sufficient to cause the output event to occur. Refer to Table VII-3 for additional information.
	AND Gate *	An output occurs if all inputs exist. All inputs are necessary and sufficient to cause the output event to occur.
	Priority AND Gate	An output occurs if all inputs exist and occur in a predetermined sequence. All inputs are necessary and sufficient to cause the output event to occur.
	Basic Event *	An initiating fault or failure that is not developed further. These events determine the resolution limit of the analysis. They are also called leaves or initiators.
	INHIBIT Gate	An output occurs if a single input event occurs in presence of an enabling condition. Mathematically treated as an AND Gate.
	External Event	An event that under normal conditions is expected to occur. Probability =1.

* Most fault trees can be constructed with these four logic symbols.

Figure 2.7 Fault tree construction symbols



Symbol	Name	Description
	Undeveloped Event	An event not further developed because of a lack of need, resources, or information.
	Conditioning Event	These symbols are used to affix conditions, restraints, or restrictions to other events.

Figure 2.8 1998 Figure provided courtesy of National Institute for Occupational Safety and Health [Clemens et al., 1998].

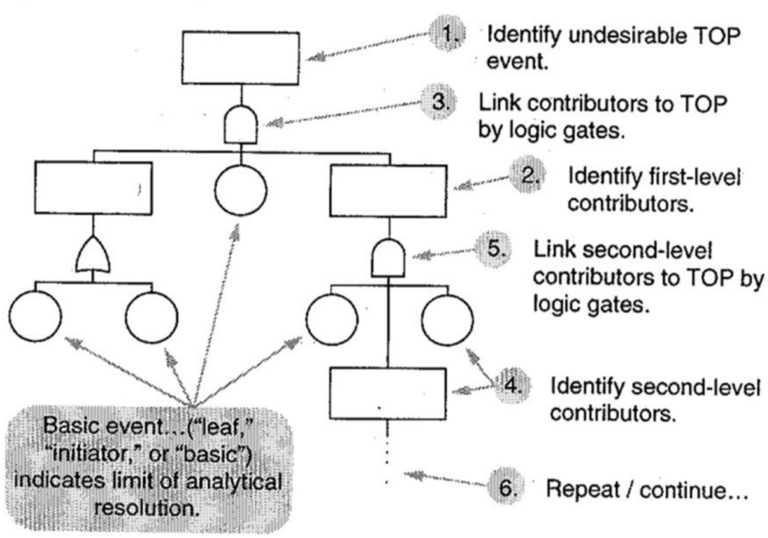


Figure 2.9 Faulty tree construction process.

APPLICATION

For high-energy systems (i.e., potentially high severity events), FTAs are especially helpful in ensuring that a collection of countermeasures appropriately minimizes the likelihood of accidents. For the analysis of complex systems and to aid in the development of design, an FTA is a potent diagnostic tool. In accident investigations, this kind of analysis might occasionally be useful to identify the cause or rank potential possibilities. Resources could be prioritized according to the action items from the research that are numerically tagged to the fault tree elements they address. [Clemens et al., 1998].

Both hardware and non-hardware systems can benefit from fault tree investigations, which offer probabilistic system risk assessment and effort prioritization based on root cause analysis. In this study, rather than at the top level, the subjective component of risk assessment is relegated to the lowest level (root causes of effects). Sensitivity studies can be carried up to investigate the TOP event's sensitivity to the fundamental initiator probability.

FTAs can be carried out during the fabrication, integration, test, and evaluation phases in addition to the design and development period. Cut sets and initiators with comparatively high failure rates can be found using FTAs. As a result, it is possible to optimize resource allocation to lower the risk of high-risk TOP occurrences.

LIMITATION.

1. The accuracy and efficiency of Fault Tree Analysis (FTA) greatly depend on the proficiency of the analysts, their capacity to pinpoint pertinent failure causes, and their comprehension of the intricacies within the fault tree. [Papadopoulos et al.,].
2. Fault Tree Analysis (FTA) is most effective when applied to smaller system assessments. In the case of large and intricate systems, the creation of extensive fault trees can lead to a time-consuming and demanding analysis process.[Kabir et al., 2017].
3. Failure data availability and quality will determine the precision of the calculated probabilities in a fault tree [Taheriyoun et al., 2015].

4. Fault tree analysis only allows you to examine one top event at a time.

5. FTA is a binary system. Each hypothesis is either validated or not, making it too rigid for assets with conditional failures (failures that only happen under certain conditions, i.e. low temperatures) or partial failures [Isermann et al., 2011].

6. It is not always possible to determine the probability of failure, which invalidates FTA as a quantitative method [wu et al., 2018].

FAULT TREE ANALYSIS IN INDUSTRY

1. Space Industry: example: NASA applied Fault Tree Analysis (FTA) for the Apollo missions, the first manned Moon landing, due to the initial assessment indicating a low probability of a safe return to Earth. Following the tragic Space Shuttle Challenger disaster in 1986, where the shuttle disintegrated shortly after liftoff, NASA started utilizing a combined FTA analysis approach.[NASA, 2000] .

2. Nuclear power industry: Example: A study was carried using the Fault Tree (FT) analysis to a coolant outlet piper snake-arm inspection robot in a nuclear power plant [Ferguson et al.,2017].

Event Tree Analysis (ETA):

An event tree analysis (ETA) is an inductive process that depicts all potential outcomes from an unintended (initiating) occurrence, taking into account other events and circumstances, as well as whether placed safety barriers are functional or not. The ETA can be used to find all conceivable accident situations and sequences in a complicated system by evaluating all pertinent accidental events. Unlike the faulty tree analysis, the ETA take account of the events leading to the event.

In 2009, a risk assessment was performed for the excavation of an underwater tunnel beneath the Han River in Korea, employing an earth pressure balance tunnel boring machine. ETA was employed to assess and quantify the risks, offering the likelihood of events occurring during the initial design phase of tunnel construction. This was crucial in averting any potential injuries or fatalities, especially considering that tunnel construction in Korea has historically exhibited the highest rates of both injuries and fatalities within the construction sector. [Hong et al., 2009].

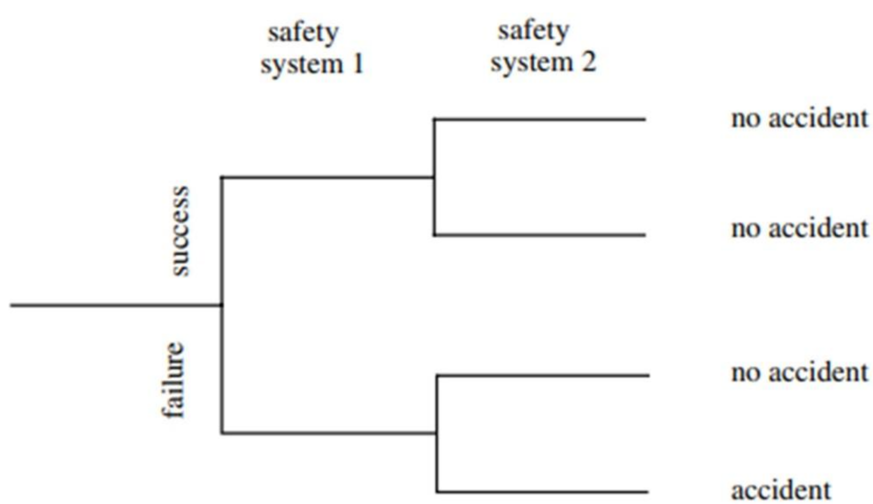


Figure 2.10 Event Tree Figure, adapted from probabilistic risk Analysis [Bedford, 2001]

APPLICATION

Studying command-start or command-stop protection devices, emergency response systems, and engineered safety features all benefit greatly from the event tree analysis [Clemens et al., 1998]. The method works well for examining managerial decision-making options, operational processes, and other non-hardware systems. The ETA is useful for determining the impact and advantages of duplicate or sub-layered design countermeasures for evaluation and design trades.

To give a method for sensitivity assessment, an ETA may be employed in conjunction with a fault tree analysis (Shahriar et al., 2012). To prevent losing the analysis's credibility, success or failure probability must be used with prudence. It is often preferable to stick with comparative probabilities rather than "absolute" values [Masalegooyan et al., 2022]. Normalizing data to a set, explicitly announced meaningless value is a useful tactic in this case.

Also, confidence or error bars on each quoted probability number are required to establish the relevance of any quantitatively driven conclusion. An ETA may also be undertaken to complement a failure mechanisms and effects analysis. This technique is typically performed in the design and development phase or the operations phase, but may also be performed in the fabrication, integration, test, and evaluation phase [Clemens et al., 1998] .

LIMITATIONS

1. Data quality and availability

The challenges of ETA is the quality and availability of data to assist the analysis. Data can contain failure rates, probabilities, human error factors, environmental conditions, and other pertinent parameters[Mokhtari et al., 2011]. However, data may be few, obsolete, erroneous, or inconsistent, which might impair the reliability and accuracy of the results. Therefore, it is vital to collect and validate data from diverse sources, apply acceptable methods to estimate or adjust data, and document the assumptions and uncertainties involved in the data analysis [De Felice et al., 2011].

2. Complexity and scalability

Another challenge ETA is the complexity and scalability of the analysis. As the system or scenario under investigation grows more complicated, the number of events, branches, and combinations increases exponentially, which can make the analysis tedious, time-consuming, and prone to errors [Al Najada et al .,2016]. Moreover, the graphical depiction of event trees might become congested and difficult to read. Therefore, it is vital to simplify and modularize the analysis, use software tools to automate and visualize the study, and apply appropriate strategies to reduce and prioritize the branches and combinations [Shahriar et al., 2012].

2 Human factors and organizational issues

A third obstacle of ETA is the human aspects and organizational concerns that can influence the analysis. Human factors can include the skills, expertise, experience, prejudices, and preferences of the analysts, experts, and stakeholders participating in the analysis [CCPS et al ., 2018] . Organizational challenges can include the culture, policies, procedures, communication, and incentives that affect the analysis process and outcomes. These characteristics can create subjectivity, variability, and uncertainty in the analysis, which can undermine the validity and trustworthiness of the results. Therefore, it is necessary to incorporate a diverse and qualified team, apply structured and transparent techniques, and solicit input and validation from appropriate stakeholders.

3 Uncertainty and sensitivity

A fourth problem of ETA is the uncertainty and sensitivity of the analysis. Uncertainty can originate from the data, assumptions, models, and methods employed in the study, which can affect the confidence and robustness of the results [da Silva et al., 2022]. Sensitivity can relate to the degree to which the results change with respect to changes in the input parameters or assumptions, which might affect the relevance and usefulness of the results [Hamby, 1994]. Therefore, it is vital to quantify and explain the uncertainty and sensitivity of the study, utilize appropriate methodologies to disseminate and analyse uncertainty and sensitivity, and perform sensitivity analysis to discover the primary drivers and uncertainties of the results.

4 Validation and verification

A fifth problem of ETA is the validation and verification of the analysis. Validation can refer to the extent to which the analysis reflects the reality of the system or scenario under examination, which might affect the application and acceptability of the conclusions [Gallivan et al., 2005]. Verification can refer to the amount to which the analysis is completed correctly and consistently, which might affect the dependability and correctness of the results. Therefore, it is vital to validate and verify the analysis, use empirical or experimental data to compare and calibrate the analysis, and undertake quality checks and audits to ensure the validity and consistency of the analysis.

