UNIVERSIDADE EDUARDO MONDLANE

FACULTY OF ENGINEERING

MASTER'S IN HEALTH, SAFETY, AND ENVIRONMENT

MASTER'S THESIS

OCCUPATIONAL HEALTH AND SAFETY RISK ASSESSMENT IN WAREHOUSE OPERATIONS: THE CASE STUDY OF MANUFACTURING COMPANY

By

Dirce Flora Feliciano Dembele

Maputo, March 2023

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Dirce Flora Feliciano Dembele

Supervisors:

Orlando Zacarias, PhD

Raed Kouta, PhD

Maputo, March 2023

AUTHENTICITY STATEMENT

This is to certify that to the best of my knowledge; the content of this thesis is my work. This dissertation has never been presented for the attainment of any degree or any other or other purposes.

I certify that the intellectual content of this thesis is the product of my work and that all assistant received in preparing this thesis has been acknowledged and consulted bibliographic sources are cited and referenced accordingly.

Maputo, March 2023

The author

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(Dirce Flora Feliciano Dembele)

ACKNOWLEDGEMENT

I thank first and foremost the Almighty God for the gift of life.

To my supervisors Prof. Orlando Zacarias and Prof. Raed Kouta for their guidance, availability, incentive, and contribution to the enrichment of this work through their suggestions and criticism.

A special thanks to Company A for the internship opportunity granted to me that culminates with this report. To the employees of Company A, especially the team of the HSE department for their support and sharing of experiences during the internship period.

To Master Lucas Tamele, my godfather and academic tutor for the accompaniment and monitoring throughout my training

To my parents Feliciano Faduco Dembele (in memory) and Glória Maluzane Dembele for the invaluable investment in my education, backing, understanding, and support at all moments. To my brother and partner Chaca Mafuiane for encouraging my projects and for all the support given to make this training process as pleasant as possible.

To all the teachers of the Master in Health, Safety and Environment program for the cordial way in which they transmitted the knowledge in their disciplines, and for the advice and encouragement in academic life.

I dedicate this work to my nephews Enzo, Lennon and Noah Liquela, and Sasha Foloco so that it may serve as an incentive in the constant search for knowledge and academic experiences.

ABSTRACT

This study relates to the analysis and assessment of risk (RAA) of a warehouse in a cigarette manufacturing company. Two risk analysis and assessment tools were applied to conduct the study. The first, "broadband", was the Failure Mode and Effects and Criticality Analysis (FMECA) methodology, covering occupational risk, more specifically the risks inherent to the tasks of loading and unloading products, quality control and operations, including the risk intrinsic to the equipment and facilities. Afterward, the Fault Tree Analysis (FTA) was applied, for a more specific analysis of the operation risk, thus complementing the deviation analysis methodology. The application of both methodologies proved to be essential, for the identification of a larger number of risks. The results obtained made it possible to identify the hazards and dangerous situations that present the greatest risk to the workers and manufacturing premises. Concerning risk during loading and unloading operations, it was verified that the situations with the highest risk for the operators are the use of forklifts, pallet jacks, and handling of goods. Whereas in the area of operations in the warehouse, we found falling objects, inhalation of substances from hot glues, and the possibility of risk of fire as the riskiest issues. On the other hand, during product quality control operations, the risks with the highest index are falling to different levels, asphyxiation, and a drop in concentration due to working in places with high temperatures (thermal stress). The quantitative analysis of the fault tree points to 0.5 and 0.27 frequency of occurrence of an accident during loading/unloading procedures and quality control processes. The linear regression analysis showed that Temperature variation is a parameter that determines the presence of beetles in the FGW of the Company. Therefore, the temperature should be more controlled during the storing of goods in the warehouse to avoid the growth of beetles and consequently health issues. For the implementation of some of the safety measures a cost-benefit analysis may be required. As a result of the application of the 5W1H preventive measures method, it can be concluded that some of the suggested recommendations entail an excessively large investment for the benefit they bring.

Keywords: FMECA; FTA; 5W1H; Risk analysis; Occupational Risk, Finished Good Warehouse.

