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Analyzing Storage Tank Incidents: Utilizing Fishbone Diagram and Fault Tree Methods

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ABSTRACT

Oil and gas are the most important energies in the word. To exploit them both, go through a set of steps such as exploration; drilling, extraction, refining and storage. In this last step (storage), there are several methods of storage using floating Roof Tanks, Fixed Roof Tanks, Fixed Roof Tanks with internal floating Roof, Sphere…. etc. In storage phase happen many accidents and incidents. This paper divided in two main parts, the first part reviews storage tank types, storage tanks accidents types and accident locations. And in the second parts we used Fish bone Diagram (Ishikawa Diagram) and Fault tree method to investigate the causes of storage tanks accidents/incidents and their mitigation action. The statical analysis of the accident shows that 74%of accident happened between refinery facilities and the most common accidents are Fire and Explosion by 80%. While the most two major causes of accidents are Lightning by 33%, followed by human Error by 30%.

Introduction

Storehouse tanks within refineries and chemical shops are depositories for significant volumes of ignitable and dangerous substances[1-4]. Even a minor incident within these installations can precipitate substantial property damage, frequently reaching millions of bones, along with several days of product time-out. Again, a major accident can spark a waterfall of impacts, including expensive suits, sinking stock values, or even the eventual bankruptcy of the company[5]. These incidents illustrate not just the expansive destruction in the vicinity and the implicit environmental ramifications, but also the imperative to forestall similar accidents[4, 6, 7]. Thus, maintaining the utmost alertness and adherence to safety protocols within these surroundings is necessary to alleviate the potentially disastrous consequences associated with any mishap[5, 8, 9]. Over the past seven decades, trade associations and engineering societies such as the American Petroleum Institute(API), American Institute of Chemical Engineers(AIChE), American Society of Mechanical Engineers(ASME), and National Fire Protection Association(NFPA) have diligently drafted strict engineering guidelines and norms governing the construction, material selection, design, and safe operation of storehouse tanks and their ancillary factors[10-19] While numerous companies adhere nearly to these established protocols throughout the design, construction, and operation phases, incidents involving storehouse tanks still occur. Drawing assignments from literal circumstances is incontrovertibly pivotal for enhancing the unborn safety of storehouse tanks. Chang and Lin [1] conducted a thorough disquisition, gathering references and data from applicable literature, to take over a statistical examination of accidents passing in storehouse tanks[1-3, 5]. The end of the present study is to propose a new methodology to define the implicit causes of 242 storehouse tank accidents passed between 1960 and 2003 using two different risk analysis methods. The first is a quantitative method, which is fault trees, and the second is a qualitative method, which is fishbone diagrams and styles. The posterior sections of this paper include Section 3, furnishing a description of the colorful types of storehouse tanks; Section 5, conducting a statistical analysis of storehouse tank accidents and incidents; Section 6, applying the fault tree and fishbone diagram styles to prize implicit causes of these accidents; and Section 7, agitating the results attained from these analyses.

STORAGE TANK TYPES

Large tanks employed for the storage of liquids are crucial components within the gasoline and chemical industries, serving to store raw, intermediate, or finished materials. These tanks are typically situated in enclosed spaces, often segregated from the rest of the facility. The containers utilized for storing combustible or flammable liquids vary in type. The Institute of Chemical Engineers categorizes fuel hydrocarbons into three primary classes.

- Cone or fixed-roof tanks
- Roof Tanks that Float.
- Tanks with a fixed roof and an internal floating roof

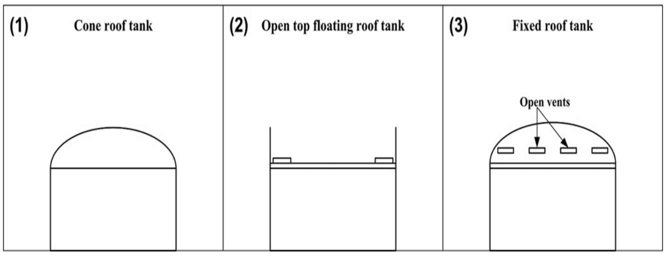

Figure. 1. Storage Tanks Types [5, 7]

Crude oil and "White" Light products (petrol, diesel, and jet) are among the volatile liquid hydrocarbons that are served by the second and third container classes. A number of different types of fires, including rim seal fires, spills on roofs, full surface fires, bund or dyke fires, pontoon explosions, and boil overs, can occur in storage tanks.

Table 1 : A comparison between Fixed Roof Tank and Floating Roof Tank

Tank Types	Advantages	Disadvantages
Fixed Roof	straightforward construction and low maintenance needs (no moving parts)	• Liquid evaporation loss • If flammable vapor is ignited, there is a substantial risk of an interior explosion due to the large vapor space.
Floating Roof	• Minimized vapor space and hence low chance of internal explosion; • Reduced evaporative loss of liquid and limiting of VOC emission.	Potential buildup of snow and rainwater on the roof that could cause the roof to sink

Data Collection

The article offers a thorough analysis of 240 mishaps and incidents that happened in atmospheric storage tanks globally between 1960 and 2003. The majority of the data came from studies written by Jérome Taveau (2011), Samia Chettouh, Rachida Hamzi, Khemissi Benaroua (2016), James I. Chang and Cheng-Chung Lin (2006), W. Atherton and J. W. Ash (2014), and J Fail. Anal. and Preven. (2017), Parisa Moshashaei . Seyed Shamseddin Alizadeh . Leila Khazini . Mohammad Asghari-J[20],. Information was also obtained from accident reports, pertinent books, and the French databases maintained by the (BARPI)[21].The evaluation most likely addresses a number of these mishaps and incidents, including their causes, effects, contributing elements, and potential preventative or mitigating measures. A thorough understanding of the difficulties and dangers related to atmospheric storage tanks can be obtained by analyzing data from numerous sources over several decades. This analysis offers insightful information that can be used to improve industrial safety policies and regulations.