5 Presentation and communication

A sixth obstacle of ETA is the analysis' communication and presentation. The process of conveying and exchanging information, knowledge, and insights among analysts, experts, stakeholders, and decision-makers involved in or influenced by the analysis is referred to as communication. The manner and style of displaying and delivering the results of the analysis can be referred to as presentation. These factors can have an impact on the results' comprehension, interpretation, and application. As a result, it is critical to effectively communicate and present the analysis, to utilize clear and simple language, visuals, and tables, and to match communication and presentation to the audience and purpose of the analysis.

HAZOP vs. Event tree Analysis(ETA); Key Difference

1. **Purpose:** HAZOP's primary goal is to uncover potential hazards and operational concerns in a process or system [Venkatasubramanian et al., 2000], whereas ETA is used to analyze the repercussions of loss-making events in order to find solutions to mitigate, rather than avoid, losses [Arone et al., 2022].

2. **Methodology**: HAZOP is a systematic, structured, and team-based approach for identifying potential hazards and process operability issues [Fenelon et al., 1994], whereas ETA is a deductive modeling method that proceeds in a logical, top-down manner to evaluate both success and failure scenarios. It begins with a single initiating event and provides a framework for estimating the probabilities of various outcomes, enabling a comprehensive analysis of the entire system. [Van Weyenberge et al., 2016].

3. **Focus:** HAZOP focuses on detecting probable causes and implications of deviations from the intended process design, whereas ETA focuses on failure outcomes.

4. **Applicability**: HAZOP is best suited for complicated continuous processes where the interactions of numerous elements can result in unexpected outcomes. It is frequently used during the design and early stages of a process to ensure that safety considerations are incorporated from the beginning [Cameron et al., 2017]. ETA is ideal for reducing undesirable results by checking the effects of functions or any error mechanisms [Sirish et al., 2013].

5. **Outcome:** A HAZOP analysis produces a thorough report that outlines identified dangers and recommends appropriate management actions [Cameron et al., 2017]. ETA, on the other hand, calculates the likelihood of potential bad outcomes that can cause injury as a result of the specified beginning event [Fenelon et al., 1994].

BOW TIE ANALYSIS

The Bow-Tie analysis is a qualitative risk assessment tool that illustrates in an understandable graphical way the relationship between the sources of unwelcome occurrences and the escalation potential for loss and damage [Book et al., 2012]. According to each threat, Bow-Tie Analysis can suggest orders that would stop the top event from happening first. It can also suggest recovery plans that would be prepared to lessen the effects of the top event once it had already happened.

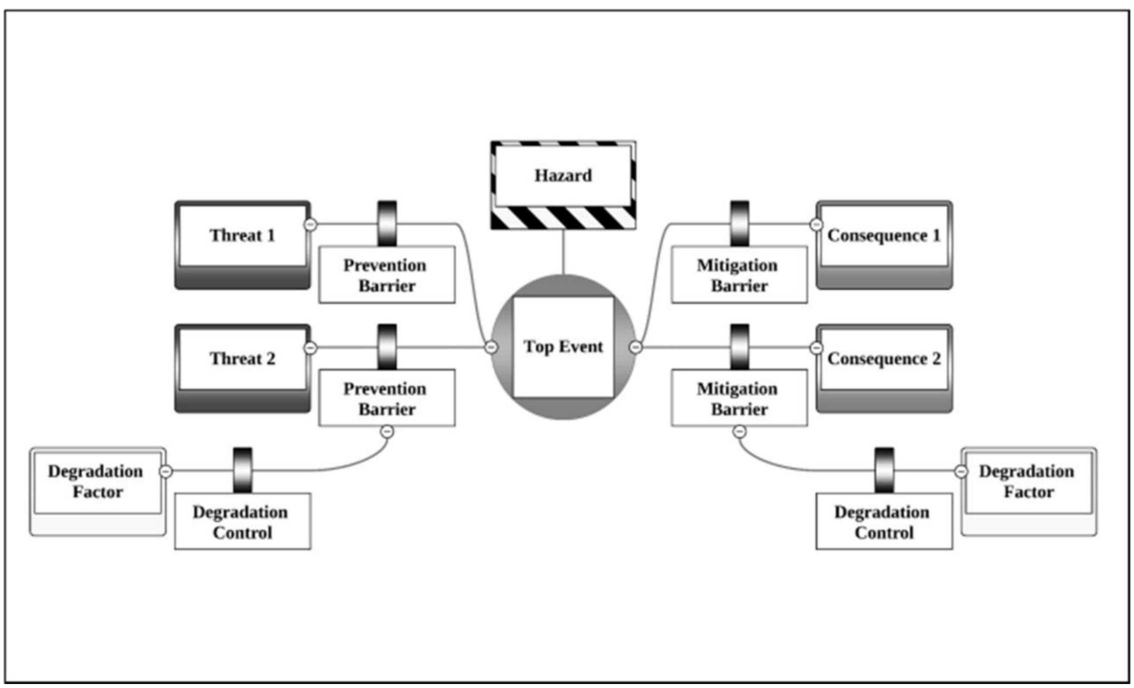


Figure 2.11 Standard Bow Tie Showing all the Basic Elements

Figure provided courtesy of CCPS, Energy Institute [CCPS et al ., 2018]

The first 'real' Bow-Tie diagrams are said to have appeared in the course notes of a lecture on HAZAN (Hazard Analysis) given at The University of Queensland, Australia (in 1979), but how and when the method found its exact origin is not completely clear [CCPS et al ., 2018].

In the early 1990s, the Royal Dutch/Shell Group was the first major company to adopted the Bow-Tie technique as the business standard for risk analysis and management. Based on their best practices, Shell facilitated considerable study in the use of the Bow-Tie approach and produced a precise rule set for the definition of all parts. Shell's key reason was the need to ensure that suitable risk controls are consistently in place across all global activities [CCPS et al ., 2018].

HAZOP vs. Bow-Tie; Key Difference

i. **Graphical Representation :** Enables a far more understandable, clearer picture of the risks and their management.

ii. **Flexibility:** In addition to considering process risks, which is often where HAZOPs are used, Bow-Ties can also be applied to a much larger range of hazards, such as those related to logistics, construction, security, etc.

iii.**Barrier Identification:** While Bow-Ties will take into account a wider range of safeguards, including as training & competency, exterior protection, inspection & maintenance, etc., HAZOPs tend to focus on the engineered safeguards in place.

iv. **Internal vs. External**: When compared to Bow-Ties, which also allow for the consideration of external events like external impact, weather, human mistake, etc., HAZOPs often focus on what is happening inside the process.

v. **Preventative vs. Mitigative:** HAZOPs tend to focus on the safeguards used to prevent a sequence from occurring; Bow-Ties permit a more in-depth analysis of the mitigating controls.

vi.**Representation of Risk**: HAZOPs frequently come to an end with a static risk representation. Bow-Ties provide a more thorough examination of the protections, asking not just what is present but also why it will continue to function in the future.

QUANTITATIVE RISK ASSESSMENT (QRA):

A quantitative risk assessment (QRA) is a formal and systematic method for evaluating the likelihood and consequences of hazardous events and quantifying the outcomes as risk to people, the environment, or enterprises[Arendt et al., 1990]. It also assesses the validity and robustness of quantitative data by highlighting key presumptions and risk factors.

In the early 1970s, the application of quantitative risk analysis, originally developed for nuclear safety, was proposed as a solution to address the recurring incidents of fires, explosions, and other disasters in large chemical clusters in the Netherlands. This specific problem prompted authorities in the Netherlands to formulate a strategy for the management and control of major hazards [Ale, 2002]. Within a few years, the practice of quantified risk analysis was introduced, leading to the establishment of quantified risk criteria that were subsequently integrated into legislation. While the primary use of QRA in the Netherlands pertains to land-use planning within the scope of external safety measures, the method has found successful application in evaluating and, if necessary, enhancing plant safety as well as in conducting emergency preparedness planning [Ale, 2002].

BENEFITS OF QRA

1. It examines thousands of situations that involve multiple failures, thereby offering an in-depth understanding of system failure modes Such

An vast number of conceivable accident scenarios are not investigated by typical approaches. The completeness of the analysis is greatly boosted by the QRA inquiry.

2. Increases the possibility that complex interconnections between events, systems, and operators will be recognized.

3. Provides a shared understanding of the problem, therefore improving communication. among multiple stakeholder groups.

4. This is an integrated strategy, thereby recognizing the needs for inputs from multiple fields like as engineering and social and behavioural sciences.

5. It focuses on uncertainty quantification and offers a better picture of what the community of experts know or do not know about a particular subject, thereby offering significant input to decisions regarding essential research in diverse disciplines, e.g., physical phenomena and human errors.

6. Facilitates risk management by identifying the dominant accident scenarios, so that resources are not squandered on issues that are inconsequential contributors to the risk.

Limitations of Quantitative Risk Assessment (QRA):

1. Data Availability and Quality: QRA relies on previous data, and projections based on this data can be constrained by the data's quality, availability, and application. Without reliable historical or experimental data, forecasts are restricted by the data's limits and assumptions imposed at the design stage.

2. Human factors: The difficulties of quantifying human elements, such as human error or sabotage, can limit QRA.

3. Sensitivity to Input Parameters: Changes in the input parameters can have an impact on the results of a QRA. Significant changes in risk assessments might result from even minor errors or uncertainty in these factors.

Failure Mode and Effects Analysis(FMEA) and Failure Mode, Effect and Critical Analysis(FMECA):

Failure modes and effects analysis (FMEA) is a forward logic, tabular technique that examines the different potential failure modes for each system component and assesses the implications of each failure [Clemens et al., 1998]. In practice, top-down "screening" frequently guides its application to establish the analytical resolution's upper bound.

A **Failure Modes, Effects, and Criticality Analysis (FMECA)** assesses the significance and risk associated with specific failures. It allows for the identification of remedies for each type of failure and the subsequent assessment of risk reduction. Both **FMEA** and **FMECA** serve as valuable tools for conducting cost-benefit analyses, implementing efficient risk reduction strategies, and serving as preliminary steps for a fault tree analysis. Modern analysts are beginning to accept FMEA and FMECA as the preferred technique for identifying probable single-point failures within a system.

FMEA has been around since the early 1950s, when flight control system development and design were its primary applications.[Booker et al., 2006].The difference between **FMEA** and **failure modes, effects, and criticality analysis (FMECA)** is that **FMEA** is a qualitative technique for evaluating a design, whereas **FMECA** is a related design technique that combines **FMEA** and **criticality analysis (CA)**. **Criticality analysis** is essentially a quantitative tool for ranking crucial failure mode effects based on their likelihood of occurrence.