RESUMO

Este trabalho teve como objetivo a realização de uma análise e avaliação de riscos (AAR) de um armazém robotizado na empresa de produção de cigarros, para a qual esta avaliação era sentida como uma necessidade urgente. Para a realização do estudo foram aplicadas duas ferramentas de análise e avaliação de riscos. A primeira, de "banda larga", foi a metodologia checklist, isto é, abrangendo a vertente de risco ocupacional, mais especificamente os riscos inerentes às tarefas de carga e descarga de produtos, controlo de qualidade e operações, ou seja, o risco intrínseco aos equipamentos e instalações. Posteriormente foi aplicado a metodologia FMECA, para uma análise mais específica ao risco de operação, e deste modo complementar a metodologia de análise dos desvios. A aplicação das duas metodologias revelou-se essencial, para identificação de um maior número de riscos. Os resultados obtidos permitiram identificar os perigos e situações perigosas que apresentam maior risco para o trabalhador e para a instalação. Na vertente do risco durante as operações de carga e descarga, verificou-se que as situações com risco mais elevado para os operadores, são a utilização de empilhadores, porta-paletes e manuseio de bens. Na vertente de operações no armazém, foram a queda de objectos, inalação de substâncias provenientes das colas a quente e risco de incêndio. Por outro lado, durante as operações de controlo de qualidade dos produtos, os riscos com maior índice são a queda em diferente nível, a asfixia e a queda de concentração devido a trabalho em locais com elevadas temperaturas (stress térmico). A análise quantitativa da árvore de falhas aponta para 0.5 e 0.27 frequência de ocorrência de acidente durante os procedimentos de carga/descarga e o processo de controlo de qualidade. A análise de regressão linear mostrou que a variação de temperatura é parâmetro que determina a presença de bichos de fumo no FGW da Empresa, portanto, a temperatura deve ser mais controlada durante o armazenamento de mercadorias no armazém para evitar o crescimento de bichos de fumo e consequentemente problemas de saúde. Para a implementação de algumas das medidas de segurança, é necessária uma análise custo-benefício. Como resultado da aplicação do método do plano de acção 5W1H, pode concluir-se que algumas das recomendações sugeridas implicam um investimento excessivamente grande para o benefício que trazem.

Palavra-chave: FMECA; FTA; 5W1H; Análise de risco; Risco Ocupacional, Armazém de Produto Acabado.

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LIST OF SYMBOLS AND ABBREVIATIONS

ABS – American Bureau of shipping

ANOVA – Analysis of variance

C– Cost and technical complexity

cF – Constrains Functions

CPE – collective protection equipment

CREA –Clinical Risk and Error Analysis

DMRA –Decision Matrix Risk-Assessment

EF_H – Exposure/frequency

EI – Extent of the impact

ES – Elementary System

FGW – Finished Good Warehouse

FIFO – First in First Out

FMEA– Failure Modes and Effect Analysis

FMECA – Failure mode, effects, and criticality analysis

FTA – Fault Tree Analysis

HAZOP – Hazard and operability study

HSE – Health Safety and Environment

ILO – International Labor Organization

IoDSA – Institute of Directors in Southern Africa

ISO – International Organization for Standardization

LH – Hazard Level

MSDS – Material Safety Data Sheet

OHS – Occupational Safety and Health

OSHA – Occupational Safety and Health Administration

PC –Performance of prevention and control systems

PPE – Personal Protective Equipment

PRAT –Proportional Risk-Assessment

QADS –Quantitative Assessment of Domino Scenarios

QH – Quantification of the hazard

QRA –Quantitative Risk-Assessment

QRMSR –Quantitative Risk Measures of Societal Risk

RPN – Risk Priority Number

SCRM – Supply Chain Risk Management

S – Severity

sF – Service Functions

SPSS – Statistical Package for the Social Sciences

STEP–Sequentially Timed Event Plotting

WRA –Weighted Risk Analysis

CHAPTER I: INTRODUCTION

1.1. Context

In today's world, the increasing prevalence of risk in most industrial activities is a major characteristic of the rapidly expanding business, stimulated by massive technological change, innovation, global competition, and communication technologies (Nazam *et al*., 2015; Wang *et al*., 2014).