STATICAL ANALYZE

The statistical analysis is the best and most effective method to investigate and get the real causes and consequences of any type of accident. Various studies have investigated accidents across different sectors and countries, providing valuable insights into their causes and characteristics[22]. For instance, Lizhong et al. [23] examined fire incidents in China in 1998, focusing on monthly and daily distributions as well as root cause analysis and location patterns. Ohtani and Kobayashi[24] conducted a statistical analysis of accidents involving dangerous goods in Japan to elucidate their causes. Liu et al [25] analyzed industrial accidents in China from 1990 to 2003, exploring the relationship with economic development and identifying safety. measures.Sweis [26] provided a statistical analysis of fire incidents in Jordan between 1996 and 2004, categorizing accidents based on types and causes. Nivolianitou et al [27] analyzed major accidents in the petrochemical sector using the European Major Accident Reporting System (MARS), focusing on categorization fields and immediate causes. Mihailidou et al. and Fabiano and Currò [28]conducted historical analyses and statistical investigations on accidents in the oil industry, identifying historical trends and investigating accident causes. Zhang and Zheng [29] studied hazardous chemical accidents in Mainland China from 2006 to 2010, discussing various aspects such as time, location, and causative factors. Calvo et al. (2014) developed an accident and incident database for the biodiesel industry from 2003 to November 2013, containing information on adverse events, mitigation, and consequences[30].
These studies collectively contribute to our understanding of accidents across different sectors and regions, highlighting the importance of proactive measures and safety regulations to prevent and mitigate such events. In this section, we present for each accident in atmospheric

storage tanks between 1969 and 2003 all the available information, such as the number of accidents, types of facilities, storage tank products, number of accidents in each tank type, accident types, and accident causes, summarized in Tables 2, 3, 4, 5, 6, and 7.

5.1 Continents where accidents occurred.

In this part for each accident we present its location.

Table 2 : Storage tank accidents locations

Year	North America	Asia & Austorali a	Europe	Africa	South America
1960-1969	3	7	6	1	0
1970-1979	18	9	6	1	2
1980-1989	26	9	9	5	4
1990-1999	36	33	12	2	2
2000-2003	31	14	5	0	1
Total	114	72	38	9	9

As shown in Table 2 and Figure 2, the most accidents happened in North America by over 47%, followed by Asia by around 30%, while the rate of accidents in Europe is 15%, but only 4% of them happened in Africa and South America

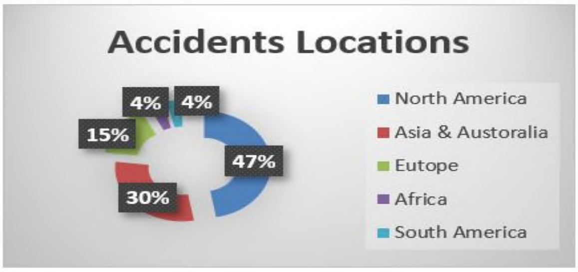

Figure. 2. Storage Tank Accidents Locations

5.2 Accident frequency

The frequency analyze is so important to determinate what is the era that the accidents increased .

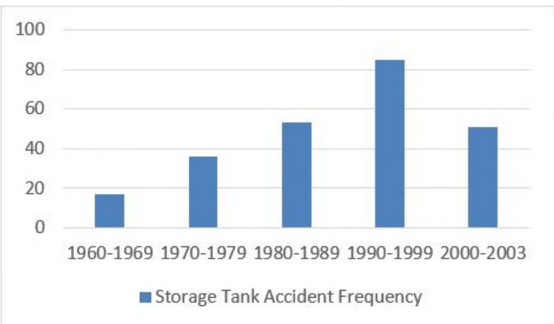

Figure 3 : Storage Tank Accidents Frequency

By studying Figure 3 and Table 2, we conclude that the number of accidents has increased in function of time, with a significant increase of 62% between the periods 1990 and 1999 by 62%. This increase is due to the number of accidents in this period in America (32%), Asia (46%), and Europe (32%), which is considered the largest number of total recorded accidents..

5.3 Storage Tanks Accidents Facilities

In this section we present for each accident the type of facility that have been happened .

Table 3 : Storage tank accidents facilities

Year	Rafinery	Terminal Storage	Chemical Plant	Oil Field	Mix	Total
1960-1969	10	5	1	0	1	17
1970-1979	22	11	0	0	3	36
1980-1989	25	17	5	2	4	53
1990-1999	41	22	16	1	5	85
2000-2003	18	9	9	3	12	51
	116	64	31	6	25	242

By learning from **Table 3,** we show that accidents happened more frequently in refineries facilities, accounting for around half of the total number of accidents (48%), followed by terminal storage with 26.4%, 12.80% occurred in chemical plants, and 10.33% of accidents occurred in other facilities, while only 2.47% of them happened in oil fields.