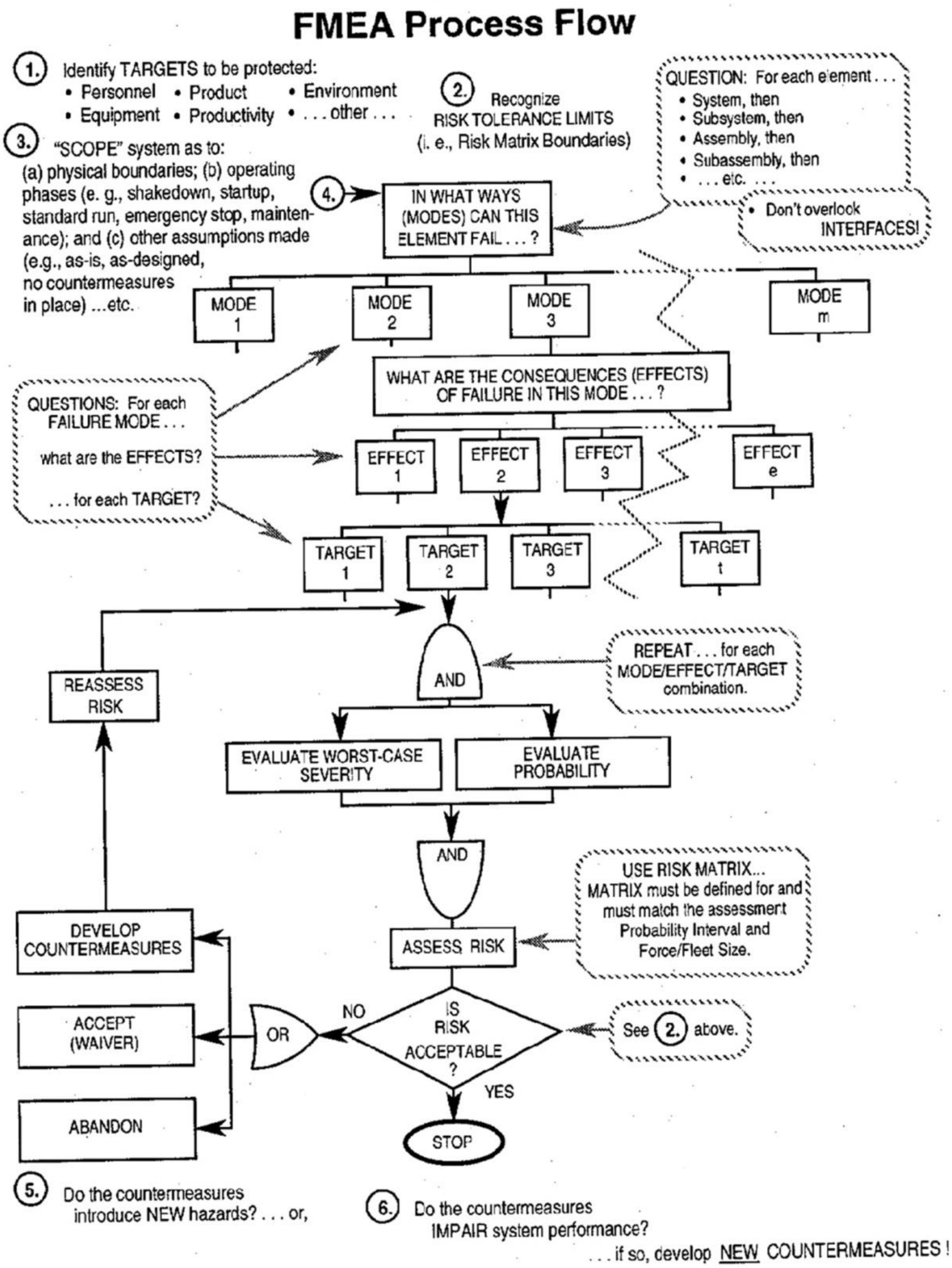


Figure 2.12 Failure Mode, effect,(and criticality) analysis process flowchart.

1998 Figure provided courtesy of National Institute for Occupational Safety and Health

[Clemens et al., 1998].

BENEFITS:

The failure modes and effects analysis helps the analyst in several ways. Some of these are as follows:

1. Providing data for developing fault tree analysis and reliability block diagram models.

2. The foundation for establishing corrective actions .

3. Choosing high-reliability design choices early in the design process.

4. Identifying possible failure modes .

5. Developing test methods.

6. Basis for qualitative reliability and safety evaluations.

LIMITATIONS:

The following limitations are imposed when performing FMEAs and FMECA:

1. Manpower is expensive, especially when working on large, intricate systems at the parts-count level.

2. The effects or likelihood of system failures brought on by concurrent, multiple-element faults or breakdowns within the system are not addressed or taken into account.

3. Although there are processes, standards, and check sheets available to assist, there is no check technique to determine how thorough the analysis is.

4. This analysis is strongly reliant on the analyst's ability and expertise in locating all relevant modes.

5. Failure probability data for an FMECA are frequently difficult to collect.

6. If too much emphasis is focused on discovering and eliminating single-point failures, attention may be diverted away from more serious system dangers (presented by co-existing failures/faults).

7. An FMECA can be a very thorough study beneficial for diverting resources to higher risk regions if conducted early enough in the planning process. The level of design maturity required for an FMECA, on the other hand, is often received late in the design phase, which is frequently too late to drive this decision.

WHAT-IF ANALYSIS:

What if Analysis is a structured brainstorming method for identifying what could go wrong and estimating the likelihood and implications of those events occurring [Reniers et al., 2005]. The answers to these questions serve as the foundation for deciding whether those risks are acceptable and determining a recommended course of action for those risks considered unacceptable. An professional review team may efficiently and productively discover critical flaws in a process or system. Each member of the review team, guided by an energetic and focused facilitator, identifies what can go wrong based on their previous experiences and knowledge of similar scenarios.

Division:	Desc. of Operation:	By: Date:

What If?	Answer	Likeli-hood	Conse-quences	Recommendations

Figure 2.13 What-if Analysis Form.

Figure provided courtesy of Journal of Loss Prevention in the process industries [Reniers et al., 2005]

Benefit of What if Analysis:

1. Increased Project Predictability:

A what-if analysis is speculative thinking about how to solve a problem in the future. The more questions you ask, the better your ability to predict difficulties will be. This suggests that the project's outcome will be predictable [Cairns et al.,2017].

2. Decisions and actions that are well-informed:

What-if analysis enable project managers to make more informed decisions. It alerts them of any impending difficulty, allowing us to adapt quickly and make sound decisions [El Khatib et al., 2022].

3.Assessment of Potential Outcomes:

What-if analysis can be used to determine how changes in one element affect the overall outcome of a project. This improves understanding of potential risks, obstacles, and their impact [Bird et al., 2012].

Limitation:

1. **Experience and organization**: If the analysis team is experienced and well-organized, the What if analysis can be an effective tool. Otherwise, it can be difficult to use successfully due to its very unstructured nature [Yue et al., 2011].

2. **Misinterpretation of data:** One disadvantage of employing the What if analysis is the possibility of data misinterpretation. This might occur when data is not collected or understood correctly. If data is not adequately acquired and analyzed, it might lead to inaccurate results and judgments [Appelbaum et al., 2017].

3. **Difficult to quantify benefits:** When conducting a What if analysis, companies may come across variables that are difficult to quantify. It is critical to assess if it is possible to impute or estimate a value for such variables [Azur et al., 2011].

HAZARD AND OPERATIONAL ANALYSIS(HAZOP):

A Hazard and Operatability (HAZOP) analysis is a thorough examination of the process to review the planning and functioning of a processing facility [Venkatasubramanian et al., 2000]. The HAZOP can be regarded of as a rigorous, organised analysis aimed to evaluate potential deviations from the process's design intent. The technique begins with a complete description of the process (often in the form of piping and instrument diagrams {P&IDs}), then systematically questions every step of the process to see how deviations from the design purpose can arise and whether these deviations can cause hazards. The framework is formed by predefined groupings of words that are combined to form questions.

The HAZOP methodology was developed in the 1960s and gained widespread acceptance as a formal risk assessment procedure after the Flixborough disaster in 1974. HAZOP is a structured and systematic approach to identifying and evaluating potential hazards and operational challenges in complex systems. It is a valuable tool for risk management and is used in a wide range of industries.

Trevor Kletz was a leading advocate for HAZOP and played a key role in its adoption as a widely used risk assessment methodology [Brazier et al., 2021].

The HAZOP study, as detailed in the US Department of Labor's Occupational Safety and Health Administration (OSHA) guidelines, follows a structured and thorough method to [Choi et al., 2020]:

1. Identify potential deviations from normal operations,
2. Assess their impact, and
3. Ensure appropriate safeguards are in place to prevent accidents from occurring.

HAZOP starts with identifying a node that is an isolation point constituting the flow of the P&ID valve or equipment. This node divides the system into manageable sections that require independent evaluations of process deviations based on the chairperson's process knowledge, which is the primary function of HAZOP. As a result, the process engineer and chairman are essential to the process, and evaluations are unavoidable. Furthermore, HAZOP nodes are not based on HSE (health, safety, and environment) engineering standards because they reflect process issues rather than operator stability.

During HAZOP, engineers from many disciplines gather in a workshop to review (through brainstorming) the issues associated with the corresponding node part. The detailed technique is depicted below.

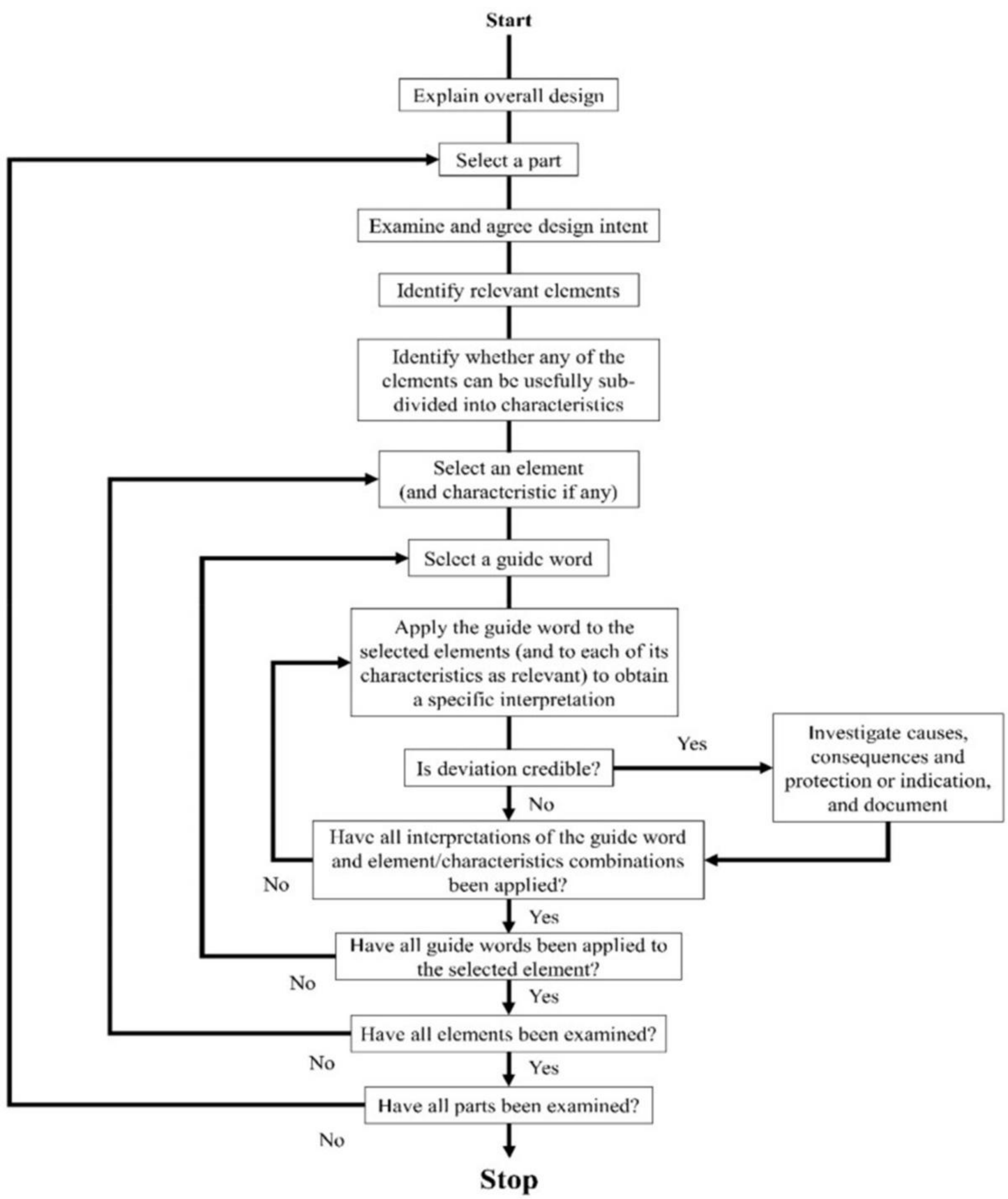


Figure 2.14 Flow chart of the HAZOP examination procedure.