Warehouse procedures in the production industry are among the most hazardous processes and need a comprehensive and simple-to-administer tool to continuously assess and promote their health and safety performance. According to the International Labor Organization (ILO), annually over one million work-related deaths and hundreds of millions of workers suffer from workplace accidents and occupational exposure to hazardous substances worldwide.

Working at a height, using different types of machines and equipment, dermal and inhalation exposure to different hazardous materials, inappropriate practices, awkward postures, employing workers from other countries with different languages and cultures, and the variable nature of working conditions pose many unacceptable risks to all in the workplace, including workers, engineers, managers, and so on (Mahmoudi *et al*., 2014).

Moreover, studies conducted by (Wang *et al*., 2006) have revealed that a lack of attention to occupational safety and health (OHS) issues results in irreversible costs, including costs associated with workplace accidents, reworking, delays, and loss of reputation of the organization. Additionally, in production industries, one must consider environmental risks such as improper chemical waste disposal, air and water pollution, and soil contamination.

Risk assessments are a tool that can be adapted to all manufacturing settings and provide a structured approach to identify and control hazards before incidents occur. The use of risk assessment is essentially the first step to finding root causes, taking corrective action, and training employees before near-misses or accidents occur. A risk assessment is a process of determining potential workplace safety, health, and environmental hazards through collected information or workplace inspections, investigating incidents, and implementing controls for the hazards, prioritizing the most severe hazards first. After controls are in place, the hazards can then be reevaluated to estimate whether additional controls would be beneficial(Antunes, 2009).

Several methods of evaluating occupational risks and environmental risks are applied, however, in this work were chosen the failure modes, effects, and criticality analysis (FMECA) method was combined with the Fault Tree Analysis (FTA) method for the identification and quantification of deviations for being, a simple, and affordable methodology, but with a planned and systematic character.

The present work was carried out at cigarette manufacturing in Mozambique, however, the name of the company will not be revealed due to confidentiality issues, hereinafter, the company will be designated as Company A.

This research study was conducted specifically in the warehouse of company A, where daily loading and unloading of raw materials and finished products from different types of commercial vehicles takes place. In this assessment of risks and environmental impacts, it is intended to evaluate the risks to which operators are subject in the act of their duties, deciding subsequently which are the individual protection equipment (PPE) and collective protection equipment (CPE) indicated, to minimize or eliminate the damage to the worker and the impact on the environment as a result of the work carried out in the warehouse.

1.2. Objectives

1.2.1. General objectives

To evaluate occupational health and safety risk assessment in warehouse operations.

1.2.2. Specific objectives

- ✓ To identify and characterize the occupational hazards in the finished product warehouse using the FMECA method;
- ✓ To make a qualitative and quantitative analysis of risks in the warehouse operations using FTA probabilistic study;
- ✓ To analyze the effect of temperature and humidity on the occupational health of workers in the warehouse system.
- ✓ To propose preventive measures to reduce the probability of occurrence of the identified risks in company A warehouse.

1.3. Research questions

i. What type of identified hazards in the warehouse operations present a high-risk probability index of occurrence?

ii. Which of the various root causes analyzed in the failure trees of the warehouse operations most influence the occurrence of the feared event?

iii. Which physical factors influence the proliferation of tobacco beetles in storage?

1.4. Hypotheses

i. The highest RPNs of the identified hazards in the warehouse operations are related to the unloading and loading activities of the finished product.

ii. The failure tree analysis shows in its critical path that the root causes that most influence the occurrence of the feared event is related to the poor/non-use of EPC and CPE.

iii. The effects of temperature and humidity in the warehouse are not conducive to the emergence of tobacco beetles.

1.5. Study relevance

Along with rapid industrial development experienced worldwide, especially in African countries such as Mozambique, the logistics sector has developed rapidly to accommodate the demand for products in the market. However, the activities in a warehouse have a high physical load and a high rate of repetitiveness. During the processes of unloading, storage, and distribution employees are exposed to a multitude of risks caused by human or technology errors, and identifying such risks is not a simple task for companies.

