UNIVERSIDADE EDUARDO MONDLANE

FACULTY OF ENGINEERING

DEPARTMENT OF CHEMICAL ENGINEERING

MASTER IN HEALTH, SAFETY AND ENVIRONMENT ENGINEERING

RISKS ARISING FROM THE OPERATION OF TANKER TRUCK LOADING AT PETÓLEOS DE MOÇAMBIQUE (PETROMOC)

Dissertation Submitted to the Faculty of Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Health, Safety and Environment Engineering

Student: Maria Adelaide Crescência Arone

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Student: Maria Adelaide Crescência Arone

Supervisor: Prof. Doutor Afonso Daniel Macheca, Engº

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Authenticity Statement

This is to certify that to the best of my knowledge; the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Maria Adelaide C. Arone

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RESUMO

Actualmente, a segurança no trabalho é um dos temas mais discutidos e disseminados em todo o mundo, ultrapassando fronteiras, mesmo que ainda em estágios diferentes em cada continente. Independentemente do porte da organização, este assunto é destaque na rotina de qualquer empresa visto que a responsabilidade social e a preocupação com o bem estar dos funcionários e de seus familiares são assuntos muito discutidos actualmente. O problema abordado neste trabalho, é producto do uso limitado de ferramentas de gestão para a identificação correcta dos riscos associados às actividades de manuseamento de combustíveis na empresa Petróleos de Moçambique (Petromoc), especificamente na área do abastecimento de caminões-tanque. A fim de dar resposta a esta fragilidade desenvolveu-se um trabalho de pesquisa e análise, com vista a dotar a mesma de ferramentas de gestão de riscos eficientes. A metodologia utilizada cingiu-se à pesquisa-acção baseada em dados históricos de ocorrências registradas na área de estudo, observação de prácticas e comportamentos, análise das características dos sistemas de abastecimento em uso, e posterior tratamento de dados utilizando ferramentas como, a análise de modos de falha e efeitos, árvore de falhas e eventos, análise funcional e estatística de weibull. Os resultados do estudo mostram que os componentes e funções mais críticas são as que estão directamante relaccionadas aos operadores e ao sistema de abastecimento com maiores indices de criticidade maiores que 4, bem como os riscos inerentes a operação, entre os tais, derrames, paragem da operação por falha de equipamentos, incêndios e outros. Os resultados obtidos apoiam a hipótese de que, a ocorrência dos riscos identificados é derivada dos longos intervalos de realização das manutenções preventivas e acções de treinamento estabelecidas pela empresa.

Palavras-chave: Gestão de riscos; sistemas de carregamento; camião cisterna; ferramentas de gestão.

ABSTRACT

Currently, safety at work is the most discussed and disseminated topics throughout the world, crossing borders, even if still at different stages in each continent. Regardless of the size of the organization, this subject is highlighted in the routine of any company since social responsibility and concern for the well-being of employees and their families are subjects that are much discussed today. The problem addressed in this work is the result of the limited use of management tools for the correct identification of the risks associated with the activities of handling fuels in the *Petróleos de Moçambique* (Petromoc) company, specifically in the area of supply of tank trucks. In order to respond to the fragility, a research and analysis work was developed, with the aim of providing the company with efficient risk management tools. The methodology used was limited to action research based on historical data of occurrences recorded in the study area, observation of practices and behaviors, analysis of the characteristics of the supply systems in use, and subsequent data processing, using tools such as analysis of failure modes and effects, tree of failures and events, functional analysis and weibull statistics. The results of the study showed that the most critical components and functions are those that are directly related to the operators and the supply system with higher criticality indices greater than 4, as well as the risks inherent to the operation, among which, spills, stoppage of the operation due to equipment failure, fire and others. The results obtained support the hypothesis that the occurrence of the identified risks is derived from the long intervals of carrying out preventive maintenance and training actions established by the company.

Keywords: Risk management, supply system, tanker trucks, management tools.

LIST OF ABBREVIATIONS AND ACRONYMS

PETROMOC – Petróleos de Moçambique (Mozambique Oil)

FT – Failure tree

ET – Event tree

FMEA – Failure mode and event analyse

FA – Functional analysis

CF – constrain functions

SF – Service functions

SONAREP – Sociedade NAcional de refinação de Petróleos (*National Petroleum Refining Society*)

HSE – Health, safety and enviromental

ISO - International Organization for Standardization

RNP – Risk Priority Number

S – Severity

O – Ocurrence

D – Detectability

t - Time

β - Shape or slope parameter

η - Scale parameter of the distribution

CHAPTER I – GENERAL INTRODUCTION

1.0 Introduction

Management of safety includes establishing and applying an effective management system, it has to integrate all elements of management so that requirements for safety are established and applied coherently with other requirements, including those for human performance, quality and security. Safety measures shall be applied in an integrated manner and also has to ensure the fostering of a strong safety culture, the regular assessment of safety performance and the application of lessons learnt from experience. The management system supports the development of proactive and responsive management (Diptendu, 2018).

The industry has been increasingly required in terms of the safety of its operations. Its great challenge is the operational continuity in a horizon of growth of its operations. In the area of energy and specifically oil, this challenge translates into ensuring the operation of the facilities at the desired levels of safety.

The Oil & Gas sector is particularly sensitive, as companies live with operational risks that, if poorly managed, can compromise their existence. Operational risks cover a large part of the portfolio, extending across operational, human resources, and technology processes, and need to be monitored with a short- and long-term perspective (du Pont, 2018).

In the oil and gas industry, the main risks involved are fire and explosion risks that are associated with oil exploration and production (E&P). Furthermore, the results of these risks, in most cases, if left unchecked, are catastrophic. Although risk analysis applied to work safety is still quite restricted, it is essential for the development of an effective risk management system, which can reduce the number of accidents and incidents in industries.

As any oil and gas company, *Petróleos de Moçambique* Company (*Petromoc*) faces a variety of risks, which have to be assessed, and prevented, it is in this context, that this project aims to develop a risks management system, focused on the *Petromoc* truck supply, in order to reduce the levels of the risks associated with the critical components, ensuring a safe and accident-free operations.

To ensure that all activities carried out in this area occur accordingly, it is necessary to develop standards and control mechanisms to identify, treat and reduce risks and hazards, which must also be properly identified and analyzed.

1.1 Justification

Currently, safety at work is the most discussed and disseminated topics throughout the world, crossing borders, even if still at different stages in each continent. Regardless of the size of the organization, this subject is highlighted in the routine of any company since social responsibility and concern for the well-being of employees and their families are subjects that are much discussed today. In addition, the increase in competitiveness required organizations to exposure to risk that was adequate with the desired results, something important to provide security to customers, investors and support the decision-making process. That makes risk assessment an effective measure for achieving goals established and in increasing the company's profitability. Studies have shown that in more than 96% of accidents, the behavior of risk is the main cause. According to Llory (1999) in the 1980s there were several accidents of undeniable relevance worldwide where risk behavior was extremely used to explain such events. For Cooper (2000), through data from professionals in the area of occupational safety, it can be considered that most work accidents are caused mainly by unsafe behavior. Also according to Massera (2005), risky or unsafe behavior is identified as the main cause of accidents.

The oil and gas industry is highly prone to the occurrence of undesirable events, which can cause damage of varying order and magnitude involving people and goods, which can, among others, be economic, environmental, physical and moral.

As *Petromoc* is a national Company in the field, which operates in fuel transportation activities, the present project is motivated to establish clear mechanisms for the identification, treat, control and monitoring of undesirable events through the implementation of an efficient risk assessment model, focusing on the tanker truck loading operations, considering the characteristics of the company's existing supply systems.

The successful development of this project can help the company to improve its planning taking into account the risks of the process; it can be applied in other areas/processes of the company, in addition to contributing to the reduction of financial losses and increase in profits. Bearing in mind that the company is in the process of certifying the ISO 45001 and 14001 standards, it will also ensure compliance with certain normative requirements and regulations that govern the activity. On the other hand, the study can provide the company with tools and risk management criteria that will allow for a deeper and more realistic analysis. From an academic point of view, it will serve as a consultation tool for the development of future related projects and may be applied to other areas of the industry and other market segments.

1.2 Problem Statement

The research problem is related to the fact that the company (*Petromoc*) has a certain weakness in its risk management system. For example, the risk identification methodology is only based on brainstorming, with little input from those who know the operation, which leads to repeated occurrences of undesirable events during the truck loading operations, such as spills, contaminations and others, making it impossible to identify the root cause of the problem in question and define prevention and mitigation actions. To solve this problem, it is intended to introduce risk management tools appropriate to the operation in question. Thus, treating and responding to the problem under analysis poses the following questions;

- How critical can it be for the company in terms of costs?
- What can be the associated consequences and how impactful can they be for the company?
- What prevention and mitigation actions can be recommended to the company?
- What is the type and level of risk, its degree of criticality and possible consequences?

1. 3 Objectives

1.3.1 General objective

Assess the risks arising from the tanker truck loading operations at *Petromoc* Company.

1.3.2 Specific objectives

- Map the activities or processes involved in the study area;
- Identify critical components and potential risks;
- Measure process reliability and associated costs.

1.4 Methodology

Five main steps were followed in the present study namely:

- Continued review of the relevant literature for the study;
- Historical data collection;
- Processing and analysis of the collected data;
- Discussion of the results; and
- Dissertation compilation.

CHAPTER II - FUNDAMENTAL CONCEPTS

2.1 Safety Management System

Management for safety is managing activities and applying principles, framework, processes to help prevent accidents, injuries and to minimise other occupational risks. Management for safety can be achieved by:

- Establishing goals that are consistent with the safety policy;
- Integration of all elements so that safety is not compromised;
- Determining the competences and resources necessary to carry out the activities of the organization safely;
- Clear assignment of responsibilities to individual for carrying out work safely;
- Effective management of processes and activities to achieve the organization's goals without compromising safety;
- Arrangements with suppliers for specifying, monitoring and managing the supply of items, products and services that may influence safety;
- Management for safety can prevent safety and health risks at the workplace. Three underlying

Management principles, which are key for enhancing safety and health are:

- Effective and strong leadership;
- Involving workers and their constructive engagement; and
- Ongoing assessment and review.

The systematic and well planned management driven activity which control the safety and health hazards is called as Safety Management System. An effective Safety Management System comprises the following elements (Figure 1). It may vary from industries to industries. But the major elements will be almost similar.

Figure 1: Safety Management System (Adapted from Rafiq, 2006).

2.1.1 Risk Management

Risk management refers to a series of ongoing activities to identify and analytically assess risks that may affect management, respond to the risks, confirm the responses made, and make improvements to the responses.

There are five basic steps that are taken to manage risk, these steps are referred to as the risk management process. It begins with identifying risks, goes on to analyze risks, then the risk is prioritized, a solution is implemented, and finally, the risk is monitored, in manual systems, each step involves a lot of documentation and administration (Olivia, 2020).

Figure 2 : Top 5 steps in risk assessment process (Adapted from FAA, 2017).

2.1.1.2 Risk Identification

The first step is to identify the risks that the business is exposed to in its operating environment. There are many different types of risks – legal risks, environmental risks, market risks, regulatory risks, and much more. It is important to identify as many of these risk factors as possible. In a manual environment, these risks are noted down manually. If the organization has a risk management solution employed all this information is inserted directly into the system. The advantage of this approach is that these risks are now visible to every stakeholder in the organization with access to the system. Instead of this vital information being locked away in a report which has to be requested via email, anyone who wants to see which risks have been identified can access the information in the risk management system (FAA, 2017).