Figure adapted from HAZOP Methodology Based on the Health, Safety,and Environment Engineering [Choi et al., 2020].

Common terms you'll use when conducting a HAZOP assessment include:

When should a HAZOP be done?

A Hazard and Operability (HAZOP) analysis, much like any other program for managing hazards, should be structured into sequential phases within the broader framework of a risk management project [Mocellin etal., 2022] . Ideally, the initiation of a HAZOP assessment occurs when a new process is introduced or when significant alterations are made to an existing process within the workplace environment. These changes can range from the introduction of a new piece of machinery to modifications aimed at streamlining work procedures. To facilitate this process, the HAZOP methodology places strong emphasis on four distinct phases:

1. Define: At this point, the risk assessment team must explore important concepts in order to focus their efforts.

i. Define the scope, objectives, and responsibilities, and then assemble the team.

2. Prepare: This stage frequently incorporates the use of guide words to assist in identifying major concerns within a process.

i. Plan the research.

ii. Collect all necessary data.

iii.Select a documentation style.

iv. Arrange and schedule time and activities

3. Exam: The chosen guide words are used in the examination step to thoroughly search for irregularities in the procedure. It should also be highlighted that every fair use and misuse circumstances discovered during the process must be questioned in order to determine their credibility.

i. Divide the system in question into pieces and use guide words to identify probable areas of divergence from intent.

ii. Highlight the implications and causes of specific concerns that have been identified.

iii. Determine whether those issues are substantial.

iv. Create procedures or mechanisms to defend against and detect problems.

v. Determine mitigation measures.

4. Document: Templates are often used for this type of documentation. One of such can be found in the Hazard And Operability Studies (HAZOP Studies) - Application Guide.

i.Record examination and sign off on the documentation.

ii.Prepare a report on risk management measures.

iii.Follow up on the modifications made and, if necessary, re-study those changes.

iv.Create the final report.

Benefits of HAZOP

1. **Structured and detailed methodology:** HAZOP identifies the cause-to-effect chain of risks and operability concerns such as human error, procedural error, and equipment/system dependability difficulties. It aids in the development of preventative and mitigation measures [Venkatasubramanian et al., 2000].

2. **Synergistic approach:** HAZOP values the perspectives of expert team members from all fields. The interaction fosters creativity and ensures that a wide range of potential outcomes can be incorporated into the study [Javaid, et al., 2021].

3. **Good economics:** It saves a lot of money by avoiding the costs of catastrophic accidents and inefficient plant operation. A well-executed HAZOP ensures that accidents are avoided during the lifetime of the running plant from the processes under consideration [Mehos et al., 2020].

4. **Time savings**: It saves time by allowing for a more streamlined and safer start-up, faster production levels, and incident-free operations [Mehos et al., 2020]..

Limitation of HAZOP

The outcome of the HAZOP is dependent on:

1. **The level of information available:** The team's success is influenced by the accuracy and breadth of system information, such as process and instrumentation diagrams (P&ID) [Single et al., 2019].

3. **The expertise of the team:** The technical knowledge and experience of the HAZOP team in engineering, operations, maintenance and inspection, safety, and emergency response are critical to the quality and completeness of a research [Mocellin et al., 2022].

PIPELINES AND RISK MANAGEMENT REGULATIONS

The use of risk management over the regulatory codes and standards is increasing in recent years and this can be affirmed by several states. In the UK, Pipeline operators have to make available a Major Accident Prevention Document (MAPD). In Canada, a Pipeline Risk Assessment Steering Committee was developed to promote risk assessment and management. The committee has the task to develop a Canada-wide database of pipeline incidents and their characteristics.

A pipeline development deal was signed in 1998 by the USA office of Pipeline Safety, providing Shell as the first participant in their risk management demonstration program.

The initiative came about as a result of the public meeting conducted in November 1995, when a collaboration between industry and regulators proposed risk management as a viable technique o f delivering similar or superior levels of pipeline safety in a more economical manner than the pr esent regulatory system. The supervision of pipelines implicated in severe incidents is now being reviewed by the European Commission, with a particular focus on those that transport hazardous goods. To do this, it will be necessary to require all businesses to create a significant Accident Prevention Policy (MAPP) that describes the broad goals and guiding ideals for managing pipelines vulnerable to significant mishaps. This MAPP approach is very similar to the UK approach of an MAPD (Major Accident Prevention Document) which must be supported by a Safety Management system. (M.J. Borysiewicz and S. Potempski Pipeline Management Systems Based On Risk Analysis)

Some Natural Gas Pipeline Regulatory Agencies in Nigeria.

Petroleum Industry Act:

In Nigeria, the exploration, production, and transportation of petroleum products, including natural gas, are governed under the Petroleum Act. It offers the governing framework for pipelines and other petroleum operations, such as licensing and regulation.

Nigerian Oil and Gas Industry Content Development Act:

This law was created to encourage Nigerian residents and businesses to work in the oil and gas sector, including pipeline building and operation. It outlines guidelines for regional industry engagement and supports the creation of local content.

Nigerian Gas Master Plan (NGMP):

The Nigerian government's strategy for the growth of the natural gas industry, including the building of the gas pipeline network, is outlined in the NGMP, a detailed policy document. It also covers topics like pricing, building up the infrastructure, and using gas.

Nigerian Gas Transportation Network Code (NGTNC):

In Nigeria, a regulatory framework known as the NGTNC controls the flow of natural gas through pipelines. It outlines the policies and processes for gaining access to the infrastructure for the transportation of gas, the pricing schemes, and the duties of network operators.

Department of Petroleum Resources (DPR) Regulations:

The DPR is the regulatory organization in charge of policing and regulating Nigeria's oil and gas sector. Regarding pipeline safety, design requirements, and operational rules, they have a number of regulations.

Regulations for Pipeline Rights of Way:

These rules control who can buy and manage rights of way for natural gas pipelines. They lay out the steps for acquiring the licenses and permissions required for pipeline development.

NOTABLE CONTRIBUTIONS TO RISK ASSESSMENT OF PIPELINES

There are several articles that have been published with relevance to risk management such as the hazard identification, methods of assessing and managing risks, and inherent safety. The (Khan and Abbasi (1998a)) focus on the existing state of risk assessment techniques and methods that finds application in pipelines. They also went further to discuss more on their merits and demerits. A different approach was however introduced by the (Aven and Kristensen 2005), where the discussion of risk assessment was categories in various approaches and prospective such as engineering, social science, anthropology, economics and unifying approaches. The (Marhavilas Et Al (2011)) went further to discuss the existing approaches to risk assessment techniques but their work was insubstantial as it only focuses on the articles that were published during the 2000 to 2009 era.

Some notable contributions to the risk assessment of pipelines and determinations of accidents in the transportation of natural gas are:

The first statistical analysis of prior occurrences inside the natural gas transportation network was carried out by Montiel et al. in 1996. They used statistical techniques on accident data that came mostly from MHIDAS. The basic features of accidents in the natural gas transportation system were determined by closely examining a total of 185 incidents that occurred up to 1995. The study found that the most frequent accident types were fire, loss of containment, and explosion, and that the main causes were mechanical failure, impact failure, and outside factors. In his work, he was able to determine that from the accidents that occurred, about 86 cases 65.6% were caused by explosion of the gas pipelines, about 63 cases, 48.1% are from contaminations in the pipeline and about 56 cases, 42.7% from fire. In his work, he ascertained that that mechanical failure has the highest causation of the accident. About 39 cases were as a result of mechanical failure, 37 cases were from impact failure and 32 cases from human error. (Historical Analysis of accidents in the transportation of natural gas, Helena Montiel, Juan A. Vilchez, Josep Arnaldos, 1996, Journal of Hazardous Materials 51 (1-3), 77-92, 1996)

By combining the multi-attribute utility theory (MAUT), Brito and de Almeida (2009b) established a novel method for evaluating pipeline risk. Pipeline failures were categorized into five main groups: external interference, erosion, mechanical failures, construction flaws, earth movements and natural disasters, and unknown causes. Combining utility theory and the ELECTRE TRI technique significantly enhanced the study (Brito et al., 2010). In their study, they presented a decision making model for the risk assessment. By using this decision model, it helps to quantitatively incorporate the decision-makers preferences and behavior regarding risk within clear and consistent risk measurements. In order to measure and verfy the effectiveness of the decision model, they did a numerical application based on a real case study. (Brito A.J and de Almeida, A.T. 2009, 94(2), pp. 187-198)

Achebe, Nneke and Anisiji (2012) analyzed oil pipeline failures in the oil and gas industries in the Niger Delta Area. Their research reveals that 42% of failures of pipelines were mechanically induced, 18% by corrosion, third party activities contributed 24%, 10% through operational error and 6% by natural hazards.

Ariavie and Oyekale (2015) analyze the risk assessment of third party damage index for gas transmission pipeline that transcends Uteko community via Benin Auchi road through Osina town and some part of Benin Agbor road, all in Edo State. They examined the third party index variable score for each of Minimum Depth of Cover, Activity level, Aboveground facilities, Line locating, Public Education, Right of way condition and Patrol Frequency third-party condition. An overall third-party index score of 29.87% was obtained (Arivie and Oyekale 2015).

Ariavie and Oyekale (2015) conducted a research on individual and societal risk analysis of pipelines failures occasioned by third party using the Chemical Process Quantitative Risk Analysis CPQRA Method. He pointed out that the CPQRA examines the hazard zones within a pipeline ROW and the number of persons that would be affected by fire / explosion.

Guided acoustics and a Radial Basis Function Neural Network (RBFNN) were used in a hybrid technique used by Fahad et al. (2017) to detect corrosion in industrial pipelines. The RBFNN classifier was given numerous features that allowed it to distinguish between corroded and non-corroded states, including Mean, RMS, Variance, Kurtosis, and Skewness. The recommended method showed a great deal of potential, reaching high accuracy in corrosion detection and classification of 99.45% (Fahad et al. 2017).

A statistical analysis of pipeline incidents involving the transportation of hazardous commodities, including crude oil, natural gas, and refined oil products, was carried out by Bubbico (2018). The study determined the main contributing factors and the subsequent effects of these releases. In contrast to some theoretical models, such as fault tree analysis and event tree analysis, the author argues that estimating the frequency of accidental scenarios using statistical analysis of historical data demonstrates to be a simple and reliable methodology, provided there is no shortage of data. However, one drawback is that it cannot take into account hypothetical situations that have never happened (Bubbico, 2018).