At present, in Mozambique manufacture companies, the assessment methods of the warehouse risks aren't enough. With the development of society and science and technology, risk problems are becoming the problem that people must face. Therefore, the author considered it opportune to reconcile the knowledge of the qualitative and quantitative risk assessment technique acquired in the master's degree with skills acquired during the professional internship to contribute to the knowledge of occupational health and safety risks taking the warehouse operations of a manufacturing company in Mozambique.

This study aims to identify and analyze risk factors in production warehouses and storage facilities using two methods: FMECA and FTA methods. The resulting findings of this research will provide the basis for defining preventive mechanisms for risks occurring in the process of receiving, storage, and distribution of goods in a warehouse.

1.4. Dissertation Structure

This thesis is structured into six chapters, which are briefly described below.

Chapter I: the first chapter is the introduction of the work, the general framework of the work, the objectives, and the relevance or motivation of the research;

Chapter II: presents a summary review of the literature oriented toward the most relevant aspects. It is structured in three parts, the key concepts, warehouses, and risk analysis and assessment methodologies.

Chapter III: a brief characterization of the host company and the studied installation (warehouse) is presented.

Chapter IV: presents and discusses the results of the application of the two methodologies, FMECA and FTA, described in chapter 3.

Chapter V: lastly, the fifth chapter presents the most relevant conclusions of the study.

CHAPTER II: LITERATURE REVIEW

2.1. Legal and regulatory framework

2.1.1. In Mozambique

In Mozambique, the legal situation regarding health and safety at work is guided by Law No. 62/2003 of 4 December approved by the council of ministers. This regulation establishes the new legal regime for occupational accidents and diseases (Nhantumbo *et al*., 2017).

This regulation aims to update, consolidate and adapt the ways of providing social protection to workers and/or their families in the event of an accident at work and occupational disease. The Regulation applies to all national and foreign employees, and also to directors, managers or equivalent. Civil servants are excluded from its application. For Civil servants and state agents, health and safety at work are guided by Decree No. 14/2018 of 28 March.

In light of chapter 11 no. 9 of Decree No. 62/2003, "any accident occurring at the place and time of work, producing bodily injury, functional disturbance or illness resulting in a reduction in working or earning capacity, or death." It also includes in the definition of a work accident, any accident occurring on the route normally used and during the uninterrupted period normally spent going to and returning from the place of residence to the workplace.

Employers are responsible for creating and developing appropriate means. to protect the physical and mental integrity of employees and continuous improvement working conditions. Employers are also required to take all adequate precautions to ensure that all jobs and means of access and exit to work are safe and free from risks to the safety and health of the workers. (art. 59 and 216 of Law no. 23/2007, of August 1, 2007). Likewise, the Labor Law requires employers to provide equipment for protection and adequate work clothing to prevent the risk of accidents or harmful effects on the health of workers and instructs them on compliance with occupational health and safety standards. (art. 216; points 2 and 5).

The Legislative Diploma No. 48/73, of 5 July, approves the General Regulation of OHS in industrial establishments. This legal diploma constitutes the framework of applicable rules in all sectors of industry, to prevent professional risks in the industrial branch of the country. It has 162 articles, which are summarized in terms of the content of its standards, in the following:

- ✓ Delimits its scope of application in all industrial establishments (Articles 1 and 2);
- ✓ Duty of employers and workers to comply with HSE standards (Articles 3 and 4);
- ✓ Forecast of professional risk prevention measures in industrial building designs, building surfaces, lighting, ventilation, temperature, humidity, noise, radiation, electricity, storage, and fire extinguishers (Article 5 to 45);
- ✓ Forecast of risk prevention measures in the use of machines, in activities repair and maintenance of metal projection machines (Article 45 to 68);

2.1.2. International conventions and protocols

The unfair and deplorable conditions of the working and living circumstances of workers caused that in June 1919 and during the Industrial Revolution it was created in Versailles, by the Peace Conference, the International Labor Organization (ILO). The Treaty of Versailles, which in its XIII parts created the ILO, is an international document prepared by the nations that were victorious in World War I (1914-1918), to promote peace, and social justice and enunciate the improvement of labor relations based on principles that would govern international labor law (Nhantumbo *et al*., 2017).