In many cases, identifying risks at multiple levels is useful and efficient. In an initial or preliminary stage, a top-down risk identification approach can be adopted, moving from the general to the specific. First, risks are identified at a general level or higher as a starting point for establishing priorities and, secondly, risks are identified and analyzed at a specific and/or more detailed level. One can, for example, first identify risks to strategic objectives and, later, risks that affect priority processes (Garcez et al., 2015).

Risk identification can be based on historical data, theoretical analyses, opinions of informed people and experts, as well as on stakeholder needs It is appropriate that people with adequate knowledge are involved in risk identification and that the organization uses risk assessment tools and techniques identification of risks that are appropriate to its objectives, capabilities and the risks faced (Lary baggal, 2011). Involving the team also helps create accountability for the risk management process and commitment to risk handling. Documentation for this step usually includes:

a) The scope of the process, project, or activity covered by the identification;
b) The participants in the risk identification process;
c) The approach or method used to identify risks and the sources of information consulted; and
d) Description of each risk, at least with the risk source, causes, event and consequences.

2.1.1.3 Risk Analysis

Once a risk has been identified it needs to be analyzed. The scope of the risk must be determined. It is also important to understand the link between the risk and different factors within the organization (Hubbard, 2009).

To determine the severity and seriousness of the risk it is necessary to see how many business functions the risk affects. There are risks that can bring the whole business to a standstill if actualized, while there are risks that will only be minor inconveniences in the analysis. In a manual risk management environment, this analysis must be done manually. When a risk management solution is implemented one of the most important basic steps is to map risks to different documents, policies, procedures, and business processes. This means that the system will already have a mapped risk framework that will evaluate risks and let you know the far-reaching effects of each risk.

Risk is a function of both the probability and the measure of consequences. In this way, the level of risk is expressed by the combination of the probability of occurrence of the event and the resulting consequences in the event of materialization of the event, that is, the impact on the objectives.

The end result of this process will be to assign each identified risk a rating, both for the probability and for the impact of the event, the combination of which will determine the level of risk. The identification of factors that affect probability and consequences is also part of risk analysis, including an appreciation of the causes, sources and positive or negative consequences of the risk, expressed in tangible or intangible terms.

Depending on the circumstances, risk analysis can be qualitative, semi-quantitative or quantitative, or a combination of these, and be more or less detailed (Omidvari, 2012). The method and level of detail of the analysis can be influenced by the objectives, the nature of the risk, the availability of information and resources.

Qualitative methods define impact, probability and risk level by qualifiers such as “high”, “medium” and “low”, based on people's perceptions.

Semi-quantitative methods use previously agreed numerical scales to measure consequence and probability, which are combined, through a formula, to produce the risk level. The scale can be linear, logarithmic or otherwise. Formulas can also vary according to need and context.

Quantitative methods estimate values for consequences and their probabilities from practical values and calculate the level of risk from specific units defined in the development of the context.

Note that quantitative analysis requires factual data and, due to the lack of this information or the degree of effort required, it may not always be possible or desirable. In these cases, according to the NBR ISO/IEC 31010 standard, the use of a qualitative or semi-quantitative method, based on expert opinion, may be sufficient and effective (ABNT, 2012).

In qualitative and semi-quantitative analyses, considering that the underlying logic is that the level of risk is proportional to both probability and impact, the 'Risk' function will essentially be a product of these variables.

However, this simple relationship may not reflect non-linear relationships, so it is necessary to include a weighting factor for one of the components (probability or impact) in order to achieve the necessary relative scale between them. Also, an exponential operator may be required for one or both components. In its most elementary qualitative form, the relationship between risks and their components can be illustrated using a simple matrix.

Qualitative analysis is generally used to carry out an initial risk assessment at a general level or higher in order to prioritize risk identification and analysis at a specific and/or more detailed level, as well as when quantitative precision is not required or when Numerical data, time and resources are not available.

Semi-quantitative analyzes often use scales, such as those exemplified below, to establish a common understanding of probability and impact ratings. It should be noted that, in real situations, these scales are constructed in a way that is compatible with the context and specific objectives of the activity that is the object of risk management.

2.1.1.4 Evaluating or Ranking the Risk

Risks need to be ranked and prioritized. Most risk management solutions have different categories of risks, depending on the severity of the risk. A risk that may cause some inconvenience is rated lowly, risks that can result in catastrophic loss are rated the highest. It is important to rank risks because it allows the organization to gain a holistic view of the risk exposure of the whole organization. The business may be vulnerable to several low-level risks, but it may not require upper management intervention. On the other hand, just one of the highest-rated risks is enough to require immediate intervention.

The purpose of risk assessment is to assist in decision making, based on the results of the risk analysis, about which risks need treatment and the priority for implementing treatment. It involves comparing the risk level with the risk criteria established when the context was considered, to determine if the risk and/or its magnitude is acceptable or tolerable or if some treatment is required (Fekete, 2012).

At this stage, therefore, the understanding and level of risk obtained in the risk analysis stage are used to make decisions about the analyzed risks, in particular:

a) Whether a particular risk needs treatment and the priority for that;
b) Whether a particular activity should be performed or discontinued; and
c) Whether internal controls should be implemented or, if they already exist, whether they should be modified, maintained or eliminated.

A good practice to support the risk assessment process is to establish criteria for prioritization and treatment associated with risk levels (recommended level of care, required response time, who should be communicated, etc.) (Omidvari, 2012).

2.1.1.5 Treating the Risk

Every risk needs to be eliminated or contained as much as possible. This is done by connecting with the experts of the field to which the risk belongs. In a manual environment, this entails contacting each and every stakeholder and then setting up meetings so everyone can talk and discuss the issues. The problem is that the discussion is broken into many different email threads, across different documents and spreadsheets, and many different phone calls. In a risk management solution, all the relevant stakeholders can be sent notifications from within the system. The discussion regarding the risk and its possible solution can take place from within the system. Upper management can also keep a close eye on the solutions being suggested and the progress being made within the system. Instead of everyone contacting each other to get updates, everyone can get updates directly from within the risk management solution.

The treatment of risks involves the selection of one or more options to modify the level of each risk and the elaboration of treatment plans that, once implemented, will imply in new controls or modification of the existing ones. One of the benefits of risk management is the rigor it provides to the process of identifying and selecting alternative risk responses (Coso, 2006).

Risk treatment options include avoiding, reducing (mitigating), transferring (sharing) and accepting (tolerated) risk, it should be noted that they are not mutually exclusive. Avoiding risk is the decision not to start or to discontinue the activity, or to dispose of the object subject to risk. Reducing or mitigating risk consists of taking measures to reduce the probability or consequence of risks or even both.

The procedures that an organization establishes to address risks are called internal control activities. Sharing or transferring the risk is the special case of mitigating the consequence or probability of occurrence of the risk by transferring or sharing a part of the risk, by contracting insurance or outsourcing activities in which the organization does not have sufficient control.

To accept or tolerate risk is to deliberately take no action to alter the probability or consequence of the risk. Occurs when the risk is within the organization's tolerance level (e.g. when the risk is considered low), the ability to do anything about the risk is limited, or the cost of taking any action is disproportionate to the potential benefit. (e.g. spending more financial resources to protect an asset than the value of the asset itself).

Selecting the most appropriate option involves balancing, on the one hand, the costs and efforts of implementing the risk mitigation measure and, on the other hand, the resulting benefits, taking into account that new risks may be introduced by the treatment and that there are risks whose treatment preventive action is not economically justifiable, as risks of great negative consequence, but with a very low probability of happening (Heldman, 2005). A special way of mitigating risk is preparedness through business continuity management. Evaluating this treatment option is especially important when the following conditions occur:

- The management object is the organization's critical activity or process, so the impact is very high;
- The risk event has a low probability, which could lead to the false impression that the level of risk could be tolerated after implementing preventive controls.

However, in these cases, it is advisable to assume that the risk event will someday materialize and, depending on the criticality of the affected object, the need for a specific reactive control is evaluated: business continuity plan. The objective of this type of preparation is to restore the functioning of the activity or work process affected, normally in another location, in a timely manner and with the level of performance adequate to the objectives of the institution. The risk events that are dealt with in these cases are usually catastrophic, for example, fires, floods, earthquakes, epidemics, etc. The main resources affected in these cases are processes, facilities, equipment, people and technology, and the focus of actions will be to recover or replace them, regardless of the type of risk event or its source (Intosai, 2007). The treatment process is cyclical and includes:

- Evaluation of the treatment already carried out;
- Assessing whether residual risk levels are tolerable;
- If not, definition and implementation of additional treatment; and,
- Evaluation of the effectiveness of this treatment (ABNT, 2009).

The documentation of this step integrates the organization's risk register and constitutes a risk treatment plan that must define the order of priority for the implementation of each treatment action, as well as identify:

- The reasons for selecting treatment options, including expected benefits;
- Those responsible for approving and implementing the plan;
- The proposed actions, required resources, including contingency arrangements, and timeline;
- Performance measures and reporting requirements; and
- Ways of monitoring the implementation of treatment and risks.

2.1.1.6 Monitor and Review the Risk

Not all risks can be eliminated, some risks are always present. Market risks and environmental risks are just two examples of risks that always need to be monitored. Under manual systems monitoring happens through diligent employees. These professionals must make sure that they keep a close watch on all risk factors. Under a digital environment, the risk management system monitors the entire risk framework of the organization. If any factor or risk changes, it is immediately visible to everyone. Computers are also much better at continuously monitoring risks than people. Monitoring risks also allows your business to ensure continuity. We can tell you How you can create a risk management plan to monitor and review the risk. Monitoring is the essential step in risk management and aims to (Jordão, 2002):

- Detect changes in the external and internal context, including changes in risk criteria and in the risk itself, which may require a review of risk treatments and their priorities, as well as identifying emerging risks;
- Obtain additional information to improve the risk management policy, structure and process;
- Analyze events (including "near misses"), changes, trends, successes and failures and learn from them; and
- Ensuring that controls are effective and efficient in design and operation.

It is important to note the need for segregation of duties also in monitoring activities. Responsibilities related to monitoring and critical analysis must be clearly defined in the policy and detailed in risk management plans, manuals or regulations and include activities such as:

Continuous (or at least frequent) monitoring by the functions that manage and own risks and by the functions that supervise risks, with a view to measuring the performance of risk management, through key risk indicators, analysis of the pace of activities, current operations or flows compared to what would be necessary to achieve objectives or maintain activities within the established risk criteria:

- Critical analysis of risks and their treatments carried out by the functions that manage and own risks and/or by the functions that supervise risks, through a self-assessment of risks and controls (Control and Risk Self Assessment - CRSA); and
- Audits carried out by functions that provide independent assessments, whether through internal or external audit, focusing on the risk management structure and process, at all relevant levels of organizational activities, that is, seeking to test the systemic aspects of risk management risks rather than specific situations.

Monitoring and review activities must ensure that the risk register is kept up to date, as well as that the results of the actions mentioned above are documented therein.

2.1.1.7 Risk analysis tools

The purpose of the Risk analysis is to comprehend the nature of risk and to determine the level of risk. For every risk and risk scenario identified in the previous risk identification stage, the risk analysis process carries out a detailed (and if possible quantitative) estimation of the probability of its occurrence and the severity of the potential impacts.