Kyrian, Adewale , Eseosa and Ojiyovwi (2021) analyzed failures in Natural gas pipeline systems. The performance of PIMPs in natural gas pipeline systems were reviewed. Furthermore, the study analyzed pipeline failure modes, associated losses due to gas leak and the critical failure factors militating against effective implementation of Pipeline IMPs. The results showed that PIMPs were poorly implemented because of natural factors and human errors such as corrosion, ageing and mal operation as well as wilful damage/Vandalism.

The journal with the highest number of articles is the journal of loss prevention in the process industries, JLPPI. JLPPI focuses on the following areas: explosion modeling and prevention, fire and release characterization, modeling and prevention. The journal of process safety progress (PSP) published by American Institute of Chemical Engineers (AIChE), focuses on accident investigation and hazard identification and assessment, consequence analysis and risks assessment, regulatory compliance, standards, training, and education. The journal of process safety and environmental protection (PSEP) started in 1996 and has about 53 articles published. The journal of risk and reliability (JRR) published in 2006 as part O of proceedings of the institution of mechanical engineers focuses on reliability and risk. The majority of the articles published in the journal of Reliability Engineering and system safety (RESS) focus on process safety and the risk assessment related to the nuclear industry. (Methods and models in process safety and risk management: Past, present and future *Faisal Khan, Samith Rathnayaka, Salim Ahmed)*

CHAPTER 3

MATERIALS AND METHODOLOGY

MATERIALS

EQUIPMENT AND TOOLS USED

The equipment and tools used are shown in Table 3.1 below

Table 3.1 Equipment and tools used

S/N	EQUIPMENT/TOOLS	USES
1.	A Rod	Used for measuring the depth precisely at different points along the pipeline's path.
2.	Tape	Used to measure the right of way distance and to determine the pipeline's external diameter.
3.	Drone	Used to take overhead pictures of the pipeline site to supplement our ground investigation
4.	Python	Used for data analysis, statistical analysis, simulations, risk modeling, data visualization, risk reporting, integration with data sources, etc
5.	Matpilotlab	used for data visualization in risk analysis; to create informative charts, plots, and graphs to visualize risk data and results.

METHODS

PROCESS OF FIELD ASSESSMENT

The steps in our field assessment procedure were as follows:

SITE VISIT

To collect data on the ground and evaluate the pipeline's physical state, our team went to the pipeline's location. After examining the location,

1. We picked a particular start point and end point to begin the analysis with. The start and end point indicated our nodes, which was about 300m.
2. We picked areas that had buildings, shops and were busy.
3. There after we proceeded to counting of the numbers of houses, churches and buildings in the nodal mark we indicated.

DETERMINING THE DEPTH OF COVER

The depth of the cover was measured using the rod at several points throughout the pipeline's path. Here are the steps we followed to obtain the depth of cover

1. We marked the 2 node points we wanted to dig and measure. These node area was made of soft soil so that the rod could easily penetrate through.
2. We also identified areas which had been washed of due to erosion. These washed up soil areas made the pipeline appeared visible and hence, we also took as reference point
3. With the help of the rod, we measured the depth of cover and also got the corresponding point from the marked points

Figure 3.1 determining the depth of cover

RIGHT OF WAY EVALUATION

We assessed the right of way distance using the tape measure to make sure it complied with safety rules.

1. Firstly, we divided the node we earlier selected into 4 different sections
2. Secondly, we measured distances to both the left and right of the pipeline path to determine the houses and shops that were in the right of way, and also the ones that were not in the ROW.

Figure 3.2 determining the Right of Way

MEASUREMENT OF THE PIPELINE'S EXTERNAL DIAMETER

We utilized the tape measure to precisely determine the pipeline's external diameter, which helped us determine its dimensions and structural soundness.

Steps:

1. We identified the washed soiled areas that had exposed pipelines. Like we earlier mentioned the area was a erosion prone area.

2. With the help of the tape, we measured the external diameter of the pipeline and determined the value to be approximately 0.45meters.

AERIAL PHOTOGRAPHY

The drone took high-resolution pictures of the area from the air, which were then examined for environmental conditions and potential hazards. The aerial photography which was taken also helped in determining the pipeline path as it was visible from far above the ground.

Figure 3.3 Aerial Photography

OVERVIEW OF BOTH LOCATIONS VISITED

Benin-Akure Pipeline Route Geographical View:

The Benin-Akure pipeline route is situated in an erosion-prone area, characterized by unique geographical features and land conditions. The environment exhibits the following notable characteristics:

1. Erosion-Prone Terrain: The area is susceptible to erosion, and there are visible signs of land erosion. Parts of the land have been washed off due to natural erosion processes. This erosion may be influenced by factors such as rainfall and soil type.
2. Vegetation: The location features an assortment of bushes and trees, suggesting a mix of natural and possibly cultivated vegetation. The presence of vegetation can impact visibility and access along the pipeline route.
3. Population Density: The area is sparsely populated, with only a few buildings present. These buildings can be classified as having a Class 1 population density, indicating a low-density residential or commercial area.
4. Encroachment into Right-of-Way (ROW): There are indications that some of the existing buildings are encroaching into the pipeline's right-of-way (ROW). This encroachment could pose risks to both the pipeline and the occupants of these buildings.
5. Lack of Safety Markings: Notably, there are no visible markings or signs to indicate the presence of potential dangers, the pipeline route, or the boundaries of the right-of-way. This absence of markings may pose safety concerns, particularly for residents and workers in the area.

Overall, the Benin-Akure pipeline route presents a unique set of geographical challenges, including erosion susceptibility, limited population density, and the need for increased awareness and safety measures due to the encroachment into the pipeline's right-of-way. Addressing these challenges is essential to ensure the safety and integrity of the pipeline in this specific location.

Eyaen Pipeline Route Geographical View:

The Eyaen pipeline route is situated in a more urbanized and residential area compared to the Eyaen location. It can be divided into two distinct parts separated by an express road, each with its own characteristics:

First Part (Side 1):

1. Residential and Commercial: This side of the pipeline route features a mix of residential buildings and commercial establishments, including stores. It is a more densely populated area compared to the Eyaen location, indicating a higher population density.
2. Well-Maintained ROW: In this part of the route, the right-of-way (ROW) is properly maintained and cleared. The absence of encroachments on the ROW suggests better compliance with safety standards, allowing for easier access for maintenance and inspection activities.
3. Lack of Safety Markings: Similar to the Benin Akure location, there are no visible markings or signs to indicate the presence of the pipeline or potential hazards. Improved safety signage could enhance awareness in this area.

Second Part (Side 2):

1. Stores and Houses on ROW: On the other side of the express road, there are stores and houses that encroach onto the pipeline's right-of-way. This encroachment could pose safety risks to both the pipeline and the occupants of these structures. Proper measures may be needed to address this encroachment issue.
2. Urban Landscape: This part of the pipeline route exhibits a more urbanized landscape, with businesses and residences located in closer proximity to the pipeline. It may be necessary to consider safety measures and awareness campaigns tailored to the urban environment.

Overall, the Eyaen pipeline route presents a mix of urban and residential characteristics. While one side of the route shows proper maintenance and compliance with safety standards, the other side raises concerns due to encroachments onto the right-of-way. Enhancing safety measures and awareness, along with addressing encroachment issues, will be important for maintaining the safety and integrity of the pipeline in this location.

Calculation for the Third party Damage Index

In this comprehensive analysis, we present the Third-Party Damage Index (TPDI), a crucial tool meticulously designed to assess and quantify the risk associated with third-party damage to the Eyaen, agbor road and the Benin akure road. The safety and integrity of the pipeline infrastructure heavily depend on minimizing the risks posed by external factors, particularly those arising from human activities and environmental conditions (Morgan, B., et al. 11-1996)

Third-Party Damage Index Components and Scoring

The TPDI consists of seven distinct components, each thoughtfully weighted to reflect its significance in assessing the risk of third-party damage. The scoring criteria for each component are as follows:

A. Minimum Depth of Cover (20% Weightage)

The Minimum Depth of Cover component evaluates the depth of cover over the pipeline. The scoring is determined as follows:

0–20 points: Score assigned based on the depth of cover, with lower scores indicating shallower cover, which poses a higher risk of external impact.

B. Activity Level (20% Weightage)

The Activity Level component assesses the intensity of activities within the proximity of the pipeline, including construction, excavation, and other relevant activities. Scoring is determined as follows:

0–20 points: Score assigned based on the intensity of activities near the pipeline, with higher scores indicating higher activity levels that may increase the risk of accidental damage.

C. Aboveground Facilities (10% Weightage)

This component considers the presence of aboveground facilities in close proximity to the pipeline, such as buildings, roads, or utility structures. Scoring is determined as follows:

0–10 points: Score assigned based on the density and proximity of aboveground facilities, with higher scores indicating greater potential for accidental damage.

D. Line Locating (10% Weightage)

The Line Locating component evaluates the effectiveness and accuracy of line locating practices near the pipeline. Scoring is determined as follows:

0–10 points: Score assigned based on the reliability and precision of line locating practices, with lower scores indicating potential inaccuracies that could lead to accidental damage during excavation.

E. Public Education Programs (10% Weightage)

Assessment of public education and awareness programs regarding the presence and significance of the pipeline in the community. Scoring is determined as follows:

0–15 points: Score assigned based on the reach and effectiveness of public education initiatives, with lower scores indicating limited awareness and potentially higher risks of damage.

F. Right-of-Way Condition (5% Weightage)

The Right-of-Way Condition component examines the overall condition of the pipeline's right of way, considering factors such as vegetation growth, buildings, stores and obstructions. Scoring is determined as follows:

0–5 points: Score assigned based on the condition of the right of way, with lower scores indicating suboptimal conditions that may increase the risk of accidental damage.

G. Patrol Frequency (10% Weightage)

Frequency of patrols and monitoring activities along the pipeline route is assessed in the Patrol Frequency component. Scoring is determined as follows:

0–10 points: Score assigned based on the regularity and effectiveness of patrol activities, with lower scores indicating less frequent patrols and potentially higher risks of damage going undetected.

H. Erosion susceptibility (15% Weightage)

How the area is susceptible to erosion is accessed also to determine the level of exposure the pipeline has Scoring is determined as follows:

0–15 points: Score assigned based on the susceptibility of the soil and exposure of the pipeline, with more points indicating lower susceptibility and less point indicating higher susceptibility.

Third-Party Damage Index Calculation

The TPDI is calculated by summing the scores obtained for each of the seven components, with consideration for their respective weightages. The formula used for TPDI calculation is:

TPDI = (A x 0.20) + (B x 0.20) + (C x 0.10) + (D x 0.10) + (E x 0.10) + (F x 0.05) + (G x 0.10) + (H x 0.15)

The TPDI provides an overarching assessment of the risk of third-party damage, with higher TPDI scores indicating a higher level of risk.

CALCULATION FOR THE BENIN AKURE PIPELINE ROUTE

The following weighting scores were assigned to the third party damge index based on the observation from the visit to to the pipeline location:

1. **Depth of cover:**

the formula used for the depth of cover is shown below

Amount of cover in inches ÷ 5 = point value up to a maximum of 20 point

Depth of cover obtained was 2.1meters = 82.6 inches

Weight = 82.6/5 = 16.52

2. **Activity level**: they were no much activity in the area because it was a corrosion prone area hence they were few houses, stores and buildings.