Those results are very important because refineries and storage areas always contain flammable materials (petroleum and its derivatives) and are therefore the most vulnerable to accidents.

5.4 Storage Tanks Substance

Table 4 : Storage tank accidents substance

Year	1960-1969	1970-1979	1980-1989	1990-1999	2000-2003	Total
Crude Oil	6	8	17	23	12	66
Oil products	3	7	14	19	16	59
15	0	13	17	21	6	55
Petrochemicals	3	3	4	11	6	27
LPG	3	3	1	5	1	15
Waste Oil Water	2	2	0	4	1	9
Ammonia	0	0	0	0	3	3
Hydrochloric Acid	0	0	0	1	2	3
Molten Sulfur	0	0	0	1	1	2
Total	17	36	53	85	51	242

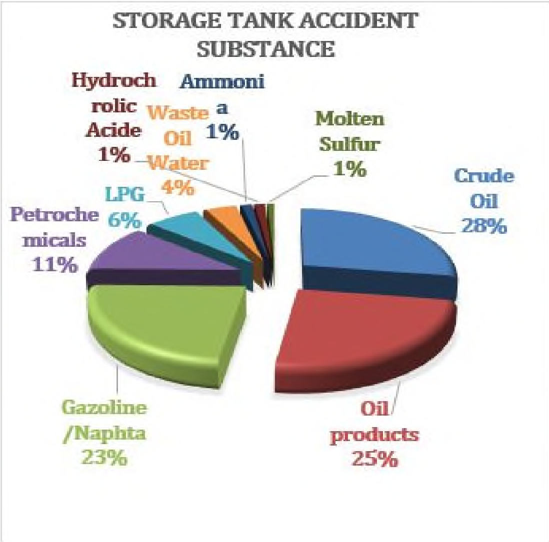

Figure 4 : Storage tank accidents substance

Table 4 and Figure 4 present the ratio of its substances associated with the reports of accidents in atmospheric storage tanks for the period 1960–2003.

In most cases, heavy products such as crude oil, oil products with a total of 75%, secondly petrochemicals, liquid petroleum gas ("LPG" and waste oil water (21%), while ammonia, hydrochloric acid, and caustic soda are less than 4%.

5.5 Number of accidents in each tank types

Table 5 : Storage tank accidents in each type of tank

Products	Grude oil	Oil products	Gasoline	LPG	Propane	Hydrolic acid	Mythyl cyanate
External floating top	23	3	20	0	0	0	0
Cone top	5	10	3	0	0	0	0
Sphere	0	0	0	11	0	0	0
Internal floating top	2	1	3	0	0	0	0
Refrigerated tank	0	0	0	0	1	0	1
Wooden top	2	0	0	0	0	0	0
Fiber glass	0	0	0	0	1	2	0
Total	32	14	26	11	2	2	1

After analyzing **Table 5**, we obtain that the external floating tank and fixed roof tank are the most prone to accidents by 52.27% and 20.45%, respectively, while the ratio of accidents in the internal floating roof tank is 6.81%. The three are used to store petroleum and its derivation, and the and the sphere is used to store liquid petroleum gas with a ratio of 12.5%. Refrigerated tanks, wooden tops, and fiberglass are less used to store oil or their products, for a total of 7.95%.

5.5 Tank accidents types

Table 6 : Storage tank accident types

Year	1960-1969	1970-1979	1980-1989	1990-1999	2000-2003	Total
Fire	8	26	31	59	21	145
Explosion	8	5	16	22	10	61
Spill	0	5	3	2	8	18
Toxic gas release	0	0	2	1	10	13
Mix	1	0	1	1	2	5
Total	17	36	53	85	51	242

The **Table 6** proves that fire is the most common accident in storage tanks at 60%, followed by explosion at 25%, toxic gas release at 5.37%, and other scenarios with a ratio of 2%. Those ratios are logic because the majority of stored substances are characterized by their flammability and explosive properties, and when there is any source of sprk, they can initiate directly; otherwise, they desperce in the environment (realease in the environment).

5.5 Accidents causes in atmospheric storage tanks

Table 7 : Storage tank accidents causes

Year	1960-1969	1970-1979	1980-1989	1990-1999	2000-2003	Total
Lightning	4	10	19	37	10	80
Maintentance/hotwork	1	5	9	12	5	32
operational error	1	5	6	8	9	29
equipement failure	3	1	5	7	3	19
Sabotage	2	5	2	6	3	18
Crack/rupture	0	3	3	3	8	17
leaks and line repture	0	3	2	5	5	15
Static electricity	2	1	2	2	5	12
Open Flame	1	0	4	2	1	8
Nature Disasters	1	2	1	1	2	7
Runway Reaction	2	1	0	2	0	5
total	17	36	53	85	51	242