The OSHAS 18001 standard, in its 2007 version, defines this concept as the set of "conditions and factors that affect or may affect, the safety and health of employees and other workers, including subcontracted workers and personnel, visitors and any other person in the workplace. In this way, HSE must be taken into consideration in all and any organization, regardless of the area of activity in which it operates and its size. All activities related to this practice should be seen in a company as an investment and not as a risk since if there is good management, control, and proper training, it is the right way to have a healthy workplace.

Regarding health and safety and the environment, some protocols ratified by Mozambique are:

- ✓ The Labour Inspection Convention, 1947 (No. 81);
- ✓ Convention No. 18: On compensation for occupational diseases adopted by the ILO Conference in 1935;

- ✓ No. 87: Convention on Freedom of Association and Protection of the Right to Organize, 1948 - guarantees all workers and employers the right, without prior authorization, to form organizations of their choice and to join them and establish a set of guarantees for the free functioning of these organizations without interference from public authorities;
- ✓ No. 98: Convention on the Right to Organize and Collective Bargaining, 1949 - which provides for protection against acts of anti-union discrimination and protection of workers' and employers' organizations against acts of interference by one another, as well as measures to promote collective bargaining;
- ✓ No. 138: Convention on Minimum Age for Employment, 1973 – aims at the abolition of child labor, stipulating that the minimum age for admission to employment cannot be lower than the age for completing compulsory education;
- ✓ No. 182: Convention on Worst Forms of Child Labor, 1999 - calls for immediate and effective measures to ensure the prohibition and elimination of the worst forms of child labor, including slavery and similar practices, forced recruitment of children with a view to their use in armed conflicts, the use of children for prostitution, the production of pornographic material and any illegal activity, as well as work that is likely to harm the health, safety or morality of children;
- ✓ The Rio Declaration on Environment and Development;
- ✓ The Estocolmo convection about persistent organic pollutants in 2005;

2.2. Defining Risk

The Institute of Directors in Southern Africa (Io DSA, 2016) defines risk in three parts, namely “uncertainty of events”, “the likelihood of a such event occurring”, and their “effects both positive and negative”. The International Organization for Standardization (ISO) 31000:2018 defines risk as an effect of uncertainty on objectives (ISO, 2018). As claimed by Berg (2010), the prominent concept in all definitions of risk is the uncertainty of outcomes. In line with Duong (2013), uncertainty is a much broader term, while the risk is just part of the uncertainty.

Risk, therefore, should be a term used to describe cases of known probability, for example, a store can calculate the probabilities that the cashier might mistakenly check an order per every certain number of customers. Hence, the store account might lose some balance (Duong, 2013).

Whereas, uncertainty can be viewed as the chance occurrence of some event where the probability distribution is genuinely not known (Dusane & Bhangale, 2014) Some people confuse the term risk with hazard. The latter can be defined as the source or situation with the potential for harm, in terms of injury or damage to the human body or damage to health, property, the workplace environment, or a combination environment, or a combination of these (Coutinho, 2014).

2.3. Hazard identification, risk assessment, and control

According to Coutinho (2014), risks arise not only from exposure to danger but also from risk factors. Although the concepts of Hazard and Risk are well defined by several authors, one always makes the mistake of confusing both. Thus, it should be noted that the hazard/risk factor results from the identification of all the elements that may exist in the workplace with the ability to cause damage to people, property, or the environment. In risk assessment, the analysts often attempt to answer questions such as "What can go wrong?"; "What is the likelihood that it would go wrong?"; and "What are the consequences?"(Dadpouri & Nunna, 2011).

The identification of hazards/risks should therefore be carried out for all workers and elements of the environment exposed to the hazard. It is also important to take into consideration, that when starting an evaluation process, information should be collected related to the reactive evaluation data (cause, frequency, and severity of accidents, incidents, occupational diseases arising from the activity, equipment, and substances) (Indrawati *et al*., 2018). Risk assessment consists of the process of detecting, identifying, and quantifying the risks to the health and safety of workers arising from the circumstances in which the hazard manifests itself in the workplace (Dolgui & Ivanov, 2022; Msomi, 2018; Rout & Sikdar, 2017).