The activity level is classified as a low activity one:

Low activity level (15 points) This area is characterized by all of the following:

I. Class 1 population density
II. Rural, low population density as measured by some other scale
III. Virtually no activity reports
IV. No routine harmful activities in the area

3. **Above ground facilities**

Aboveground facilities in the context of pipelines include structures and equipment on or above the surface that support pipeline operations, including pumping and compressor stations, metering and valve stations, tank farms, monitoring/control centers, safety/security measures, and emergency response equipment.

For scoring purpose, the below maximum and minimum values were used

No aboveground facilities 10 pts

Aboveground facilities 0 pt

From the observations made in the line we considered, there were no above ground facilities. Hence, 10 point was assigned to this.

4. **Line locating**

The line location seemed difficult because there was no defined path which showed where the pipeline followed. Hence 4 points was assigned to it.

5. **Public Education program**

2 points was allocated for this index

6. **Right Of Way Condition**

1 points was allocated for this index because ROW was not uniformly cleared; more markers are needed for clear

identification at roads, ditches, etc

7. **Patrol frequency:**

3 points was allocated for this because even though there was no indication for frequent patrols by the right officials, it was still monitored by the community locals.

8. **Erosion susceptibility**

   The area was highly susceptible to erosion, with some area having exposed pipeline due to erosion. Hence a score of 3 was assigned to it.

TPDI = (16.52 x 0.20) + (15 x 0.20) + (10 x 0.10) + (4 x 0.10) + (2 x 0.10) + (1 x 0.05) + (3 x 0.10) + (0 x 0.15)

= 8.254

Normalize TPDI Score = (8.254 / Maximum Possible Score) x 100

(8.254/20) x 100

= 41.27%

This scores falls within the low score range and shows that the area is subjected to a high risk.

Note: the Normalize TPID score determines the safety of the area also

HIGH score(70 – 100); indicates safety

Low score (0-45); indicates high risk to failure

Calculation for the eyaen, agbor pipeline route

The following weighting scores were assigned to the third party damage index based on the observation from the visit to the pipeline location:

1. **Depth of cover:**

The formula used for the depth of cover is shown below

Amount of cover in inches ÷ 5 = point value up to a maximum of 20 point

Depth of cover obtained was 1.8 meters = 70.86 inches

Weight = 70.86/5 = 14.17

2. **Activity level**: Medium activity level, hence 8 points was assigned to it.
3. **Above ground facilities**

From the observations made in the line we considered, there was an above ground facility which was not to close to the road. Hence we allocated 5 points to it.

Figure 3.4 Above ground metering station

4. **Line locating**

The line location followed a better defined path compared to the Benin akure pipeline. And with the help of aerial photographs we identified the path of the pipeline. Hence 5 points was assigned to it.

5. **Public Education program**

5 points was allocated for this index

6. **RIGHT OF WAY CONDITION**

4 points was allocated for this index because ROW was uniformly cleared and followed

7. **Patrol frequency:**

5 points was allocated for this because even though there was no indication for frequent patrols by the right officials, it was still monitored by the community locals. It is a more occupied than the Benin Akure pipeline

8. **Erosion susceptibility**

   The area is not susceptible to erosion; it has a flat and smooth topography. Hence,12 points was assigned to it.

TPDI = (14.17 x 0.20) + (8 x 0.20) + (5 x 0.10) + (5 x 0.10) + (5 x 0.10) + (4 x 0.05) + (5 x 0.10) + (12 x 0.15)

= 8.434

Normalize TPDI Score = (8.434 / Maximum Possible Score) x 100

(8.434/20) x 100

=42.17%

MITIGATION STRATEGIES

The TPDI results serve as a blueprint for formulating targeted mitigation strategies to minimize the potential for third-party damage. These strategies are designed to enhance the safety of the pipeline and protect both the infrastructure and the surrounding environment. Key mitigation strategies include:

1. Enhanced Signage and Fencing: Install clear signage and robust fencing along the pipeline right of way to raise awareness and prevent unauthorized access.
2. Collaboration with Local Authorities: Collaborate with local authorities and construction companies to ensure safe excavation practices and compliance with regulations.
3. Public Awareness Campaigns: Launch public awareness campaigns to educate the community about the presence and significance of the pipeline, fostering a sense of responsibility among residents.
4. Regular Monitoring and Inspection: Implement regular monitoring and inspection protocols in areas with higher TPDI scores to promptly detect and address potential risks.

CHAPTER 4

RESULTS AND DISCUSSION

In this research, we were able to analyze three different pipelines route for our HAZOP Studies and also we made some results from our analysis.

CASE 1: PIPELINE RIGHT OF WAY ALONG BENIN-AKURE ROAD, OPPOSITE DUMPED SITE, OLUKU.

Selection of Nodes

The node is the distance to which our analysis was carried out in the course of this research. The selected node for this case is a distance of 300m.

Determination of Activity Level

In this pipeline route, the location is developing regions as there are many uncompleted buildings and new houses. Although some old houses exists even before the construction of the pipeline, but they are quite far from the pipeline. The location also doesn’t have a motor-able road, so cars and vehicles cannot pass through the location as it’s made up of several hills, gallops and the soil is very prone to erosion. We were able to calculate the number of buildings along the selected nodes. This is shown in the table below.

	LEFT Side (ROW)	RIGHT Side (ROW)
No. of Houses	22	30
No. of Church	2	1
Kiosk	1	0
TOTAL	25	31

Determination of the Depth of Cover

The depth of cover which was determined by taking a rod downwards and measuring the distance through which it hits the pipeline. The soil in this location was soft and in most cases, washed away to the extents that the pipeline can be easily seen. We selected four different locations and this was what we measured.

Location 1 (50m from node starting point)	2.1m
Location 2 (120m from node starting point)	2.05m
Location 3 (220m from node starting point)	1.95m
Location 4. (260m from node starting point)	2.2m
Average	2.075m

This difference between the different depths of cover distance is due to the uniformity in the burial depth distance and also due to the type of soil of the location examined. Also this depth of cover is also in-line with the standard depth of cover for pipeline installation which is given below.

Standard Minimum Depth of Cover:

Dry Land	0.9m
River crossing and river beds	1m
Drainage ditch, railroad and highway	1.2m
Rocky area	0.6m
Swamp	0.6m
Shipping Channel	1.5m

Determination of the Pipe Outer Diameter:

We were also to determine the outer pipe diameter in one location where the pipeline is very visible and the land has been washed away due to erosion.

Outer Diameter = 0.405m

Determination of the Right of Way:

We were able to measure the right of way distance from the pipeline from each role. The table below shows the right of way from each of the houses along our nodes.

S/N	LEFT Side(ROW)	RIGHT Side (ROW)	TOTAL ROW
1	18.74	18.5	37.24
2	19	12.04	31.04
3	24.7	7.68	32.38
4	17	18.8	35.8

5	18.25	13.5	31.75
6	18.56	13.6	32.16
7	24.7	8.67	33.37
8	18.52	17.6	36.12
9	19	14.5	33.5
10	17	20.5	37.5
11	13.7	7.01	20.71
12	15.6	7.82	23.42
13	12.6	16.5	29.1
14	14.2	7.45	21.65
15	12.6	20.2	32.8
16	18.6	12.04	30.64
17	25.95	12.04	37.99
18	18.72	19.2	37.92
19	19.5	19.4	38.9
20	21.5	18.2	39.7
21	24.7	20.1	44.8
22	20.1	18.5	38.6
23	18.4	16.2	34.6
24	21.3	8.85	30.15
25	21.3	18.6	39.9
26	-	20.2	-
27	-	21.3	-

28	-	7.06	-
29	-	21.2	-
30		22.3	-
31		18.7	-

In the table shown, the serial number represents the number of houses or shops or church that are along the selected nodes of 300m. This shows that when we selected the nodes, and look towards the nearest road distance, we take our left handed side as LEFT Right of way (ROW) and right-handed side as RIGHT ROW. On the left hand as shown already, we have a total number of 25 buildings on our left side and a total number of 31 buildings on our right hand side.

Analysis of the Right of way using Python Programming:

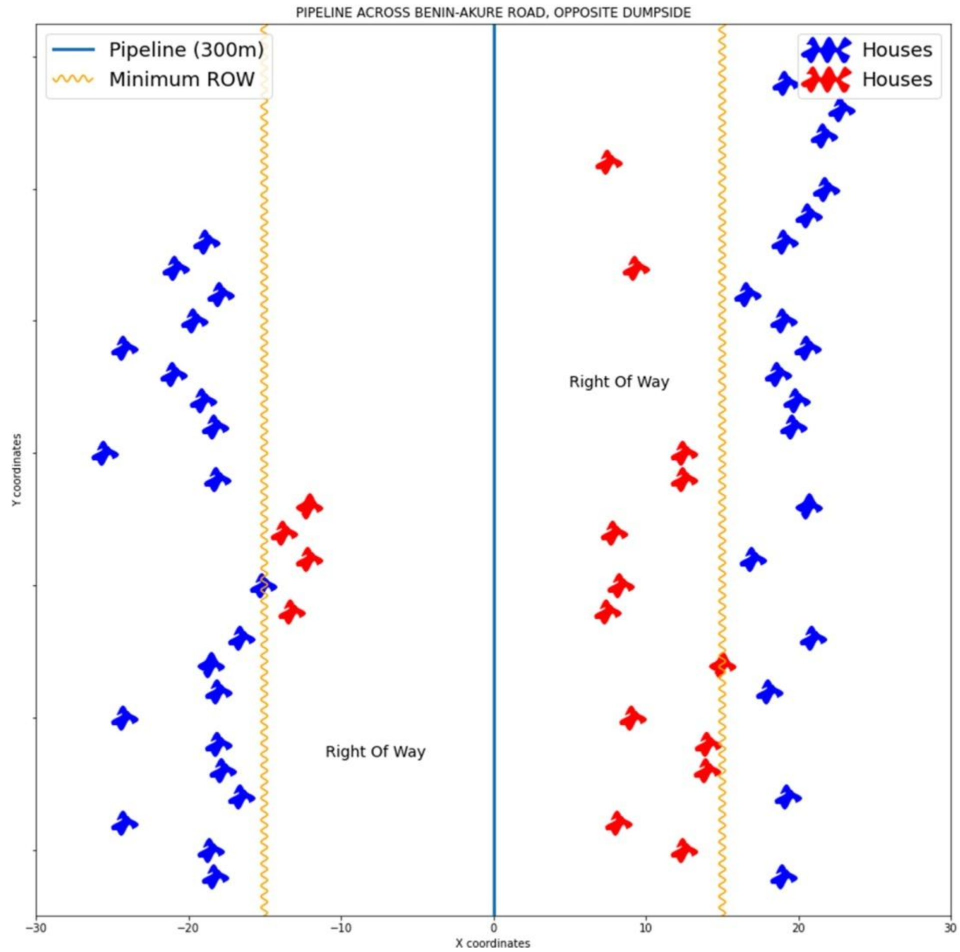


Figure 4.1 Pipeline Right of way analyses Benin-Akure Road.

As shown on the python analysis plot, the houses with blue represents those houses that exceed the minimum right of way distance while those on rod have their houses built on the right of way distance. We can see that more people build encroach into the pipeline minimum right of way distance on the right hand side and fewer on the left hand side. This poses a major danger to those houses and people living in it if there is any pipeline failure occurrence. Also, although the pipeline is not straight, we assumed it as a straight line for ease of the preparation of this plot but the right of way distance still gives the same distance as to the actual pipeline direction.