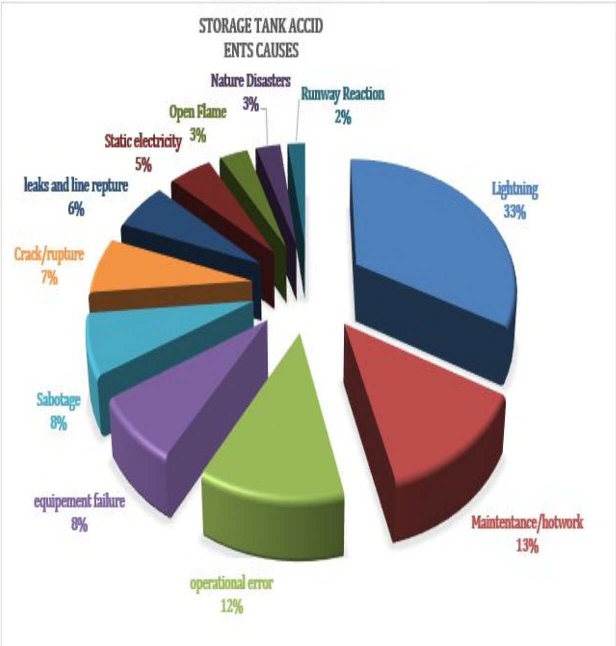

Figure 5 : Storage tank accident causes

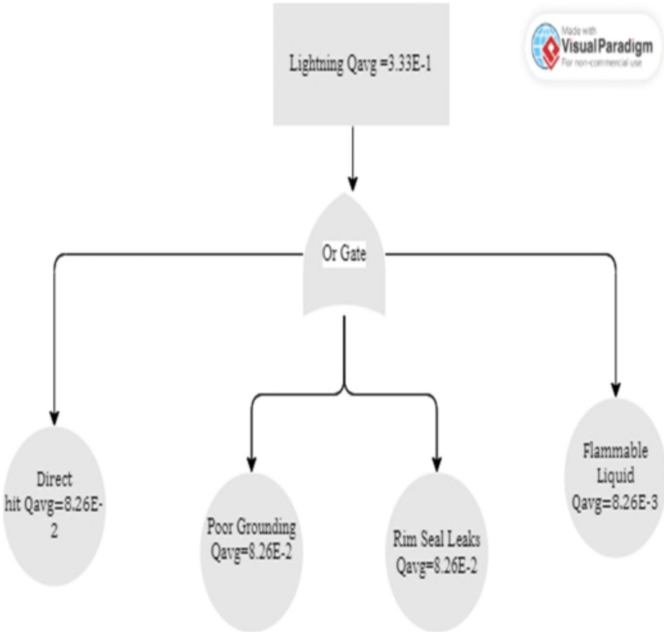

Figure 6:Fault tree of lightning.

Lightning and human error are the most common factors in accidents, accounting for 33% and 13.22%, respectively. Equipment failure, sabotage, sabotage, crack and line rupture account for a total of 48% of accidents, while static electricity, open flame, nature disasters, and runway reactions account for 5.78% of accidents.

APPLICATION OF FAULT TREE AND FISHBONE DIAGRAM METHODS

In this section, we will find all the direct and indirect causes of storage tank accidents mentioned in **Table 7 (Section 5.5)** using a quantitative method called the **fault tree method. After** that, we will summarize all these causes using the Ishikawa **Diagram (Fishbone Diagram).**

6.1 Application of fault tree method

In all the flowing Fault Tree Diagrams we use the law constant to calculate the unavailability average Q_{avg} for each causes .

$$Q_i(t)=Q_i \quad (1)$$

6.1.1 Fault tree of lightning

The main causes of Lightning accident are Direct hit **or** Poor Grounding **or** Rim Seal Leaks **or** Flammable Liquid Leak from Seal. So we associate between them by a **OR** gate the results of the fault tree analysis presented in figure6 while the table 8 present the unavailability average of the elementary events and the top event(Lightning).

Table 8 : Unavailability of Lightning

Events	Unavailability Q_{avg}
Lightning	0.33
Direct hit	0.0826
Poor Grounding	0.0826
Rim Seal Leaks	0.0826
Flammable Liquid Leak from Seal	0.0826

Table 8 showed the probability of failure of lightning is 0,33 of the total of probabilities of accidents.

6.1.2 Fault tree of maintenance error

The main causes of Maintenance are Welding **OR** Circuit Shortcut **OR** Nonexplosion-Proof Motor And Tools Used **OR** Sparks **OR** Transformer Spark. So we associate between them by a **OR** logic.

The figure 7 and table 9 present the fault tree analysis and the mean unavailability of maintenance error