The assessment of the probability of an event or hazard should be based, where possible, on the historical frequency of events of similar scale and available statistical data relevant for an analysis of the main drivers, which can help to pick up on accelerating trends.

The assessment of the level of impact should be in quantitative terms:

Hazard analysis

- Geographical analysis (location, extent);
- Temporal analysis (frequency, duration, etc.);
- Dimensional analysis (scale, intensity);
- Probability of occurrence.

Vulnerability analysis

- Identification of elements and people potentially at risk (exposure);
- Identification of vulnerability factors/ impacts (physical, economic, environmental, social/political) assessment of likely impacts;
- Analysis of self-protection capabilities reducing exposure or vulnerability.

2.1.1.7.1 Functional and value analysis

According to Society of American Value Engineers (SAVE), Functional and value analysis is a systematic application of established techniques to identify the functions of a product or component and to provide the desired functions at the lowest total cost. It is a creative approach to eliminate unnecessary costs which add neither to quality no to the appearance of the product (Omidvari, M. *et al*., 2012). It is a rational and structured process consisting of:

- Functional analysis to define the reason for the existence of a product or its components;
- Creatively analysis for generating new and better alternatives; and
- Measurement for evaluating the value of present and future concepts.

2.1.1.7.2 Failure mode and effect analysis

Failure Mode and Effects Analysis (FMEA) is a structured approach to discovering potential failures that may exist within the design of a product or process.

Process FMEA discovers failure that impacts product/system quality, reduced reliability of the process, customer dissatisfaction, and safety or environmental hazards derived from:

- Human Factors;
- Methods followed while processing;
- Materials used;
- Machines utilized;
- Measurement systems impact on acceptance; and
- Environment Factors on process performance.

Historically, the sooner a failure is discovered, the less it will cost. If a failure is discovered late in product development or launch, the impact is exponentially more devastating (Hosseinialamdavari, 2011). There are several times at which it makes sense to perform a Failure Mode and Effects Analysis:

- When you are designing a new product, process or service;
- When you are planning on performing an existing process in a different way;
- When you have a quality improvement goal for a specific process; and
- When you need to understand and improve the failures of a process

Failure modes are the ways in which a process can fail. Effects are the ways that these failures can lead to waste, defects or harmful outcomes. Historically, the earlier a failure is discovered, the lower the cost. If a flaw is discovered late in the development or release of the product, the impact is exponentially more devastating (Hosseinialamdavari, 2011).

FMEA is one of many tools used to discover flaws as early as possible in a project, product or process. Discovering a flaw early in Product Development (PD) using FMEA offers the benefits of:

- Various options to mitigate risk;
- Greater ability to verify and validate changes;
- Collaboration between product design and process;
- Improved design for fabrication and assembly;
- Low cost solutions; and
- Legacy, Tribal Knowledge, and Standard Work Usage.

There are several times when it makes sense to perform a Failure Mode and Effects Analysis:

- When designing a new product, process or service;
- When planning to execute an existing process in a different way;
- When you have a quality improvement goal for a specific process; and,
- When you need to understand and improve the failures of a process.

In addition, it is advisable to perform an FMEA occasionally throughout the life of a process. Quality and reliability must be consistently examined and improved for optimal results (Larybaggal, 2011). The analysis of an FMEA should include multi-level considerations, including:

- Severity of 9/10 or just Safety and Regulations (Failure Mode Actions);
- Criticality combinations for severity and occurrence (cause actions);
- Detection Controls (Actions and Control Plans); and
- Pareto RPN.

The RPN can be calculated by multiplying the severity, detection and criticality parameters.

2.1.1.7.3 Event and Failure tree Analysis

According to Mentes & Helvacioglu (2011), Fault Tree Analysis (FTA) is a graphically oriented systematic and deductive analysis technique used to determine the causes and probability of occurrence of a certain unwanted accident. Another definition is given by Ferdous *et al.* (2007), in which FTA is a well-recognized tool for assessing safety and reliability in system, development and operation. FTA interprets the relationship between component malfunctions and observed phenomena and assesses the probability of an accident resulting from sequences and combinations of failures. FTA uses symbols to represent the interrelationships between equipment failures or operations that can cause a specific accident. Symbols are used as nodes to build a tree representing interrelationships. Figure 3 shows some symbols used to construct the FTA fault tree. A block tree can also be built. The tree comprises only logic gates “and” and “or” can alternatively be represented by a block diagram. This is a logic diagram, which shows the functional capability of a system.

The tree construction process begins with the perception or prediction of a fault, which is then decomposed and detailed down to simpler events. Thus, fault tree analysis is a top-down technique, as it starts from general events that are broken down into primary causative events. According to Aven (2015), the fault tree is easy to understand for people with no prior knowledge of the technique. Fault tree analysis is well documented and simple to use. One of the advantages of using the technique is that the people performing the analysis are induced to understand the system. On the other hand, a disadvantage would be the static view of the fault combinations that can cause the top event to occur. The fault tree analysis method is not suitable for analyzing systems with dynamic properties. Another problem is the handling of common mode failures.

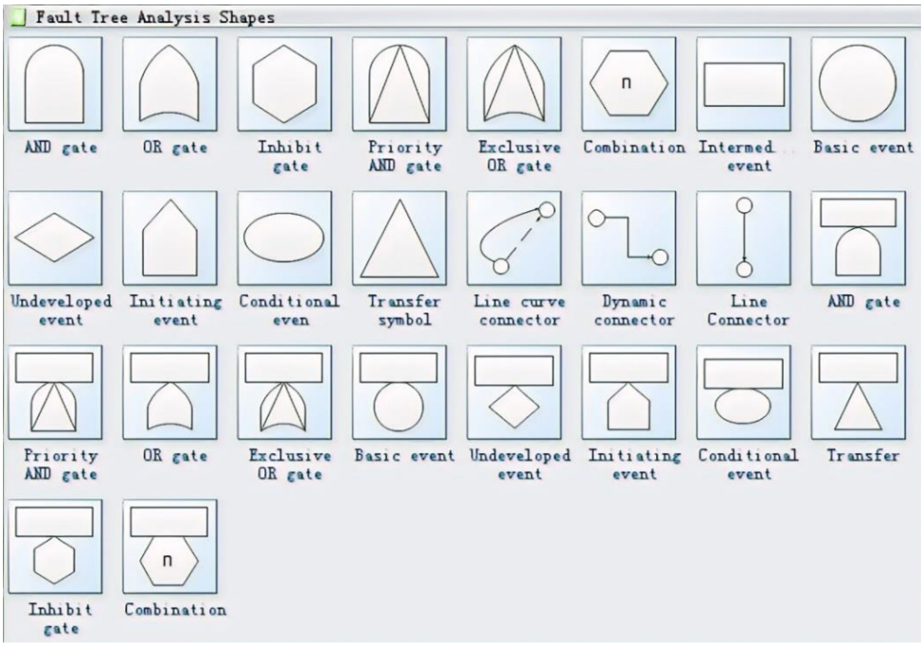


Figure 3: FTA symbols (Adapted from Asham, 2016).

Event Tree Analysis – ETA, according to Huang et al. (2001), is an inductive logic that uses the diagram method to identify the various possible outcomes of a given initial event. The ETA is commonly used to identify the consequences that may result after a potentially hazardous event occurs (Andrews & Dunnett, 2000). ETA as a tool in risk assessment can help prevent negative outcomes from occurring by providing an assessment of risk with the probability of occurrence. ETA uses a type of modeling technique, which branches events from a single event using Boolean logic. The event tree starts with the initial event where the consequences of that event follow in a binary success or failure. Each event creates a path on which a series of successes and failures will occur where the overall probability of occurrence for that path can be calculated.

Event tree (ET) is a complimentary technique to FTA but defines the consequential events which flow from the primary 'initiating' event. Event trees are used to investigate the consequences of loss-making events in order to find ways of mitigating, rather than preventing, losses (Nebosh, element A3). These two techniques are indeed complementary (and are often used together), but they focus on opposite sides of an unwanted event. In many cases, there are multiple causes for an accident or other loss-making event. Fault tree analysis is an analytical technique for tracking events that may contribute. The fault tree is a logic diagram based on the principle of multicausality, which tracks all branches of events that can contribute to an accident or failure.

2.1.1.7.4 Weibull Distribution

Weibull models are used to describe various types of observed failures of components and phenomena. They are widely used in reliability and survival analysis. In addition to the traditional two-parameter and threeparameter Weibull distributions in the reliability or statistics literature, many other Weibull-related distributions are available.

In general, a typical Weibull probability distribution function (PDF) is defined by :

$$F(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad \textbf{(1)}$$

where t ≥ 0 represents time, β > 0 is the shape or slope parameter, and η > 0 is the scale parameter of the distribution. Eq. (1) is usually referred to as the two-parameter Weibull distribution. The slope of the Weibull distribution, β, is very important, as it determines which member of the family of Weibull failure distributions best fits or describes the data. It also indicates the class of failures in the "bathtub curve" failure modes.

The Weibull shape parameter β indicates whether the failure rate is increasing, constant, or decreasing. If β < 1, the system or component has a decreasing failure rate. This scenario is typical of "infant mortality" and indicates the system or component is failing during its "burn-in" period. If β = 1, there is a constant failure rate. Components that have survived burn-in will frequently exhibit a constant failure rate. If β > 1, there is an increasing failure rate (Diego et al., 2017). This is typical for items that are wearing out. To summarize:

- β < 1 indicates infant mortality;
- β = 1 means random failures (i.e., independent of time);
- β > 1 indicates wear-out failures.

f(t) can also be estimated by using Benard's formula,

$$F = \frac{i - 0.3}{N + 0.4} \quad \textbf{(1.1)}$$

where *i* is the rank of the each data point and *N* is the total number of the samples.

The Weibull method converting the recorded times into data points for linear regression using the above mention weibull analysis we perform, linear regressions for the data points. From the linear regression of weibull analysis we estimate β and η.

The information about the β value is extremely useful for reliability-centered maintenance planning and product lifecycle management because it can provide a clue to the physics of the failures and tell the analyst whether scheduled inspections and overhauls are needed. For instance, if β is less than or equal to one, overhauls are not cost-effective. With β greater than one, the overhaul period or scheduled inspection interval can be read directly from the plot at an acceptable or allowable PoF. For wear-out failure modes, if the cost of an unplanned failure is much greater than the cost of a planned replacement, there will be an optimum replacement interval for minimum cost (Zhai et al., 2013).

The scale parameter or spread, η, sometimes called the characteristic life, represents the typical TTF in Weibull analysis and is related to the mean-time-between-failure (MTBF). In Weibull analysis, η is defined as the time at which 63.2% of systems or components under analysis will have failed (Pasha et al., 2006).

The PoF at time t, also referred to as the Weibull distribution or the cumulative distribution function, can be derived from Eq. (1) and expressed as:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{2}$$

Thus, the Weibull reliability at time t, which is 1 − F(t) = R(t), is defined as:

$$R(t) = 1 - F(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{3}$$

This can be written as

$$\frac{1}{1-F(t)} = e^{\left(\frac{t}{\eta}\right)^{\beta}} \tag{4}$$

Taking two times the natural logarithms of both sides gives an equation of a straight line:

$$\ln\left(\ln\left(\frac{1}{1-F(t)}\right)\right) = \beta\ \ln\ t - \beta\ \ln \eta \tag{5}$$

The above equation represents a straight line in the form of "y = ax + b" on log/log(Y) versus log(X), where the slope of the straight line in the plot is β, namely the shape parameter of Weibull distribution. Through the above transformation, the life data samples can be fitted in the Weibull model and the two Weibull parameters can be estimated.