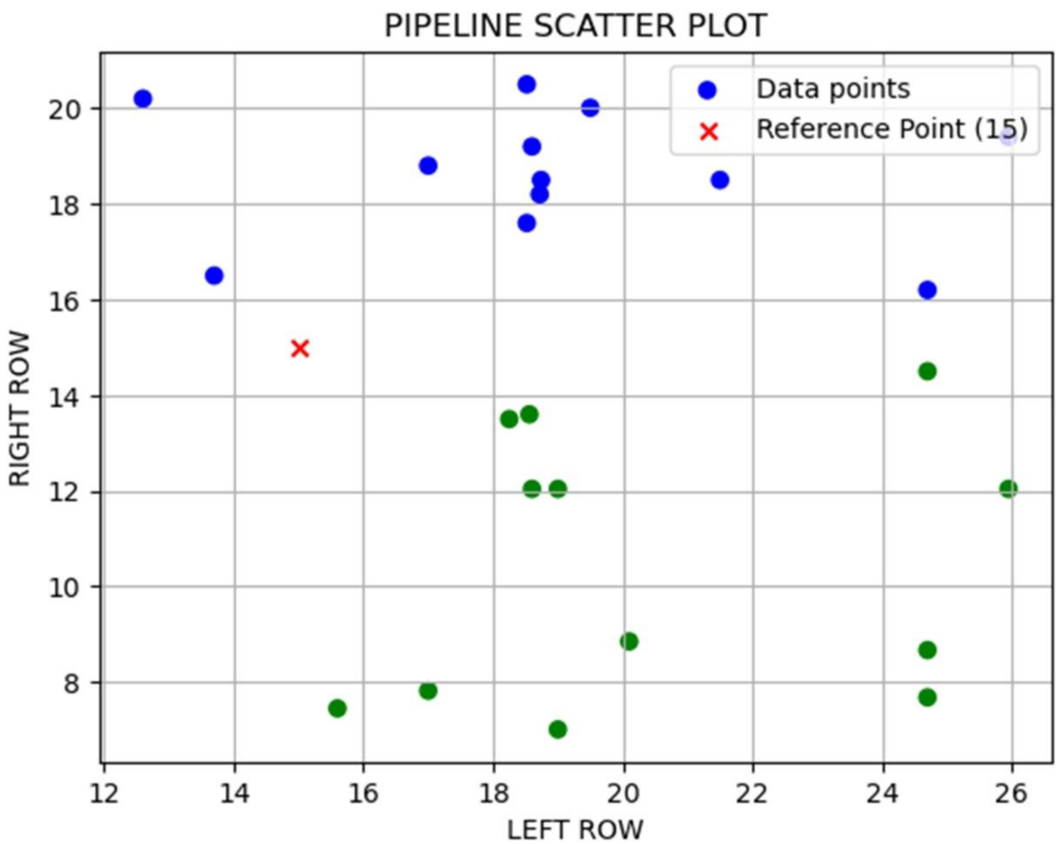


Figure 4.2 Pipeline Scatter Plot (Right of way distance Benin-Akure Road

The pipeline scatter plot is another representation of the right of way distance of the pipeline from the standard right of way. The standard minimum right of way is the reference point while the blue and green color represents the houses. The blue houses represent those houses that are above the right of way from the right row while for the green represents those houses that are at a distance of less than 15m.

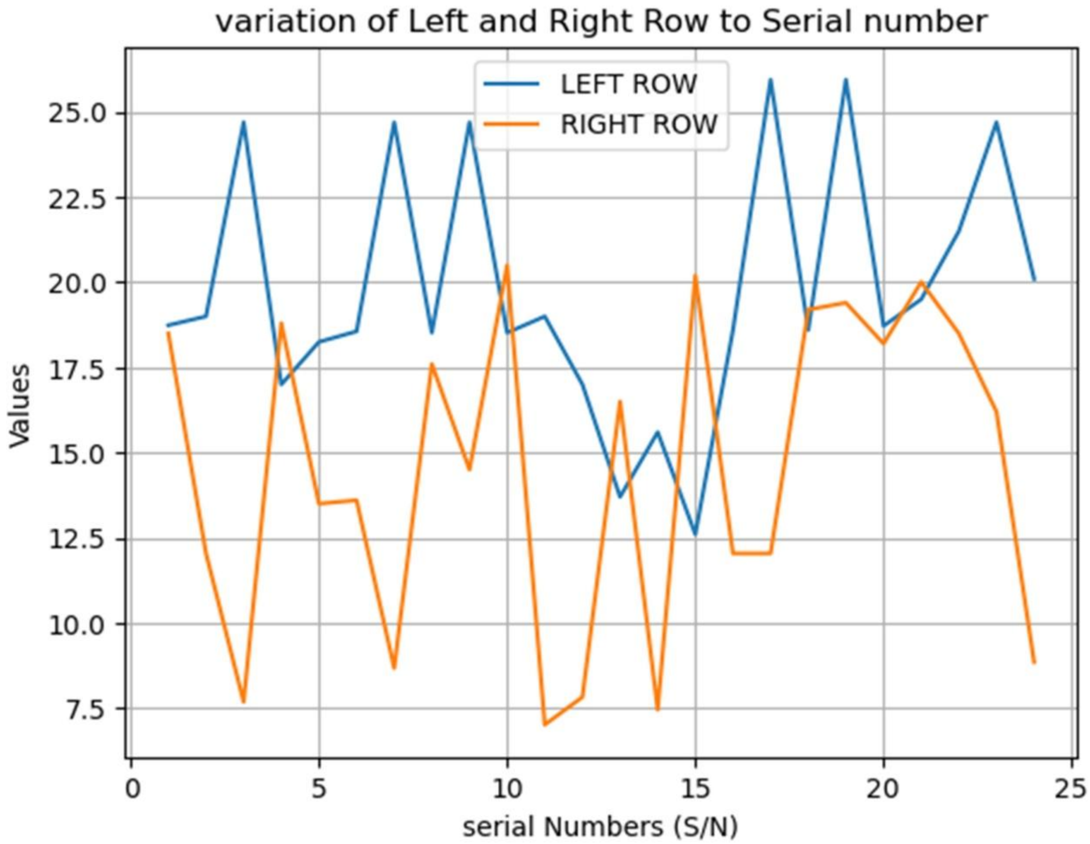


Figure 4.3 Pipeline Right of way distance variations of each side Benin-Akure Road.

This variation shows the deviations of the right of way distance from the nearest houses on the right and left handed side. It can be deducted from the variations that the construction and buildings of houses on this location is not in a uniform houses. While some houses are far from the pipeline, some are very close.

CASE 2: PIPELINE ROAD, OFF BENIN-AUCHI ROAD, EYEAN, BENIN CITY.

Selection of Node

In this case, we were able to select the nodes once again, and measured the distance between nodes. The node distance was 700m.

Determination of Activity Level

In this case, we were also able to determine the number of houses, shops and church along the pipeline road by counting them. The area is quite different from the first case and it's more developed already. Also, the soil is uniform and the road is also motor-able. Although, most houses are built behind kiosks, there exist a large number of kiosks for sales of foodstuffs and other household items. The buildings shown are represented below.

	LEFT side (ROW)	RIGHT side (ROW)
No. of Houses	17	16
No. of Church	2	1
Kiosk	31	22
TOTAL	50	39

Determination of the Right of Way

We were able to measure the right of way distance from the pipeline from each role. The table below shows the right of way from each of the houses along our nodes.

S/N	LEFT Side(ROW)	RIGHT Side (ROW)	TOTAL ROW
1	17.35	17.58	34.93
2	17.35	17.34	34.69
3	17.35	17.35	34.7
4	17.2	17.38	34.58

5	17.4	17.4	34.8
6	17.7	17.45	35.15
7	17.9	17.24	35.14
8	17.21	17.6	34.81
9	17.1	17.24	34.34
10	17.1	17.35	34.45
11	17.3	17.23	34.53
12	17.4	16.8	34.2
13	17.35	16.5	33.85
14	20.2	16.7	36.9
15	20.2	15.1	35.3
16	20.1	15.3	35.4
17	20.1	16.7	36.8
18	18.72	18.2	36.92
19	20.2	17.1	37.3
20	20.6	12.2	32.8
21	24	8.675	32.675
22	24	8.9	32.9
23	23.8	10.23	34.03
24	21.3	10.23	31.53
25	20.2	10.34	30.54
26	21.8	10.34	32.14
27	21.8	10.26	32.06

28	21.8	9.36	31.16
29	28.2	9.67	37.87
30	28.1	9.36	37.46
31	27.3	9.59	36.89
32	27.3	10.26	37.56
33	27.3	10.2	37.5
34	27.5	10.28	37.78
35	26.1	11.2	37.3
36	25.3	12.2	37.5
37	28.2	12.1	40.3
38	25.7	16.7	36.8
39	25.7	18.2	36.92
40	25.7		
41	25.7		
42	24.6		
43	24.5		
44	24.6		
45	26.8		
46	23.4		
47	20.1		
48	22.2		
49	25.3		
50	25.3		

In this case, we can see that the number of buildings presents on the left handed side is more than those in the right hand side.

Analysis using Python Programming

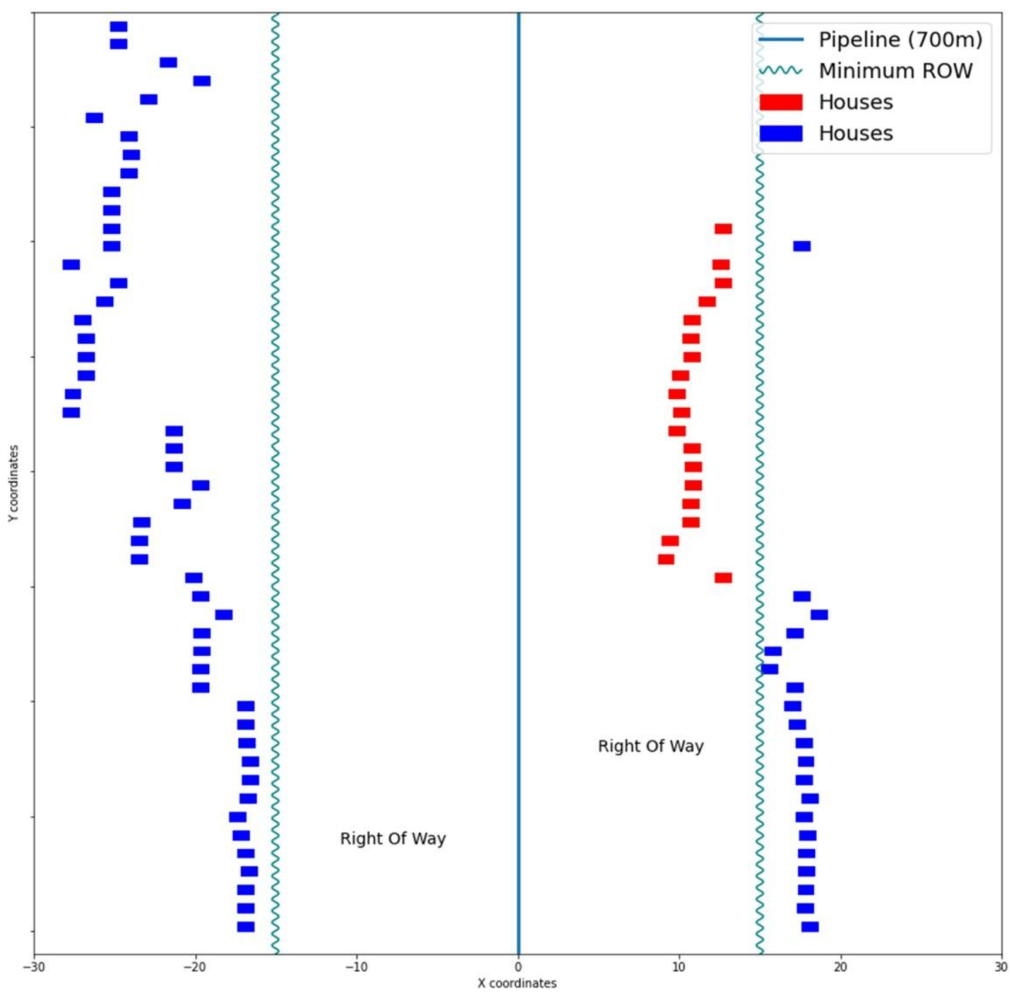


Figure 4.4 Pipeline Right of way analyses Benin-Auchi Road, Eyean.