As stated by Hanafiah *et al*. (2022), risk assessment is a cycle, that uses an approach for assessing hazards, as characterized by the likelihood and recurrence of an event of a perilous function, exposure of people and property to the hazard, and consequences of that exposure. For organizations to invest in a continuous improvement of the Safety and Health of workers, it is essential that the organization has a correct identification and assessment of risks and that the workers have a correct perception of the risk. Thus, it seems pertinent that the employer and the workers themselves are involved in the process of identification and risk assessment because it is through the involvement of all, that greater and better development of a culture of prevention and safety is possible, e.g., of a shared responsibility before the risk (Kulińska & Giera, 2019; Nazam *et al*., 2015).

It is fundamental to have the notion that hazards, when not eliminated, become risks because they will subsist in the real work context in situations of potential intersection with the worker (Coutinho, 2014). Furthermore, risk assessment aims to anticipate risks. Then, in the case of negative risks, it aims to prevent them from eventuating or to minimize their impact if they do. Risk assessment does not involve creating huge amounts of paperwork, but, rather, it identifies sensible measures to control the risks within the workplace (Msomi, 2018).

2.3.1. Risk Assessment Process

The risk assessment process is the process of collecting, organizing, analyzing, interpreting, communicating, and implementing information to identify the probable frequency, magnitude, and nature of any major incident which could occur within the organization and the measures to remove, reduce or control the potential cause of such an incident (Msomi, 2018). To conduct a risk assessment, current auditing standards emphasize the importance of gaining a complete understanding of an organization as well as its environment (Khorwatt, 2015). According to Coutinho (2014), the identification of hazards is one of the most important steps in the risk assessment process. To carry out a survey of existing hazards in the workplace, the following questions must be answered: (a) What are the sources of harm; (b) Which workers and which work components may be affected by these harms; (c) How these harms can occur. This whole process should be properly planned and organized so that it is possible to classify the various types of hazards that exist in the workplace. In risk assessment, the first step is to detect the risks and then estimate their consequences/impact, as well as to determine the level of worker exposure to the risk and the probability of an accident or damage occurring. Once the factors are identified, the various risk scenarios are defined (Costa *et al*., 2014). The Health and Safety Executive (2016) states that risk assessment is conducted in three steps (Figure 1):

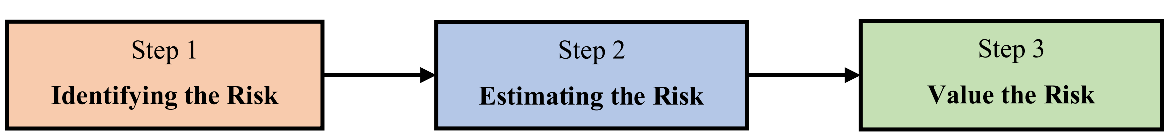

Figure 1. Risk assessment process steps

The 1st Step of the risk assessment - **Identifying the Risk**, consists in verifying the possibility that the worker has of suffering an injury caused by the work itself, and should take into account:

- ✓ The nature and location of the work;
- ✓ Mitigating or aggravating conditions of the potential harm associated with the hazard;
- ✓ Identification of the number of workers who are exposed to the hazard;
- ✓ The specific conditions surrounding this exposure, namely the work methods used and the average exposure time.

The 2nd Stage of risk assessment - **Estimating the Risk**, comprises the joint measurement of two factors, so that its magnitude can be measured:

- ✓ The probability of the damage occurring (estimate probability);
- ✓ The degree of severity or gravity (estimate the damage).

Finally, the 3rd Stage consists in **Valuing the Risk** - performing a comparative analysis of the estimate made with the safety and health reference standards, having as an objective:

- ✓ Realize whether the risk is acceptable or not;
- ✓ What is the degree of acceptability that should be attributed to it?

The objective of risk assessment is, therefore, the most complete and detailed knowledge of risks, to obtain their quantitative and qualitative evaluation. With risk assessment, it is determined whether the risk is tolerable/unacceptable and after this definition, the entire prevention process is initiated, implementing the most appropriate actions. This process should be continuous and in a permanent update. To this end, it will be necessary to monitor and review what has been done/implemented, never failing to consider the organization in question, as well as its strategy, process, and environment (Jacxsens *et al*., 2015; Ricci *et al*., 2017). Figure 2 shows the various phases required in a risk assessment process in a more details manner according to the criteria in Risk Management.