2.2 Involvement of colaborates in safety management -managers, contractors & workers

Although HSE manager is solely responsible for the safe operation of the facility, other stake holders contribute significantly in achieving this goal. The principle stakeholders in safety are Managers, Contractors and Workers.

Everyone in the workplace ─ from senior management to frontline workers ─ needs to understand his/her responsibilities when it comes for implementing and maintaining a healthy and safe workplace.

Senior Managers are responsible for establishing and maintaining the safety management system. Their roles and responsibilities primarily include establishing levels of acceptable risks, formulating HSE policy, dissemination of necessary information relevant to safety to other stake holders, allocating adequate resources essential to effectively manage the health and safety management system requirements and overseeing system performance. They must also ensure that workers put to a task are trained, qualified and competent to perform it.

Line managers are responsible for execution of activities and also for health and safety in the work under their control. Workers need to work safely, according to how they were trained. Based on the experience (hurdles) of execution of work at the bottom level (like worker and line manager level) safety/HSE policy or responsibilities may be reframed.

2.3 Risk Analysis in the Oil and Gas Industry

Oil refineries are considered sources of risk of high relative magnitude, which gives them the highest volumes of risk. However, other facilities, such as transport, storage and oil production units, are between medium and low. It is understood that refineries are considered in this way, considering that their machines and process equipment, in addition to being present in large quantities and great diversity of models, operate with normally high process parameters, and there is also a characteristic for these units very strong process (Jordão et al., 2002). According to Ferreira (2007), the number of accidents that occur in an oil and gas industry must be analyzed according to the mode of operation at the time of the accident, namely: drilling, production, construction, transfer, among others.

2.4 Regulations for Management of Safety

Historically, the process of safety management in the production process was imposed upon by the society through legislative interventions. Thus, the study of the history of safety management turns out to be a history of safety legislation. While management process evolved to be an integral part of the manufacturing process, safety management never emerged to be an essential part of it, except in highly hazardous industries. Even in twenty first century, the trend continues and there is the need for invoking the legislative intervention for injury prevention in the society since safety management is yet to be an integral part of the manufacturing process (BS 8800:2004).

2.4.1 Role of Legislation

In most of the cases, significant advances in safety have taken place through legislative intervention. Safety legislation, to a vast extent, is engaged in an examination of the actual state of affairs within 'man- machine- environment system' to determine whether and to what extent modern technology can be accepted by law. The legal system can never abandon the life and the health of the citizens to the dangers inherent in modern technology (Rafique et al, 2006). Constitutionally, labor is a concurrent subject. The main objectives are to ensure adequate safety measures and to promote health and welfare of the workers. It is the legislation governing safety, health and welfare of persons employed.

2.4.1.1 Legislation Applicable to the Oil and Gas Industry in Mozambique regarding SMS

Constitution of the Republic of Mozambique

- Contains articles on conservation and preservation of the environment, natural resources, the well-being of society and improving the quality of life of citizens, among others.
- Decree No. 89/2019
- Approves the Regulation on Petroleum Products
- Ministerial Diploma 95/2018: Approves the specifications of petroleum products marketable in Mozambique.
- Decree 62/2013: Regulation establishing the legal regime for work accidents and occupational diseases and Labor Law 23/2007
- Mozambican Environmental Law No. 20/97 of 1 October: Establishes the guidelines and requirements for action.

CHAPTER III - EXPERIMENTAL

3.1 Company Overview

The company under study (Petromoc) is among the largest in the fuel distribution segment in Mozambique. It currently has a network of terminals, warehouses and stations aimed at meeting the daily needs of consumers, offering everything from fuels and lubricants, with a predominance in the activity of receiving, storing and distributing fuels, with processes susceptible to the occurrence of leaks, fires and explosions.

The first oil installations in Mozambique date back to 1958, the year in which the terms for construction of the SONAREP (National Petroleum Refining Society) refinery in Maputo, then Lourenço Marques, were approved. In 1961, the first Petroleum Refinery was officially opened in Mozambique, and fuel storage tanks were also put into operation at the ocean terminal of Língamo - Matola.

In a period when all countries were jealously defending their currencies, the installation of this new industry in Mozambique brought, on the one hand, the advantage of the price difference between crude and already refined oil, and on the other, the benefit that obtained with the export of the product to African markets and consequent inflow of foreign exchange (Mirem, 2012).

The working capacity, when the refinery was inaugurated, was 13,000 barrels a day which, for certain types of crude oil, could represent the possibility of effective production corresponding to more than 600 thousand tons per year.

The refinery started by supplying the domestic market and neighboring countries, as well as the Portuguese overseas territories, for its administration and its favorable geographical position, under economic conditions.

The distributors that already existed in Mozambique, for example BP, Shell, etc., were assured a comfortable and consolidated remuneration, Sonarep was linked to the economic development of Mozambique (Sonarep Matola, 2018).

For Mozambique, this work represented immediate, real and highly important benefits, with a reduction of almost 40% in foreign exchange requirements, which it would use when buying liquid fuels, given the economy (at the time the cost of crude oil was less than $12 per tonne on import, and the price of more than $ 20 per tonne of liquid fuels).

Figure 4: National Petroleum Refining Society (1960) (Adapted from Mirem, 2012).

After Independence (1975), the new Frelimo Government decided to transfer the ownership of the Matola Refinery, in Maputo, from the hands of Manuel Boullosa to those of the "popular masses", it became urgent to train new staff devoted to the people who put the strategic unit to function well. They sent a dozen more young Mozambicans to Romania to take a course in Refining Engineering.

When they returned, the Refinery had not been able to stand the wait and had gone through a pile of scrap metal with no loan or return. In view of this situation, in 1977 the company *Petromoc - Petroleos de Mocambique* was created, which became the owner of the park previously belonging to the Refinery (nationalization).

In 1983, the Refinery was officially closed (obsolete equipment and unviable continuity of its operations (Mirem, 2012). Currently, *Petromoc* considered the second largest oil and gas company in Southern Africa, is headquartered in the capital of the country, Maputo, where it also has its largest terminal located in the area of *Matola - Lingamo* industrial park. Additionally, this is distributed in a very representative way through deposits and terminals throughout the country.

Figure 5: Petromoc's current installation in Matola and its distribution throughout the country (Adapted from company profile 2016).

3.2 Main activities developed by the company

Currently, the activities developed by the company are essentially based on the reception of white liquid fuels and LPG by import tankers and cargo in transit, storage and distribution of them from modern filling cranes for wagons and tank trucks for the entire southern, central and northern regions and for the hinterland countries (South Africa, Swaziland, Zimbabwe, Botswana, etc.). In this context, among the various processes that make up the company's management system, reception, storage, distribution and sales, known as operational or fulfillment processes, are the most important for the business (Process Network, 2021).

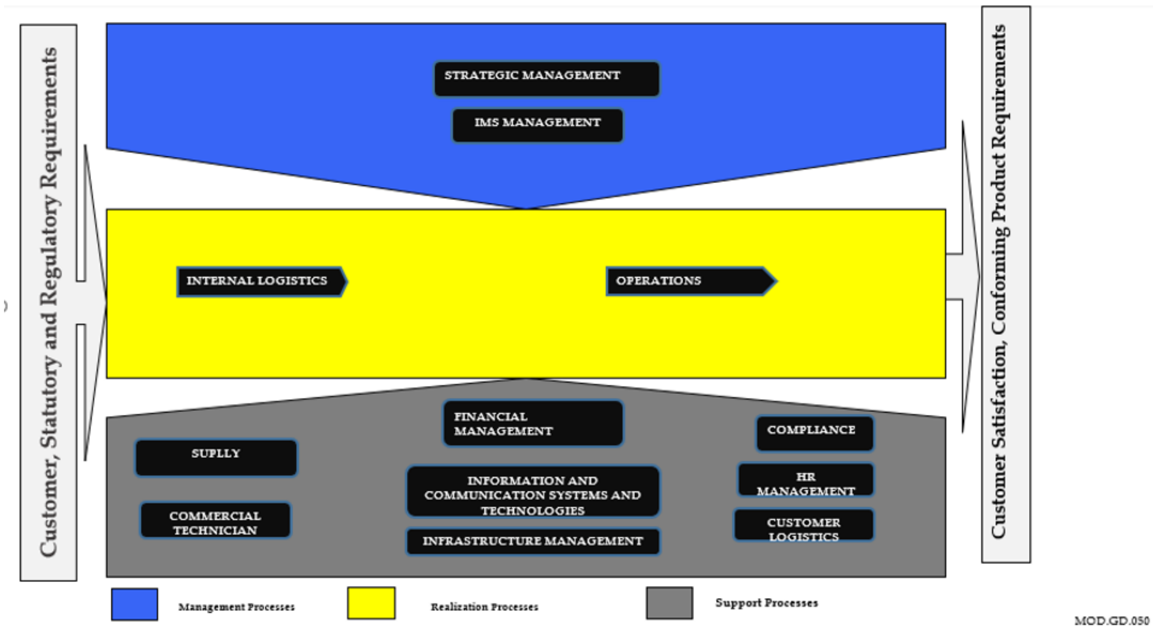


Figure 6: Process mapping (Adapted from Petromoc, 2020).

3.2.1 Reception and Storage Process (internal logistic)

The reception and storage process takes place at all Petromoc facilities, however, depending on the type of facility (Ocean Terminal or Deposit), the product can be received by ship or by tank.

When received by the ship, the product originates from the various refineries from which it is imported. On the other hand, when received by tanker truck, the product comes from a larger Petromoc terminal, called Oceanic Terminals. After receiving the product, after carrying out load compliance tests, it is unloaded and stored in tanks through pipelines.

3.2.2 Loading and distribution process

The process of loading and distributing fuel, is carried out upon availability of product in storage, it occurs according to the steps described in the flowchart below.

Before starting loading, all vehicles wishing to access the facility for this purpose must go through a pre - inspection process that consists of checking the trucks' safety conditions.