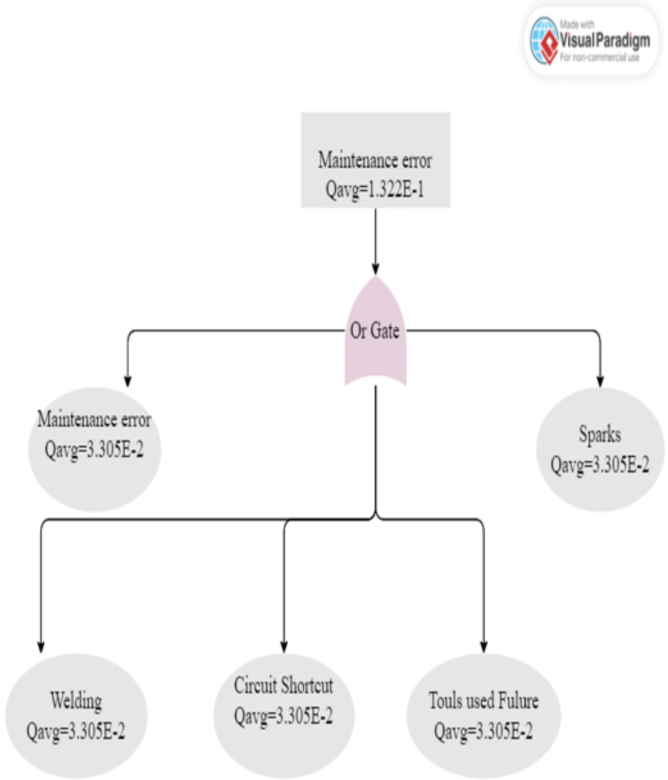

Figure 7: Fault tree of maintenance error

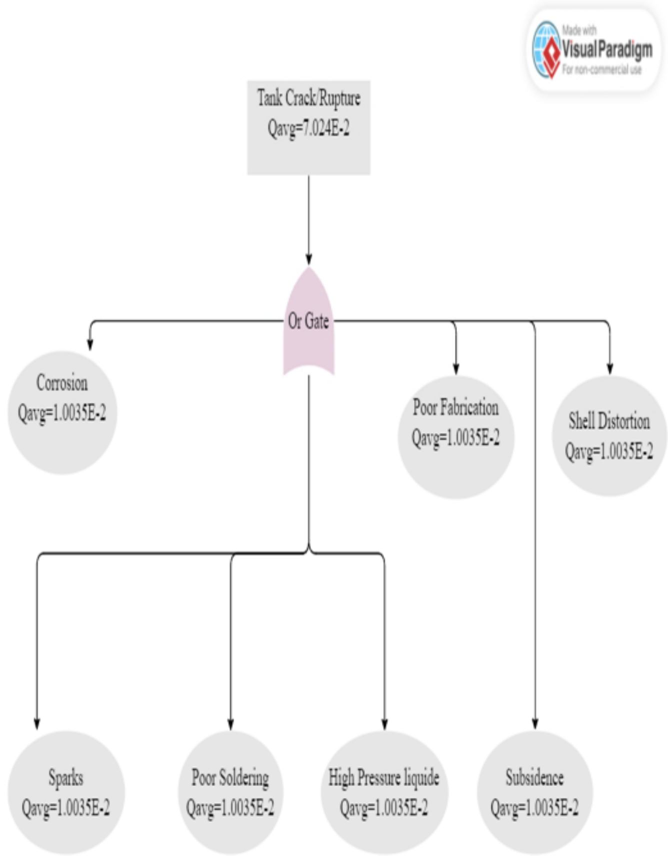

Figure 8 : Tank rupture fault tree.

Table 9 : Unavailability of maintenance error

Events	Unavailability Q_{avg}
Maintenance error	0.1322
Welding	0.03305
Circuit Shortcut	0.03305
Nonexplosion-Proof Motor And Tools Used	0.03305
Transformer Spark	0.03305
Sparks	0.03305

6.1.3 Fault tree of tank crack/rupture

The main causes are Corrosion **OR** Poor Fabrication **OR** Shell Distortion **OR** Sparks **OR** Poor Soldering **OR** High Pressure Liquid from Downstream Vessels Back up **OR** Subsidence.
The figure 8 and table 10 present the results of the fault tree of tank rupture.

Table 10 : Unavailability of tank rupture

Events	Unavailability Q_{avg}
Tank Crack/Rupture	0.07024
Corrosion	0.010035
Poor Fabrication	0.010035
Shell Distortion	0.010035
Sparks	0.010035
Poor Soldering	0.010035
High Pressure Liquid	0.010035
Subsidence	0.010035

6.1.4 Fault tree of piping rupture/leak

The main causes are Cut by Oil Stealers **OR** Pump Leak or Low Temp **OR** Cut Accidently by a Contractor **OR** Propane Line Broken by an ATV. The figure 9 and table 11 present the fault tree analysis and the mean unavailability of pipeline leak

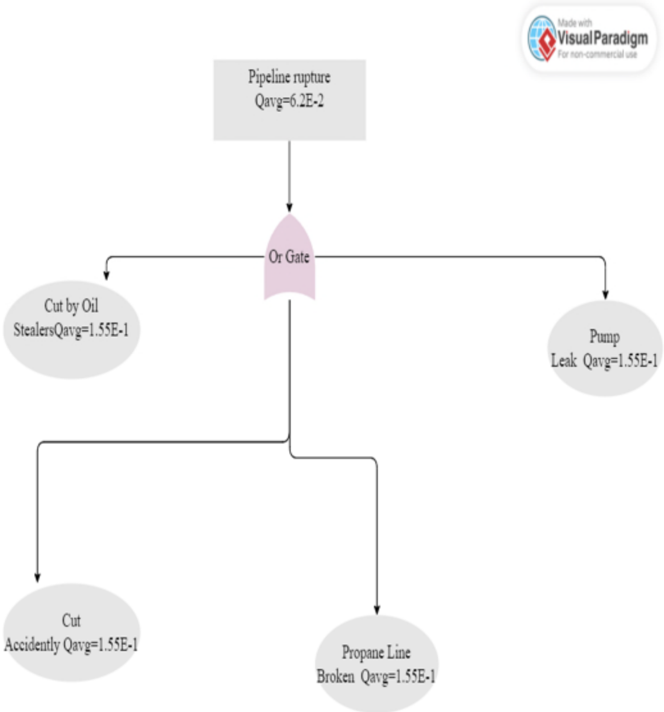

Figure 9: Fault tree of pipeline rupture.