In this case, we can see that the although there are 50 buildings on the selected nodes distance in the left handed side, none of them encroach into the right of way distance. However, in the right handed side, some of the buildings encroach into the right of way minimum distance which is represented by the red color.

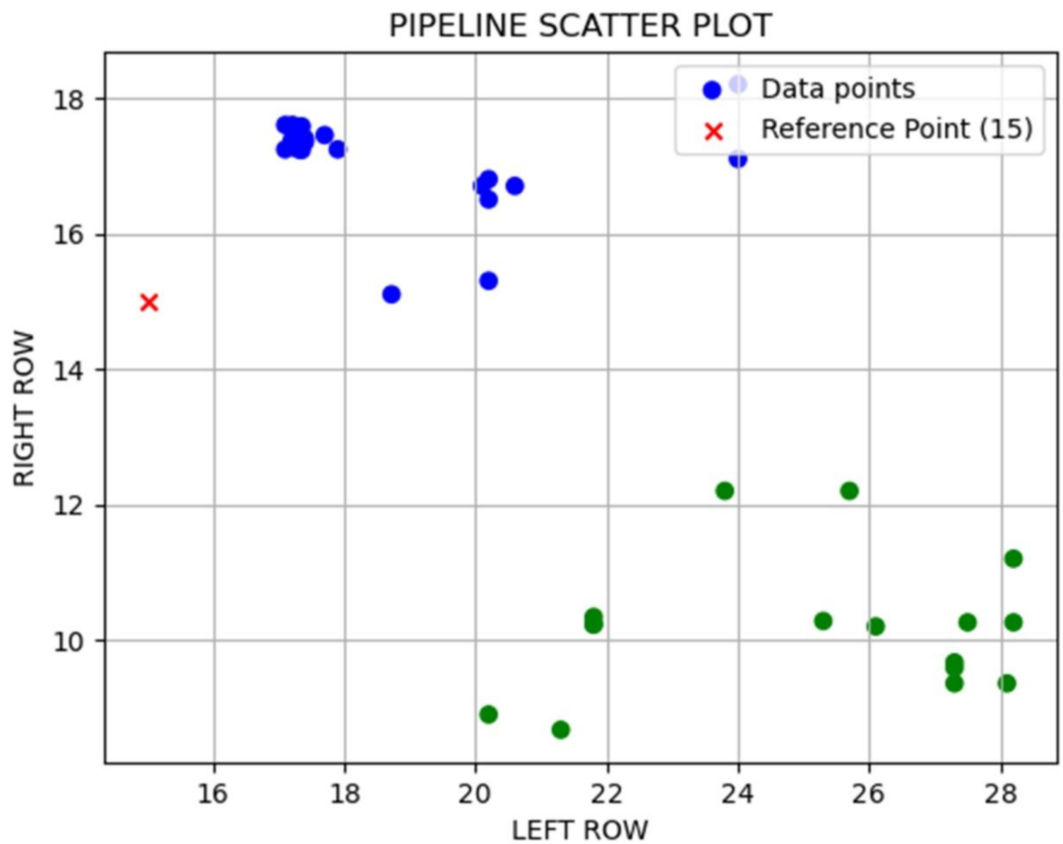


Figure 4.5 Pipeline Scatter Plot (Right of way distance Benin-Auchi Road, Eyean

The pipeline scatter plot is another representation of the right of way distance of the pipeline from the standard right of way. The standard minimum right of way is the reference point while the blue and green color represents the houses. The blue houses represent those houses that are above the right of way from the right row while for the green represents those houses that are at a distance of less than 15m.

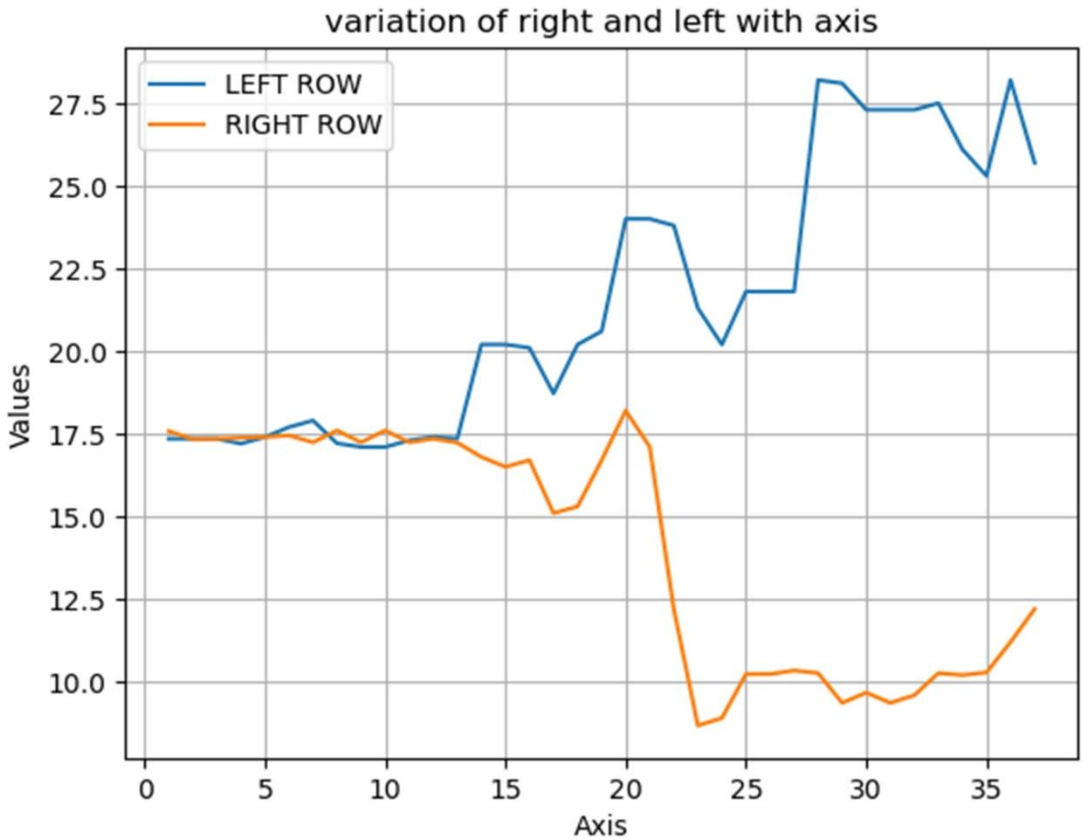


Figure 4.6 Pipeline Right of way distance variations of each side Benin-Auchi Road, Eyean

In this case, we can see that the houses are more uniform than the first case. For the left row, they start from been about 17.5m and then move upwards gradually to about 27.5m distance from the pipeline. In both cases, there were all farther than the minimum right of way distance. For the right handed row, the initial distance was more than the minimum right of way distance, the houses then move towards the minimum ROW with mostly shops coming in front of houses.

CASE 3: PIPELINE ROAD, OFF BENIN-AUCHI ROAD, EYEAN, BENIN CITY OPPOSITE SIDE.

Selection of Node

In this case, we were able to select the nodes once again, and measured the distance between nodes. The node distance was 100m.

Determination of the Right of way:

We could not measure the right of way due to obstructions from the community but here are some of our observations:

1. There are quite a number of kiosks that exists directly below the pipeline route.
2. The houses exists very close to the pipeline, and in most cases, it is less than 7m away from the pipeline.
3. There exists a gas plant very close to the pipeline route.

THIRD PARTY DAMAGE INDEX

From the calculated value obtained for both locations, it can be seen that the area is still subjected to risk and potential threats by third party. The reason for this is due to the third party damage index which enough attention is not been paid to (Godfrey Ariavie et al, 2015).

The values obtained for Eyaen and Benin-Akure pipeline routes are 42.17% and 41.27%. This values although vary due to the location and third party damage index, it shows a correlation with previous risk analysis study which has been carried out to indicate that the area is highly prone to third party risk and with and with a third party index score of 29.87% (Ariavie and Joseph 2015).

The difference in value is due to the following:

1. The weighting which was assigned to the different third party index
2. And additional third party index which was added, “Erosion susceptibility’, to accurately determine the third party index score.
3. Variations associated with the third party index over the years.

CHAPTER 5

LIMITATIONS, RECOMMENDATION AND CONCLUSION

LIMITATIONS

During the entire course of this project, some major difficulties were encountered. These difficulties ended up reducing our pace of successfully completing this project. These difficulties are as follows:

1. Location of pipeline routes: Pipelines locations are not easily disclosed to the general public so as to prevent vandalism and willful interference of these pipelines. This made it difficult for us to locate the pipelines in the course of this study.
2. Unavailability of an official blueprint citing the actual pipeline distribution in the various pipeline designated areas: This was another limitation as these pipelines were buried deep underground and getting an actual blueprint of how the pipelines were laid was not feasible, because we would have to get several permissions to get access to these blueprints and it would take several weeks for our request to get a standard blueprint to be granted. Although we were able to locate the passage route of these pipelines, we were force to assume straight linear distribution, whereas they may be curved at some point. This was majorly attributed to the unavailability of an official blueprint.
3. Cost of getting risk analysis tools and software is very expensive.
4. Risk assessments and HAZOP analysis are never 100% accurate and may never be 100% accurate.
5. Finance: we were also limited financially while carrying out these HAZOP studies.

RECOMMENDATION

1. The pipeline at Oluku along Benin-Akure road is prone to serious erosion and it could be observed that at session of the pipeline erosion has swept most of the soil covering the pipeline leaving it exposed. Government should find a way to address the erosion situation and also fill up the washed soil at this portion were the pipeline was exposed.
2. Government should create public awareness and sensitization on the risk associated with tempering with the right of way distance along pipeline routes.
3. The pipeline along Benin-Auchi road was occupied by stores at the beginning, this poses a very large risk. The government should set a body to ensure that trading activities are not carried out along the right of way of pipelines.

CONCLUSION

This study entails hazard and operability analysis of pipelines with consideration mainly to third party interference on underground pipelines. The findings of this study shows that about 40% of the analyzed area along the Benin-Auchi road pipeline had residential buildings and commercial structures encroaching into the right of way, with significant encroachment observed at the beginning of the pipeline route where massive commercial activities took place. On the other hand, the findings from the pipeline route located along the Benin-Akure road Oluku, showed that 20% of buildings along the pipeline route, encroached into the right of way, with no significant commercial activity been carried out. The study also proposes that compliance with the recommended right of way distance along gas pipeline routes will mitigate hazards and casualties associated with gas pipelines.

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