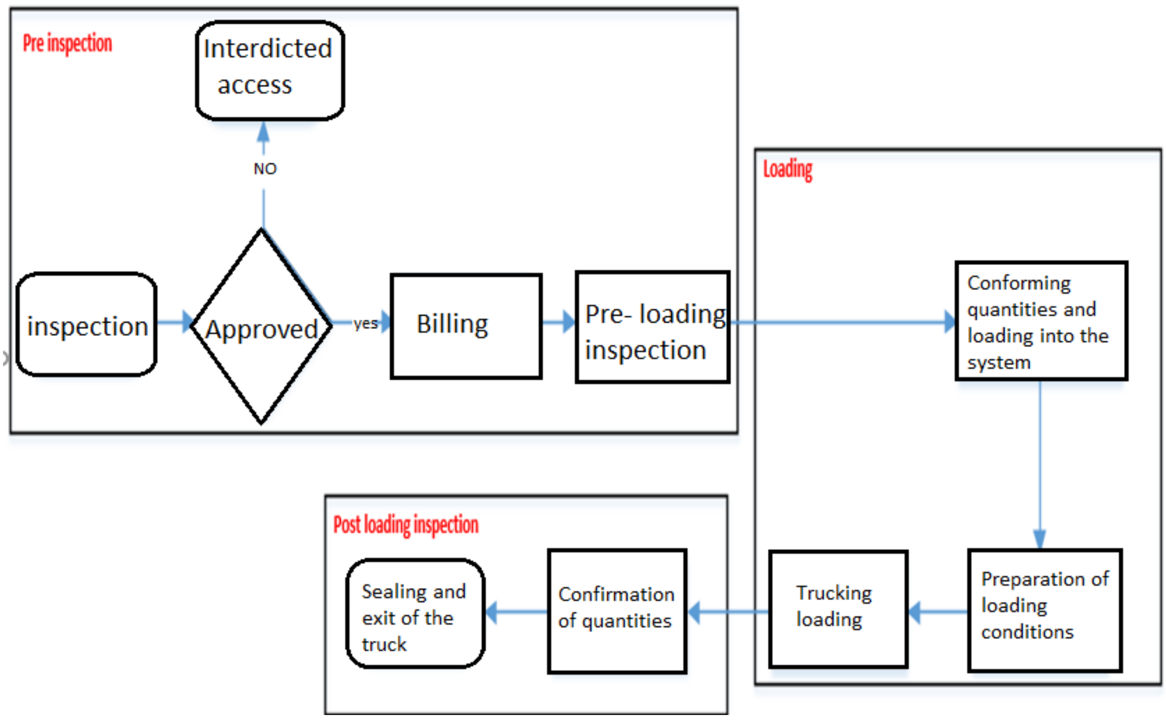


Figure 7: Process flow chart.

3.2.2.1 Types of loading operation

3.2.2.1.1 Bottom loading operation

The bottom loading loading system has as its main characteristic the loading carried out at ground level. As soon as the truck enters the loading platform, they are grounded, and then the loading arms are directly attached to the truck's piping located on the sides of the truck. This type of loading has the advantage of gaining productivity, due to the simple fact that it allows loading to take place in one or more compartments at the same time, according to the products and loading arms available, considering that the operator and the driver are free to circulate on site.

Figure 8: Bottom loading system.

In the bottom loading system, the tank is completely sealed, which makes the process safer for 3 reasons:

- The tank does not need to be opened from above;
- There is no need for the operator to climb into the tank;
- The cover does not stay open.

In this way, there is no contact with liquids or vapors, eliminating the risk of accidents, such as explosions and leaks. In addition, the safety of this system prevents material transshipment at the end of loading.

3.2.2.1.2 Top loading system

The top loading loading system, in turn, has as its main feature loading in the upper part of the truck's tank, where the driver must climb the loading island's ladders and access the truck through the pantographic ladder. In this process, it is essential to use the fall arrest belt, then the driver must be positioned next to the loading arm so that it rests against the bottom of the truck compartment.

Figure 9: Top loading system.

3.2.3 Activities developed by the company within the scope of HSEQ

At *Petromoc* Company, the continuous improvement of the organization's performance in matters of safety, environment and occupational health is promoted at all levels, in order to ensure the uninterrupted growth of operations, the correction and reduction of unwanted effects, for the benefit of implementation of an approach that conforms to the canons accepted worldwide. In this context, the following are highlighted as main activities related to HSE:

- Establish quality, safety and environment policies;
- Ensure the continued availability and distribution of personal protective equipment;
- Monitor risk activities performed by both internal and external in order to ensure compliance with health and safety requirements and regulations;
- Monitor environmental parameters and safety aspects in all areas of the organization;
- Ensure the existence of properly allocated and functional safety devices in compliance with their maintenance criteria;
- Ensure that all interested parties benefit from training according to the needs of each one;
- Ensure the protection of the entire external perimeter of the organization, especially in terminals and warehouses;
- Promote awareness actions on the need to adopt HSE procedures and policies;
- Carry out the risk assessment and its respective monitoring whenever necessary;

- Ensure compliance with health and safety and environmental legislation in force in the country;
- Ensure that all subcontractors meet the HSE requirements.

The industry has been increasingly required in terms of the safety of its operations. Its great challenge is the operational continuity in a horizon of growth of its operations. In the area of energy and specifically oil, this challenge translates into ensuring the operation of the facilities at the desired levels of safety.

As *Petromoc* is a branch company, it faces a variety of internal and external risks, which have to be assessed, and a culture of prevention and preventive detection has been implemented. It is in this context that this project aims to develop a risk management system, focused on the *Petromoc* truck supply, in order to reduce the levels of the risks associated with the so-called critical components, ensuring a safe and accident-free operation that puts the integrity of the operators, equipment and environment at risk.

In a recent past at the *Oceanico da Matola - Lingamo* terminal, the company developed its tank truck dispatch loading operations in a considerably obsolete infrastructure (filling crane), which endangered the entire operation and those directly or indirectly involved. As the image illustrates, the loads were carried out from the top of the truck, which allowed the massive emission of gases into the atmosphere, exposing the operators and the environment to the risks of this effect and other factors, the environment around the crane, specifically the pavement characteristic direct contamination of the soil, if for some eventuality a spill occurred, on the other hand, the operation execution time was considerably long.

For these and other factors such as evolution and competitiveness in the market and improvements in HSE conditions, the organization made an improvement in the quality of the infrastructure, having migrated to a modern and automated system in order to reduce a series of harmful effects as well as better operations.

3.3 Methods

At this stage, through observation techniques and interviews with those responsible and executors of the operation, the different stages that constitute the process was identified and the subsequent design of the respective flow have carried out, considering the activities sequentially. This step served as a basis in this work to obtain information in a comprehensive and at the same time specific way, which allowed the execution of the subsequent steps:

Data collection

At this stage, from the company's database was collect relevant data for the development of the project, which basically consisted of different failures that occurred during the operation at different times, in a certain period of time (6 months).

Data processing

Data processing was carried out through some selected risk management tools, namely, Functional analysis (FA), Failure mode and event analyse (FMEA), Event tree (ET), Failure tree (FT) and Weibull, taking into account the characteristics of the process under analysis. In order to obtain reliable results, part of the data used, such as records in terms of failures, were extracted from the company's database. Other aspects such as characteristics of the process were possible to obtain through observation and practices from the beginning to the end of the operation as well as through details of the system's operation.

Once the process components are identified through an FMEA, was possible to identify the main failure modes, risks and critical events associated with the components and the process. Thus, based on the identification of these events, was possible to using a tree of failures and events to identify the root cause of the risks and the probability of occurrence of certain damage.

Finally, in order to avoid the occurrence of these undesirable events was important to quantify the process or equipment probability of failure, the reliability and also determine when the prevention actions should be implemented, which can be training, inspections, preventive maintenance and others. The statistical study was developed using the weibull distribution, where was additionally possible to estimate the costs associated with a preventive and corrective action. The use of each of these tools followed the following order and implementation:

Identification of the external components of the system

Based on the knowledge obtained about the characteristics and way of functioning of the system and using functional analysis tools, the main components that interact with the system were identified and their criticality assessed for the operation;

Identification of the main failure modes and risks

Once the components were identified, the main failure modes and effects associated with these components were analyzed, as well as the assessment of their degree of criticality, in order to define priorities in terms of treatment developed through the implementation of a failure modes and effects analysis (FMEA);

Identification of root causes

This assessment allowed the identification of the origin of potential failure modes. It consisted in the development of a tree of failures and events (FT and ET), having been possible through the latter, to determine the probability of occurrence of possible consequences taking into account existing controls;

Evaluation of costs associated with preventive and corrective actions

Finally, weibull distribution was implemented to assess the reliability and failure rate of the process, as well as the costs associated with possible failures.

CHAPTER IV - RESULTS AND DISCUSSION

To develop the study in question, some risk management tools were selected, such as process mapping, FA, FMEA, FT, ET and statistical analysis by Weibull method. Why were these tools selected? As is known, the study was developed for a system/process, however, in order to obtain reliable results, it was necessary to know the process/system in detail, taking into account the external components that interact with it, for such a functional analysis, it is feasible to reach the objective.

Once the process components are identified through an FMEA, it is then possible to identify the main failure modes, risks and critical events associated with the components and the process. Thus, based on the identification of these events, there are conditions for using a tree of failures and events to identify the root cause of the risks and the probability of occurrence of a certain damage.

Finally, in order to avoid the materialization of these undesirable events, it is important to know the probability of failure and reliability of the process/equipment, and to determine when prevention actions should be implemented, which can be training, inspections, preventive maintenance and others. The statistical study was developed using the weibull method, through which it was additionally possible to estimate the costs associated with a preventive and corrective action.

To develop the proposed analysis, part of the data used, such as records in terms of failures, were extracted from the company's database. Other aspects such as the characteristics of the process were possible to obtain through observation and practices from the beginning to the end of the operation, as well as through questionnaires on details of the system's operation.

4.1. External components that are in interaction with the System

Data processing began with the identification of external components that interact with the system under study, which in turn made it possible to develop subsequent analyses.In this context, based in nature of the systems and the characteristics of the operational area which was under study the following external components were identify:

- Operators
- Drivers
- Trucks
- Sun rays
- Wind/storm

- Thunderstorm
- Rain
- Fuels

In order to identify the main components that interact with the system, favorable and unfavorable factors for the system under study were taken into account, that is, factors that have negative as well as positive impacts. Among the factors identified and listed above, 50% was found to favor the system and another 50% do not. That said, there was a need to identify the functions that each of these components can exert on the system. Figure 10 shows the relation between external components with the systems, and through this relation was possible to identify the different functions necessary to the desired objective.

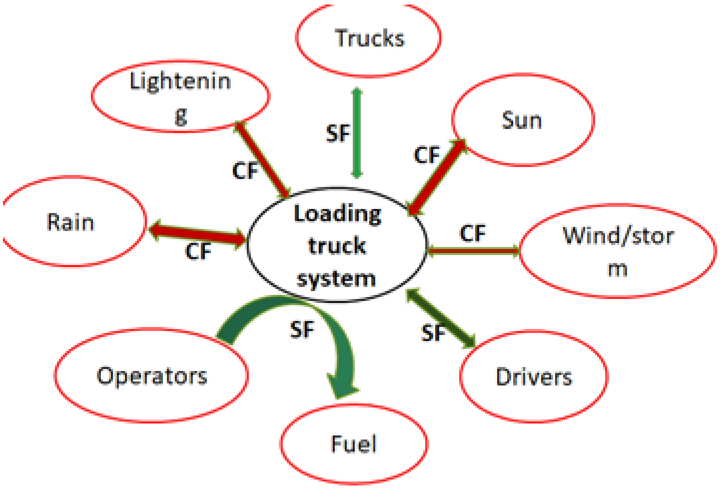


Figure 10. Relation between external components and the system.

The functions performed by the previously identified components can be of service (SF) or constraint (CF). From the analysis carried out, it turned out that the constraint factors have been mostly of environmental or natural origin, so there is no way to avoid or eliminate them, but to adopt mechanisms to control and minimize possible negative impacts arising from them.

4.1.1 List of necessary functions

Once the external components that interact with the system were identified, the functions associated with them and which exert some significant influence on the system were identified and listed from F1 to F8.

The functions performed by these components can be of service (SF) or restriction (CF), they were formulated taking into account the action they must exert on the system and impact on its operability.

F1 - The load truck system resists to the Wind/storm;

F2 - The load truck system must be manipulated by the operators;

F3 - The load truck system resists to the Rain;

F4 - The load truck system resists to the Lightening;

F5 - The load truck system must be accessible to the drivers;

F6 - The load truck system must to be in directly contact with the trucks.