Table 11 : Unavailability of pipeline rupture

Events	Unavailability Q_{avg}
Pipeline rupture	0.062
Cut by Oil Stealers	0 .155
Pump Leak or Low Temp	0 .155
Cut Accidently by a Contractor	0 .155
Propane Line Broken by an ATV	0 .155

6.1.5 Fault tree of operational error

The main causes are Drain Valves Left Open Accidentally **OR** Overfill **OR** SOP Not Followed **OR** Tank cars Moved Accidentally During Loading **OR** Vent Closed During Loading **OR** Oil Leaks due to Operators Errors **OR** High Inlet Temp. The figure 10 and table 12 present the fault tree analysis and the mean unavailability of operational error.

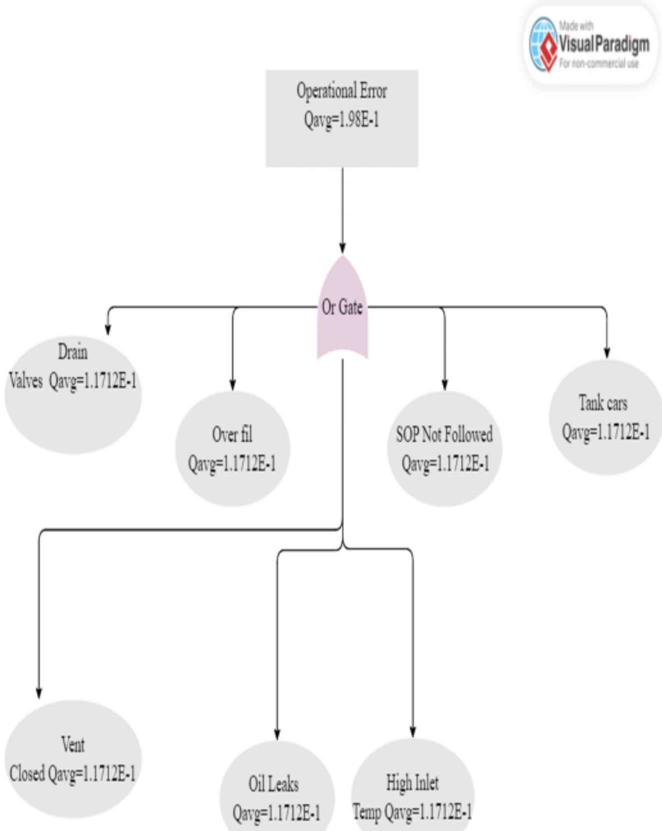

Figure 10 : Fault tree of operation error.

Table 12 : Unavailability of operational error

Events	Unavailability Q_{avg}
Operational error	0.1198
Drain Valves Left Open Accidentally	0.1712
Over fil	0.1712
SOP Not Followed	0.1712
Tank cars Moved Accidentally	0.1712
Vent Closed	0.1712
Oil Leaks due to Operators Errors	0.1712
High Inlet Temp	0.1712

6.1.6 Fault tree of equipment/instrument failure

The main causes of equipment and instrument failure accident are Relief Valves Failure Accidentally Opened, Heater Failure, Frozen LPG Valve, Level Indicator, Thermostat Failure, O_2 Analyzer Failure, Floating Roof Sun, Discharge Valve Rupture, Overheated by Steam Heater, Rust Vent Valve not Open. The figure 11 and table 13 present the fault tree analysis and the mean unavailability of tree of equipment/instrument failure