F7 - The load truck system resists to the sun;

F8 - The load truck system supply the fuel.

From the analysis carried out, it was found that the constraining factors have been mostly of environmental or natural origin, so there is no way to avoid or eliminate them, but rather to adopt mechanisms to control and minimize possible negative impacts arising from them. On the other hand, the service functions identified and associated with the key components for the functioning of the system, namely operators, trucks, drivers and supply systems, are essential for the good performance of the tanker truck supply process. However, considering that risks are always present, there is also a need to monitor these components to ensure that they perform the corresponding function accordingly.

In terms of control measures adopted by the company to control the constraint functions, associated with components of natural origin, functional mechanisms were identified, such as the use of earth cables to detect possible electrical discharges from lightning and other sources, design and construction of a structure of protection against rain and sun that make possible the continuity of the operation in case of eventual storms and reduce the exposition of the gases generated during the operation of the sun, as well as the protection of the operator, thus reducing the risk of fatigue, delays in the operation and consequent loss of capital, as well as the loss of the product by vaporization.

4.1.2 Specification of the functions

After having identified the components and their respective functions, in order to group them by degree of importance, there was a need to develop a comparative study of the functions using the matrix Mudge method as shown in Table 1, where comparisons were made between the functions. To this end, randomly, the following criteria were taken for the degree of importance:

1- Functions lightly more important than other (in comparison);
2- Function for sure more important than other (in comparison); and
3- Function much more important than other (in comparison).

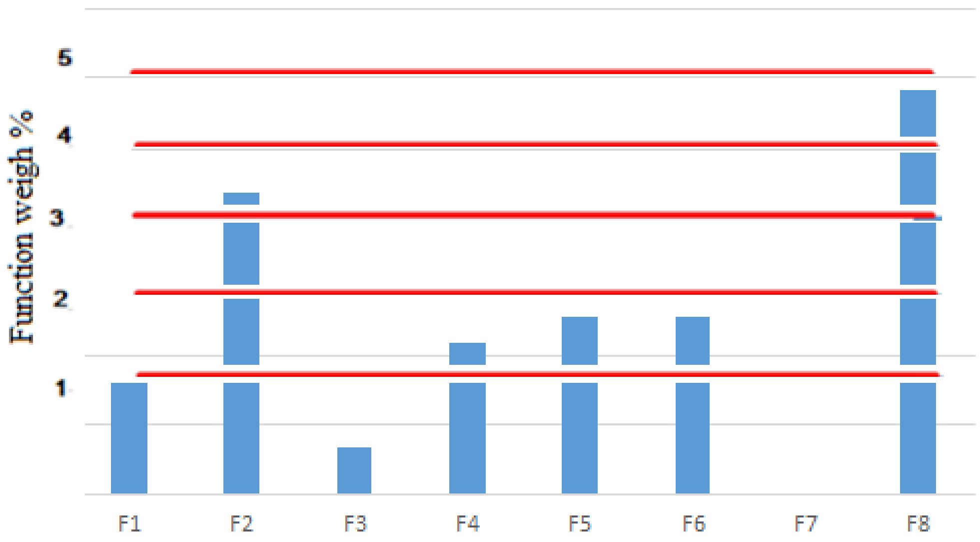
Table 1. Functions classification (Mudge matrix)

	F2	F3	F4	F5	F6	F7	F8	WEIGH	%
F1	F2 3	F1 1	F1 1	F1 2	F6 2	F1 1	F8 3	5	9.09
F2		F2 3	F2 2	F2 1	F2 1	F2 2	F8 1	12	21.81
F3			F3 1	F5 2	F6 2	F3 1	F8 3	2	3.36
F4				F4 2	F4 2	F4 2	F8 2	6	10.9
F5					F5 2	F5 3	F8 2	7	12.72
F6						F6 3	F8 2	7	12.72
F7							F8 3	0	0.00
F8								16	29.09
TOTAL								**55**	**100**

As a result of the comparison, the relative percentage of each function was obtained, an important step for specifying the degree of importance of each function in the system, functions 2 and 8 turned out to be the most important with percentages of 21.81 and 29.09%, respectively, as illustrated by the data obtained of the Mudge matrix.

Based on the weight percentage of the function, the histogram was prepared as shown in Graph 1. This was then subdivided on a scale (k) from 1 to 5 to specify the relevance of each function in the system, classified as follow :

1 - Useful; 2 – necessary; 3 – Important; 4 - Very important; 5 – Vital.



Graphic 1. Funtion percentage vs his relevance (Mudge matrix).

Considering de classification in Table 2 bellow, from the histogram, is possible to observe that the F8 and F2 present high percentage of weigh, sothere are classified by vital and very important functions for the process.

Table 2. Function criteria classification

Nr	Function	k	Criteria	Level
8	Supply the fuel	5	Supply time (hours/day)	10h/day
2	To be manipulated by the operators	5	Able to manipulate (years of experience)	≥1 years
1	Resists to the Wind/storm	3	Wind intensity (Km/h)	≥80 km/h
3	Resists to the Rain;	2	Rain intensity (mm)	≥50mm/h
4	Resists to the Lightening;	2	Height (m)	≤5m
5	Be accessible to the drivers;	1	Supply time (hours/day)	10h/day
6	be in directly contact with the truck	1	Distance (m)	≤2m

1 - Useful; 2 – necessary; 3 – Important; 4 - Very important; 5 – Vital.

4.2 Failure mode and effectsanalysis (FMEA)

FMEA is used to identify the failures associated with the main components that interact directly with the process, identify the effects that may have a direct impact on the company's performance, also enabling the definition of priority factors. To perform the FMEA (Table 3) the functions identified as the most critical for the system were selected. Based on the severity, detectability and occurrence criterias (Table 4), obtained from the company's risk management system, the risk priority number have been calculated. The results indicated failures in automatic supply cut-off systems and wrong quantity programming, as main failure modes, with priority risk number values equal to 15 and 48 respectively.

Table 3. Failure mode and effect analysis results.

Component	Function	Failure	Potential failure	Occurrence	Severity	Detection	RPN (OxSxD)
Supply platform	Supply the fuel	Pump failure	loss of flow	1	3	4	12
		Failure of automatic cutting systems	Sensor malfunction	1	5	3	15
Operators	Manipulate the system	Inputting wrong amounts	Fuel leak	4	4	3	48
		Product mix	Product contamination	1	5	2	10

The results obtained from this analysis point to the need for the company to make greater efforts to deal with the risks associated with failures in the automatic cut-off system and the introduction of quantities to supply, both related to the components of the supply system and operators.

Table 4. Risk criteria (Adpted from Petromoc Matrix, 2015).

Occurrence/ Severity		
Failure probability		Occurrence/Severity index
Low	Few Faults	1 - 2
Moderate	Occasional failures	3
High	Frequent failures	4
Very high	Persistent failures	5
Detection		
Probability		**Detection index**
Low	Few Faults	5
Moderate	Occasional failures	4
High	Frequent failures	3
Very high	Persistent failures	1 - 2

The existing control measures, namely, maintenance and training or refresher actions applied by the company need improvements in order to guarantee the achievement of the objective (minimize the risk of occurrence of the identified failures).

4.3. Top event identification and fault and event tree analysis

Considering the main failure modes identified in Table 3, as well as the reality experienced in the Petromoc company, Table 5 depicts the main events likely to occur at the level of the tanker truck loading operation, their consequences and proposed control and mitigation mechanisms.

Table 5. Risks susceptible to occur during activities and consequences.

Item	Top event	Type of risk	Consequence	Control mechanisms
1	Product leak	Accident risk	Damage to fauna and vegetation; Soil contamination; Contamination of ground water; Loss of product	Reduce equipment maintenance periods (volume sensors); Calibrate the meters develop training actions; Waterproof the area
2	Injuries	Physical risk	Death, absence from work due disability	Assign and carry out the regular replacement of protective equipment

				carry out frequent checks on the status of the infrastructures
3	Intoxication	Chemical risk	Death; Chronic respiratory disease;	converting top to bottom supply systems; raise awareness and monitor the use of protective equipment
4	Explosion/fire	Accident risk	Death; Loss of infrastructure; Pollution	Operationalization of the fire-fighting system, carrying out regular refresher and awareness-raising actions on the operation, do a circuit check before operation, do a preliminary risk analysis.

Among the top events identified, according to historical data collected from the company's database, spills and injuries have been the ones that occur most frequently, representing in its statistics about 50% of accidents that occur in an average period of 3 months. On the other hand, intoxications have occurred less frequently and mostly due to negligence in complying with internal procedures, explosions and fires have occurred less frequently and on a small scale.

In addition to the measures exposed previously (Table 5),it was necessary to develop other mechanisms such as the elaboration and availability of operational instructions, introduction of the practice of carrying out daily safety dialogues and preliminary risk analysis.

4.3.1 Fault and event tree analysis

Based on the failure modes and top events identified, an analysis of causes and probability of occurrence was developed, aiming to identify the root of the problem in question and the degree of impact of the consequences arising from them, for the more critically events.

As can be seen from Figure 11, the potential causes are related to the maintenance issues, training and failures in some equipment. In this way, through the event tree and based on existing controls, potential consequences were identified, as well as their probability of materializing and causing damage to the process. The main and critical consequences are:

- Operation stop/delay;
- Contamination of soil and air;
- Intoxication; and
- Fires.

However, considering the existing controls, if there is a failure in the primary controls (replacement pump and spill containment systems), whose failure probabilities are around 15% as shown in Figure 11, there is a high probability of occurrence of damages such as contamination and stoppage in operations. Therefore, there is a need to guarantee the reliability of secondary and third-party controls by aligning prevention actions, such as develop regular equipment maintenance, do a circuit check before operation, and training operators. It is also important to note that the 15% probability of failure should not be ignored, as they also constitute a risk to the process.