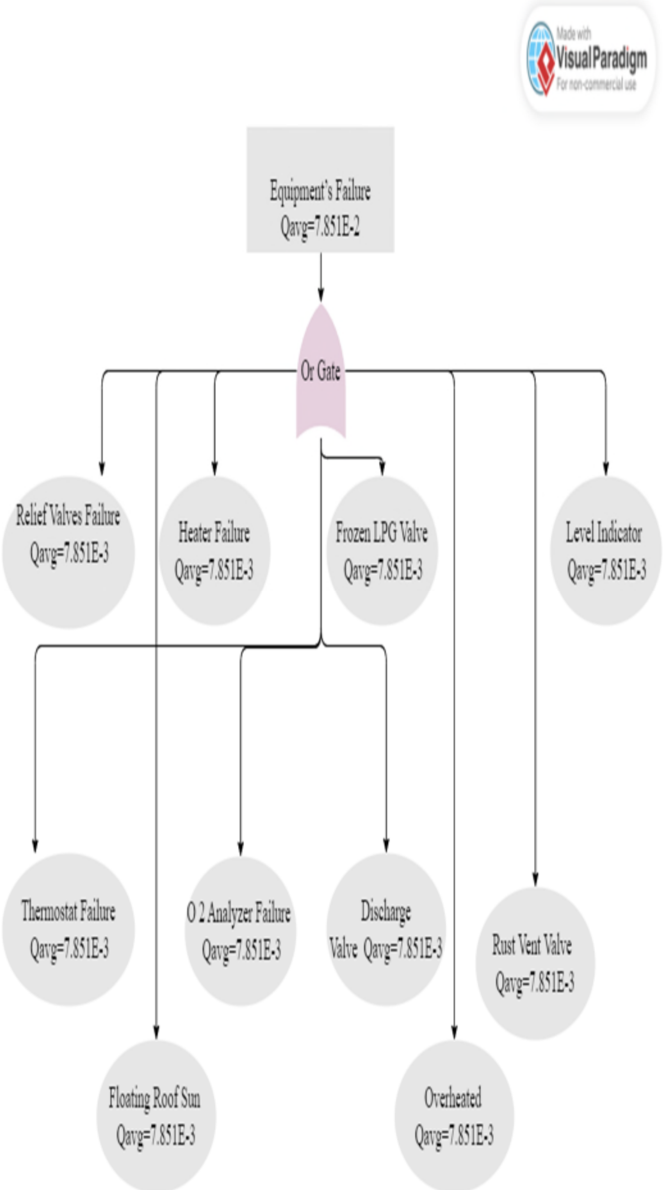

Figure 11 : Fault tree of equipment failure.

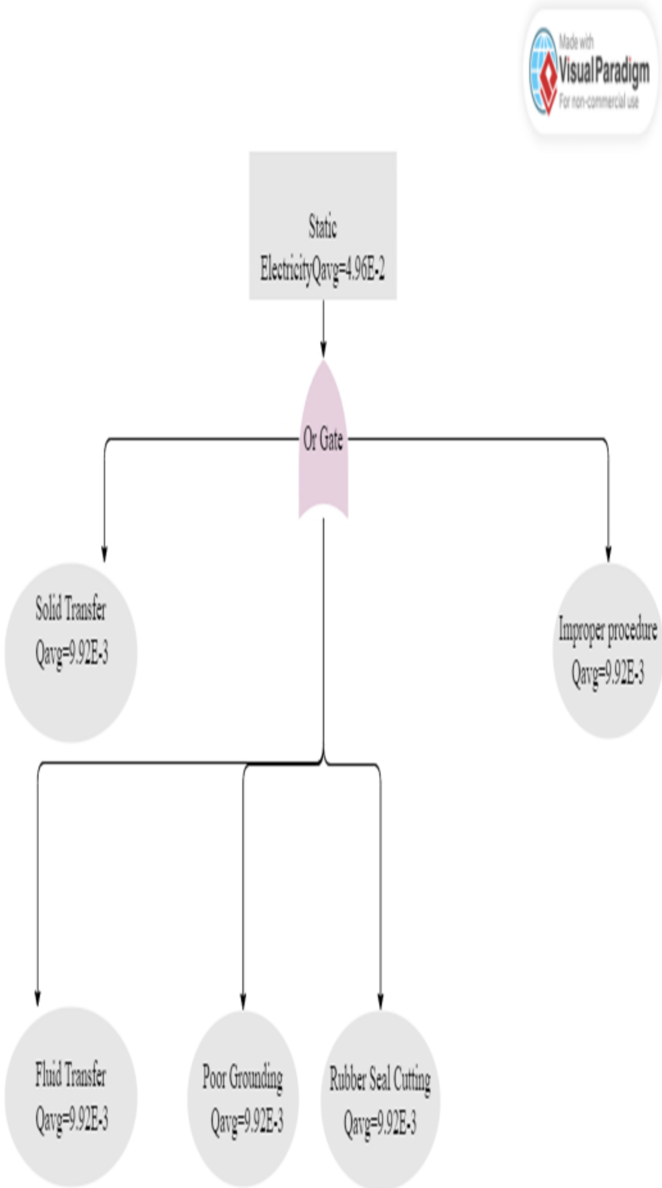

Figure 12 : Fault tree of static electricity

Table 13 : Unavailability of equipment failure

Events	Unavailability Q_{avg}
Equipment's Failure	0 .07851
Relief Valves Failure	0 .007851
Heater Failure	0 .007851
Frozen LPG Valve	0 .007851
Level Indicator	0 .007851
Thermostat Failure	0 .007851
O_2 Analyzer Failure	0 .007851
Floating Roof Sun	0 .007851
Discharge Valve Rupture	0 .007851
Overheated by Steam Heater	0 .007851
Rust Vent Valve not Open	0 .007851

6.1.7 Fault tree of static electricity

The main causes are Solid Transfer, Improper Sampling Procedures, Fluid Transfer, Poor Grounding, Rubber Seal Cutting. The figure 12 and table 14 present the fault tree analysis and the mean unavailability of static electricity.

Table 14 : Unavailability of static electricity

Events	Unavailability Q_{avg}
Static electricity	0.0496
Solid Transfer	9.92 E-3
Improper Sampling Procedure	9.92 E-3
Fluid Transfer	9.92 E-3
Poor Grounding	9.92 E-3
Rubber Seal Cutting	9.92 E-3

1.2 Application of fishbone diagram method

After applying Fault tree method in section 6.1 and determinate the real causes of each storage tank accidents and calculate their Unavailability (probability of failure) now we summarized all those causes in fishbone diagram.