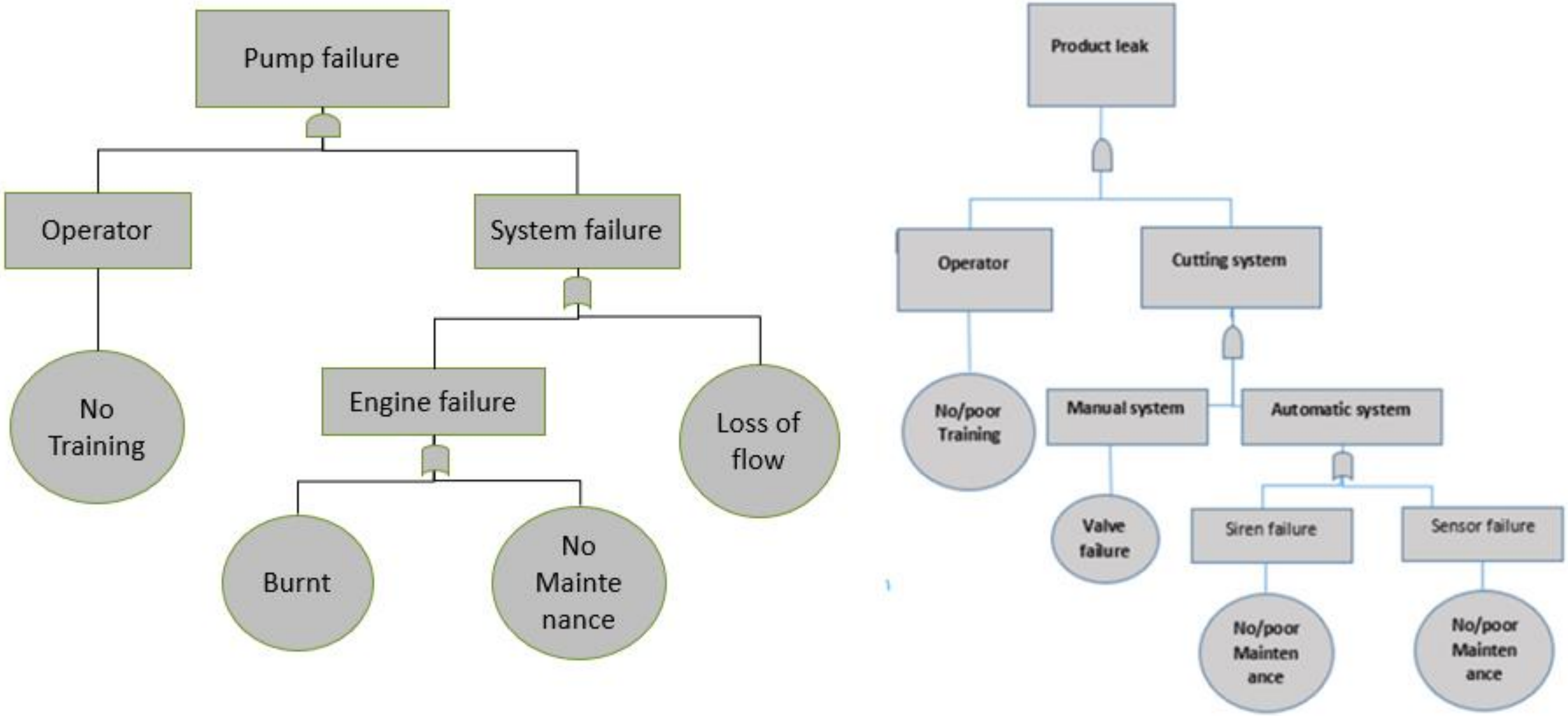


Figure 11. Failure and event tree analysis.

4.4 Weibull Distribution

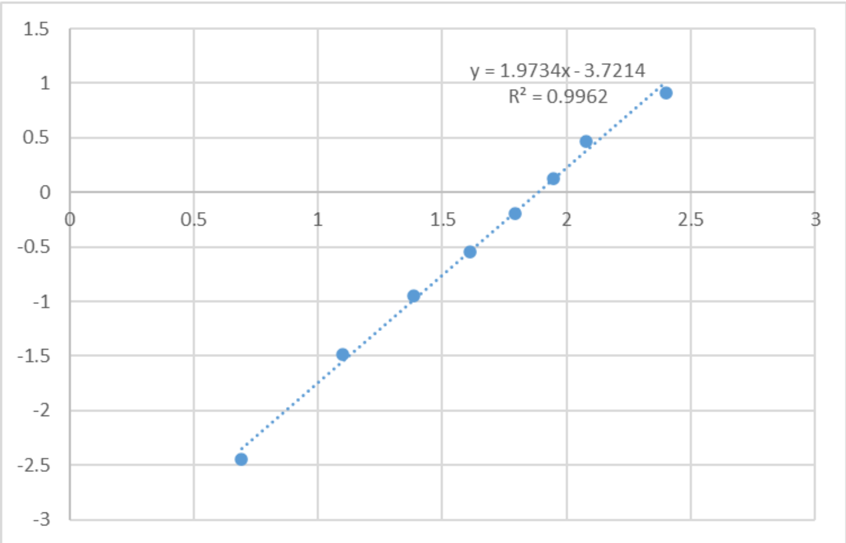
To develop the analysis of the data using a weibull distribution, data on failures registered in a certain period (see Table 6) stipulated in months were collected.

Table 6. Data collected from September 2021 to January 2022

Nr	Failure time (Months)	Type of failures
1	2	Sensor failure
2	3	Pump failure
3	4	Wrong quantities
4	5	Sensor failure
5	6	Wrong quantities
6	7	Filling arm breakage
7	8	Wrong quantities
8	11	Pump failure

The main objective of this analysis was to determine the probability of failure of the process and its reliability, so that was possible to determine the average time between failures, and thus define the optimal periods for preventive intervention both in terms of maintenance as well as training according to the underlying causes previously defined.

To start the analysis, was vitally important to obtain data from the parameters β, called the scale parameter, controls the dimensions that the curve assumes, given a constant shape, η designated position parameter, as it controls the position of the curve on the abscissa axis, which can be obtained through a linear regression equation according to Graphic 2, that represents the range of time in which failures occurred.



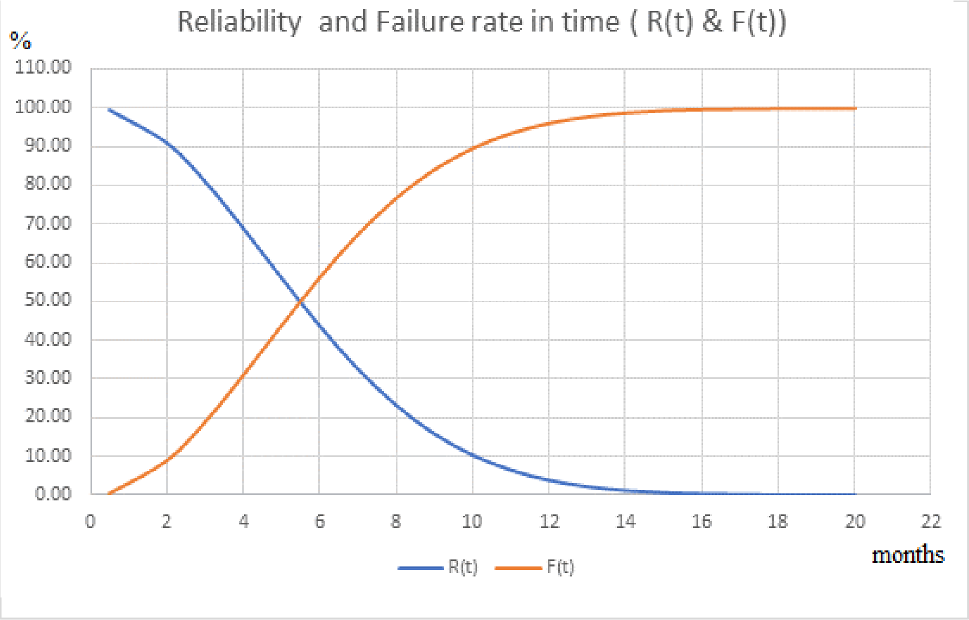
Graphic 2. Linear Regression Graph

Table 7. Calculated Weibull Parameters

β	1.973353059
a	-3.72
η	6.60828968
S (standard deviation)	0.469004951
Media	5.75
Mean time between failures	
MTBF	**5.75**

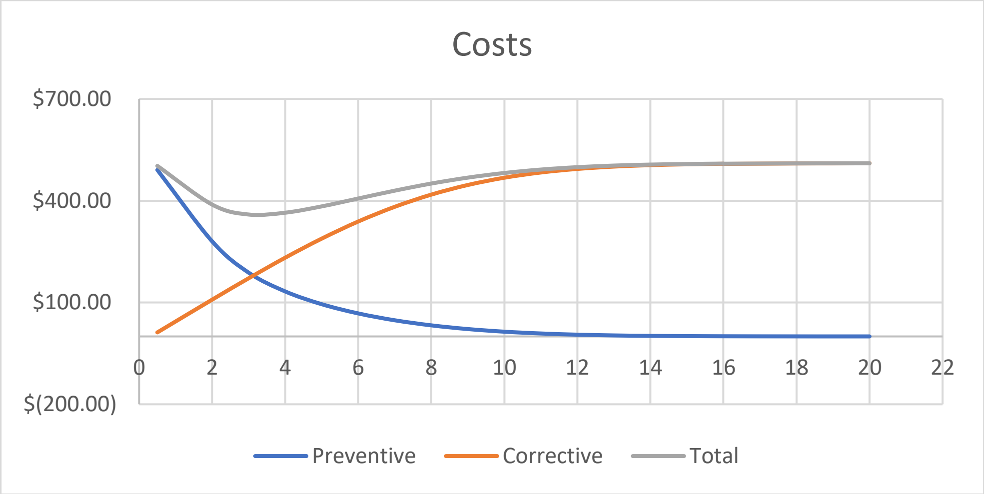
The Mean time between failures (MTBF) was calculated taking into account the total number of hours worked and the total number of failures recorded in that period. Based on the previously calculated β and η values, the reliability and failure rate associated with the process were calculated and graphed as shown in Graph 3.

As can be seen in the Graph 3, the reliability of the process tends to drop very quickly and consequently there is an exponential increase in the failure rate, which is inconvenient for the process. In an optimal situation, the reliability of a process or equipment must remain constant for a longer time when compared to the failure rate that is, it is not convenient to have a reliability rate lower than or equal to the failure rate. This fact may indicate a defect in the equipment or process or even failures in the programming.



Graphic 3. Reliability and failure rate.

Graph 4 depicts the preventive and corrective costs. As can be seen from that, at the beginning of the process, maintenance/preventive action costs tend to be higher, as it is a beginning where resources are allocated preventively to guarantee the good performance of the process. However, with the passing of the months this cost tends to reduce significantly, consequently registering a drastic increase in the costs of corrective maintenance.



Graphic 4. Preventive and corrective costs

This fact may mean some need for improvement in the preventive plan, which may be, the anticipation of maintenance, taking into account that the company carries out maintenance once every 6 months, increasing the frequency of carrying out training actions, carrying out inspections more frequently.

What would be the ideal period to carry out these actions?

The reliability and total cost graphs show an optimal reliability index and low total cost at around 3 months. On the other hand, the calculated MTBF is 5.7 months, so the interventions must take place before this period, associated with the minimum total cost factor, reliability and failure rate, the company may consider reducing the intervention periods.

The results presented here clearly reflect that, in addition to allowing an accurate identification of risks, the techniques proposed here make it possible in a quantitative way to obtain the real weight of the risks, so, that it is possible to define priorities in the execution of the action plan. These tools also made it possible to identify some mistakes made by the company in the management of its processes, such as the significantly long periods of maintenance and awareness actions, focus on actions with low impact on the causes of risks.

Another aspect to emphasize is the superficiality with which the company carries out the identification of the causes, a fact that contributes to the misidentification of mitigation actions, as the results exposed previously illustrate, the methodology proposed here (FMEA) allowed to carry out an identification of more enhanced causes.

Another aspect of vital importance to emphasize here is the fact that the company does not consider the registration and analysis of undesirable events and the respective costs involved as vitally important data for the analysis of the risks associated with the operations and mathematical definition of the reliability and failure rate of the processes and equipment. Therefore, the results presented here show how important these data are to feed the risk assessment and reduce the costs of corrective maintenance, increase the useful life of equipment, reduce constant stoppages in operations with less damage to the company.

CHAPTER V – GENERAL CONCLUSIONS AND RECOMMANDATIONS

5.1 Conclusions

As a result of the research carried out, it was found that the company presents a significant fragility in terms of risk assessment, considering that it is based only on opinions. This factor makes it impossible to identify the real causes and consequently the prevention and mitigation actions taken are ineffective, hence there are multiple cases of recurrence of unwanted events.

Among the main events and/or recurring risks identified are leaks, fires, equipment failures such as pumps, filters and meters. These events cause consequences such as contamination of soil, water courses and air with impacts on fauna and vegetation, delay in operations, financial losses, damage to the health of employees and damage to the company's reputation.

The functional and cause analysis revealed that the main components of the process, which in turn constitute the main source of failures, are the operators and the supply system, which have presented failures related to the wrong insertion of the quantities to be supplied, failures in the automatic cut-off system, non-compliance with procedures, failures in equipment such as pumps and meters, the main causes being the lack of training and poor maintenance schedule.

When evaluating the existing controls, it was concluded that the primary controls (spill containment systems and replacement pumps) present a 15% probability of failure, a fact that needs attention when it comes to risks. It was also found that, with failure of primary controls, the probability of secondary and third-party controls inhibiting the materialization of the risk and its consequences is extremely low, around 4 to 5%.

From the analysis of the performance of the process regarding reliability and failure rate, it was found that the company has high costs of corrective maintenance, which contributes to the reduction of profits, due to the high costs of corrective actions as well as the interruption of operations.

The calculated MTBF is 5.75 months, when compared to the period of preventive interventions that varies from once every 6 months to once a year adopted by the company, justifies the accelerated growth of the failure rate and reduction of reliability, as well as the high costs of corrective maintenance.

The results presented in this study are consistent with the expected for the application of the methodology proposed in this dissertation. Risk management techniques proved to be quite adequate to deal with the problem in question, in this case, the fragility that the company presents for the identification and treatment of the risks associated with the operations.

5.2 Recommandations

Based on the conclusions resulting from the research carried out, in order to improve the performance of the process, reduce losses and other factors that negatively impact the business, it is recommended that the company *Petroleos de Moçambique* consider implementing the following actions:

- Carrying out the identification of risks based on other criteria, such as individual process or product components;
- Catalog the different types of failure modes and the periods in which they are recorded;
- Determine the costs involved in preventive and corrective actions, taking into account the type of failure mode recorded;
- Improve the maintenance plans and preventive actions considering among others the criteria of reliability, failure rate and MTBF;
- Review the frequency of carrying out maintenance and training and inspection actions;
- Carry out risk analysis for the top loading supply system on all sites where the company is represented;
- Expand the practice to all other segments of the company;
- Include in the contract and in the evaluation of the performance of the carriers the obligation to comply with the requirements that may compromise the safety of the process.

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ANNEXES

Annex I. Company cost estimative for corrective and preventive maintenance/action.

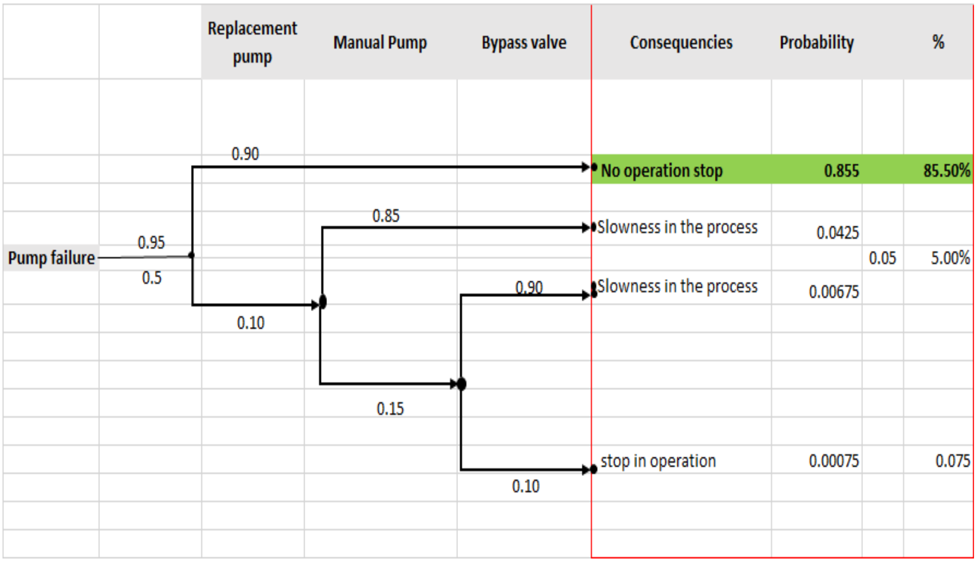
Maintenance cost/corrective acction

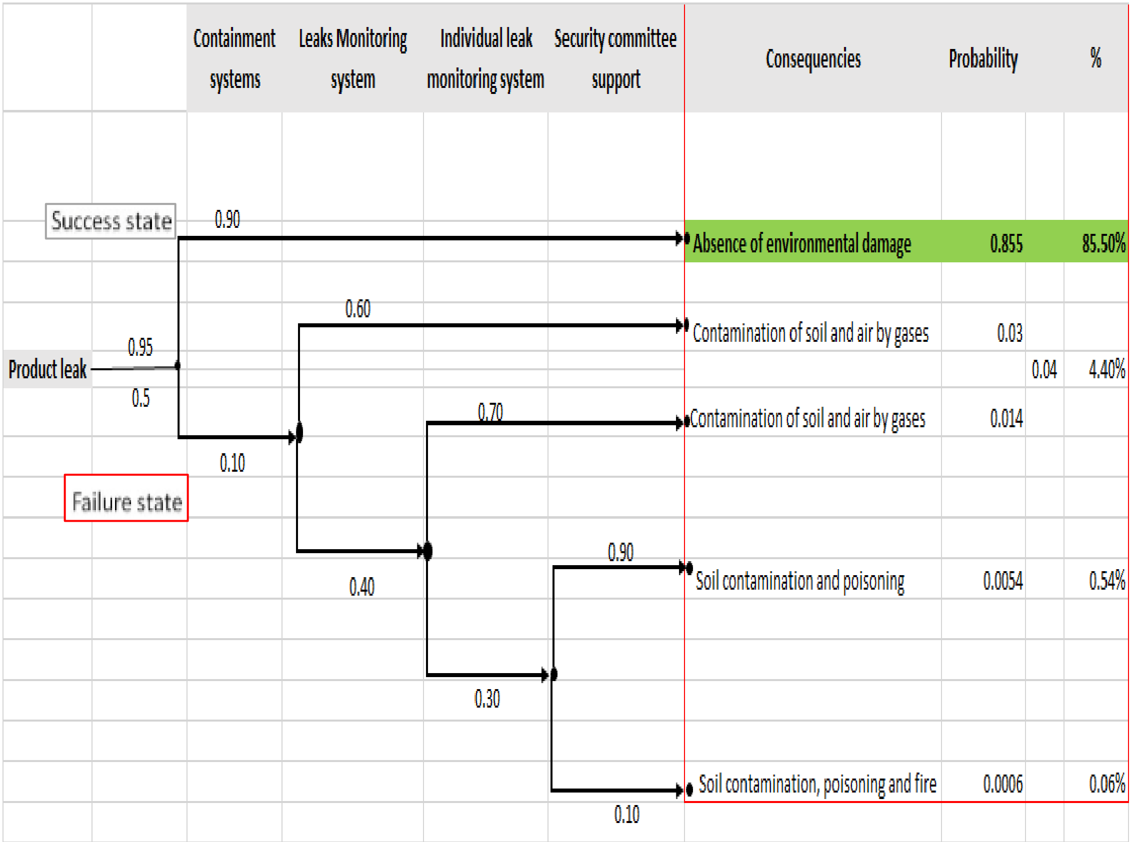
Manpower	$138.00
Product	$92.30
Repair costs	$373.13
Operation downtime costs per hour	$1,230.00
Training	$895.52
Total	$2,728.95

Maintenance cost/preventive acction

Manpower	$70.00
Product	-
Repair costs	$55.00
Operation downtime costs per hour	$500.00
Training	$80.00
Total	$705.00

Annex II – Event tree map





Annex III. Failure rate, reliability, corrective and preventive costs

T(months)	R(t)	F(t)	MC	integral	Preventive cost	Corrective cost	Total
0.5	99.38	0.62	142.73	142.73	$490.90	$11.82	$502.72
2	90.92	9.08	85.93	228.65	$280.33	$108.35	$388.69
3	80.93	19.07	74.90	303.56	$187.96	$171.42	$359.38
4	68.88	31.12	62.47	366.03	$132.66	$232.06	$364.72
5	56.06	43.94	49.86	415.89	$95.03	$288.32	$383.35
6	43.66	56.34	38.10	453.98	$67.80	$338.69	$406.49
7	32.53	67.47	27.87	481.85	$47.60	$382.10	$429.70
8	23.21	76.79	19.53	501.38	$32.63	$417.99	$450.62
9	15.85	84.15	13.10	514.48	$21.71	$446.39	$468.10
10	10.36	89.64	8.42	522.90	$13.97	$467.83	$481.80
11	6.49	93.51	5.19	528.09	$8.66	$483.25	$491.91
12	3.89	96.11	3.06	531.15	$5.16	$493.81	$498.97
13	2.23	97.77	1.73	532.88	$2.95	$500.68	$503.64
14	1.23	98.77	0.94	533.82	$1.62	$504.94	$506.56
15	0.65	99.35	0.49	534.31	$0.85	$507.45	$508.30
16	0.33	99.67	0.00	534.31	$0.43	$509.09	$509.52
16	0.33	99.67	0.40	534.71	$0.43	$508.70	$509.14
18	0.07	99.93	0.05	534.76	$0.10	$509.95	$510.04
19	0.03	99.97	0.02	534.78	$0.04	$510.13	$510.18
20	0.01	99.99	-0.14	534.64	$0.02	$510.36	$510.38

Annex IV. Questionnaire for interview

Questionnaire for interview related to tanker truck loading operation and risk management at Petróleos de Moçambique

Study area: Supply of tanker trucks of the Mozambique Oil Company (Petromoc) – Matola Lingamo

Sample number: 17

Target audience: 6 Truck loading operators;

2 Health, safety and environment managers;

1 Maintenance manager;

2 Operations supervisors.

3 Health, safety and environment officers

3 Maintenance technicians	
1	What is the name of the process in which the process loading operation is inserted?
2	Is there a systematic record of breakdowns and other undesirable events?
3	How many operators do you work in the tank truck loading section?
4	Is the work carried out in shifts or in a single period?
5	What are the steps that make up the process?
6	what are the most critical activities for the process?
7	what are the existing supply systems and how do they work?
8	What is the working principle of the supply platform?
9	What are the main undesirable events that have occurred?
10	Is there a functional spill containment system?
11	Are workers aware of how to act and their responsibilities in the event of accidents/incidents?
12	what is the average response time in the event of a breakdown in operations?
13	Is there an operational firefighting system? How often are maintenance performed?
14	How often is equipment maintenance performed?
15	How often is risk identification and monitoring carried out?
16	Have workers benefited from training in safety and the environment? how often?
17	Is there an in-house maintenance team?
18	what are the main types of faults recorded?
19	what is the average age of the equipment in us in the tanker truck loading operation?
20	how often are refresher training performed?

21	Are workers aware of the risks associated with operations?
22	Is there a risk identification and treatment mechanism?
23	Do workers have mastery of such mechanisms?
24	What have been the costs of corrective and preventive maintenance?
25	Is there a mechanism for monitoring the costs of preventive and corrective maintenance?
26	Has the training and training been carried out internally or by contracting? what has been the cost?
27	What are the criteria used for risk assessment?
28	what are the main activities carried out by the company within the scope of the HSE
29	Is there a health, safety and environment policy?
30	how many hours a day does the supply platform work?