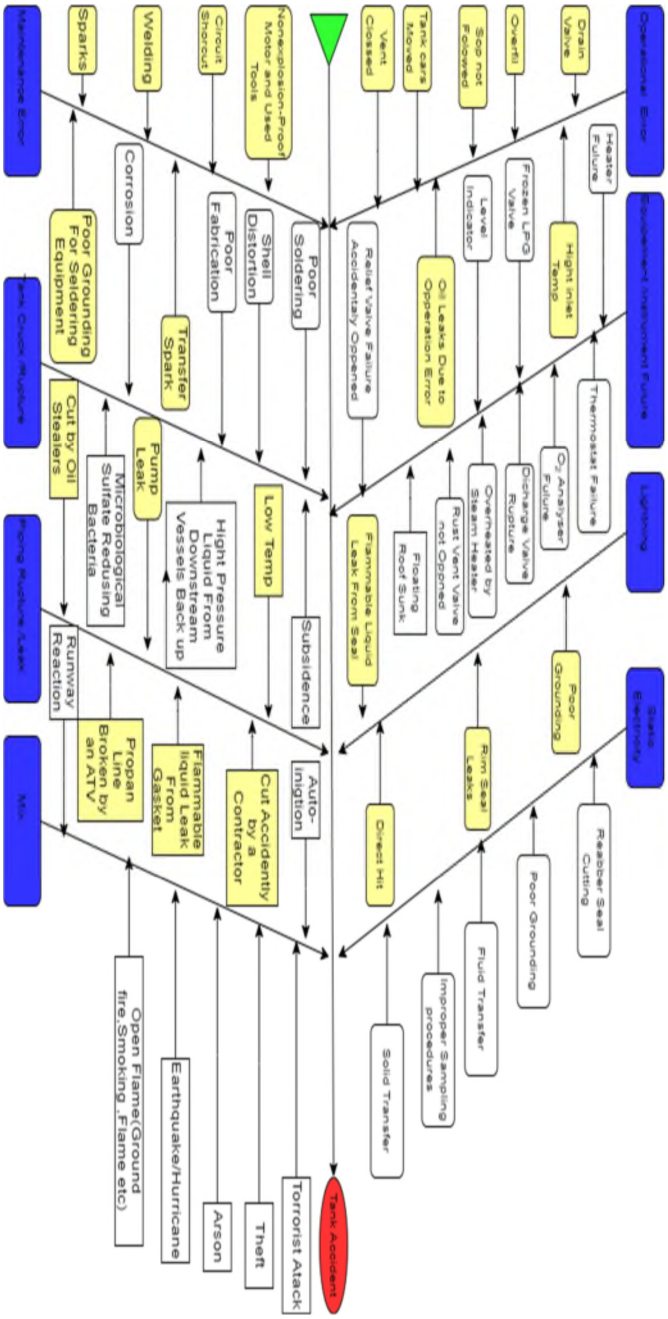

Figure 13 : Fishbon Diagram of the causes of starage tank accidents.

DISCUSION OF THE RESULTS

In this research paper, we propose a new methodology to investigate 242 storage tank accidents. Our idea is to combine two different methods. The first one is a quantitative method, which is the fault tree analysis method, to determine the mean unavailability Qavg of the causes of a storage tank accident, while the second one is an Ishikawa method or fishbone diagram (cause and effect method), as it is commonly known, which is a qualitative method. The statistical analysis reveals that a significant portion of accidents, approximately 48% of the total, have been reported in North America, followed by Asia by around 30%, while the rate of accidents in Europe is 15%, but only 4% of them happened in Africa and South America (Table 2 and Figure 2). The majority of those accidents happened more frequently in refinery facilities, accounting for around half of the total number of accidents (48%), followed by terminal storage with 26.4%, 12.80% occurred in chemical plants, and 10.33% of accidents occurred in other facilities, while only 2.47% of them happened in oil fields (Table 3). These results are very important because refineries and storage areas always contain flammable materials (petroleum and its derivatives) and are therefore the most vulnerable to accidents. In most cases, heavy products such as crude oil have a total of 75%, followed by petrochemicals, liquid petroleum gas ("LPG"), and waste oil water (21%), while ammonia, hydrochloric acid, and caustic soda are less than 4% (Table 4 and Figure 4). Also, we obtain that the external floating tank and fixed roof tank are the most prone to accidents by 52.27% and 20.45%, respectively, while the ratio of accidents in the internal floating roof tank is 6.81% (Table 5). The three are used to store petroleum and its derivation, and the sphere is used to store liquid petroleum gas ("LPG") with a ratio of 12.5%. Refrigerated tanks, wooden tops, and fiberglass are less used to store oil or their products, for a total of 7.95%. Furthermore, in most of them (accidents or incidents), the predominant nature, constituting approximately 85.12%, is attributed to fire and explosions. This high incidence is directly correlated with the flammability of the majority of stored materials within these facilities. Notably, heavy products account for 75% of the vulnerable substances prone to accidents.

CONCLUSION

A thorough examination was undertaken concerning 242 tank accidents occurring within industrial facilities spanning from 1960 to 2003. The root causes and contributing factors leading to these incidents were methodically illustrated utilizing a fishbone diagram and fault tree analysis. The primary culprits behind these accidents were identified as lightning strikes, accounting for 80 incidents, and human errors, responsible for 32 accidents. Additionally, the investigation demonstrated that the implementation and execution of sound engineering practices in design, maintenance, construction, and robust safety protocols could have significantly mitigated the occurrence of most of these accidents.

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