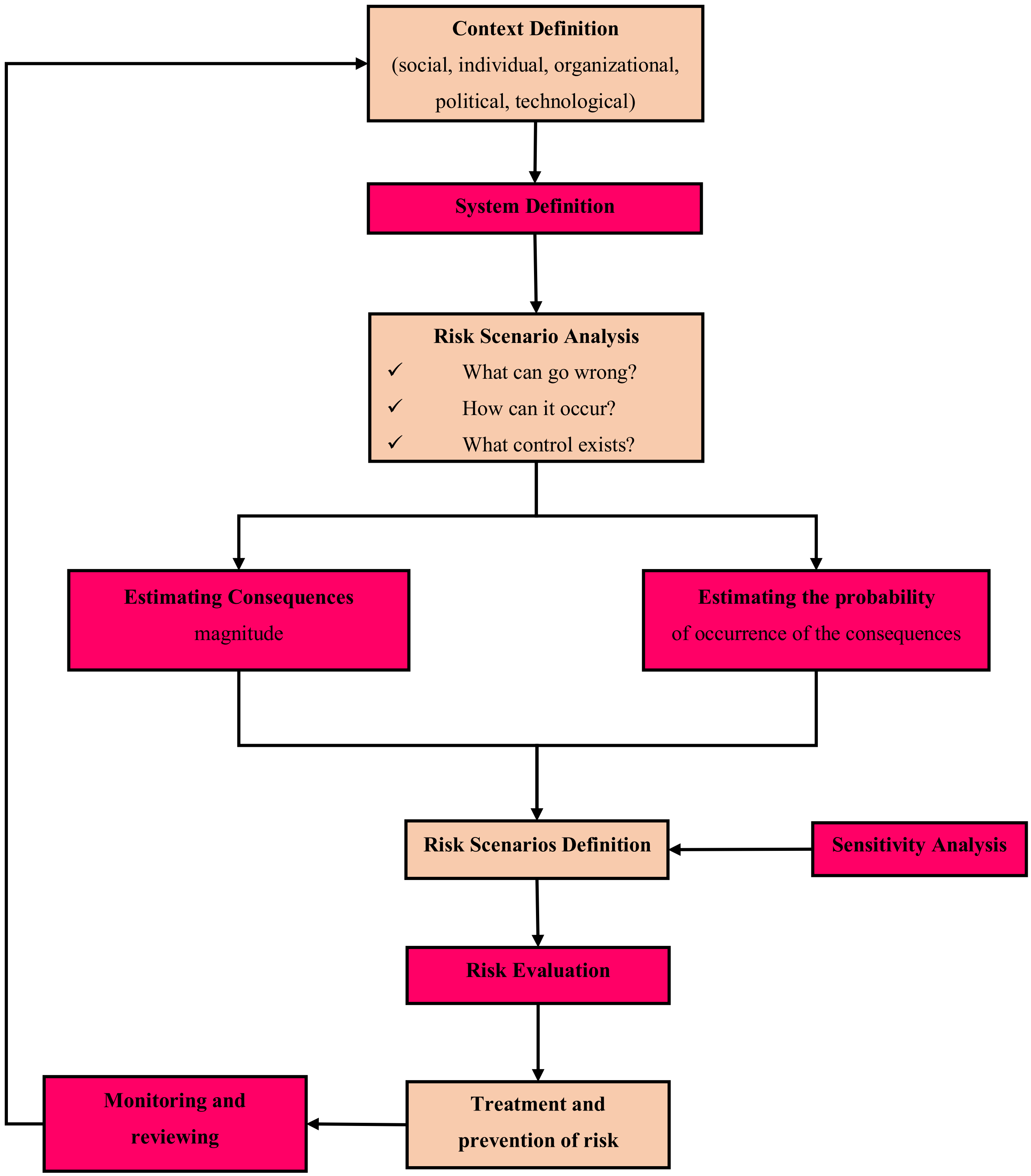

Figure 2. Risk Assessment Process. **Source:** Kulińska & Giera (2019)

2.3.2. Types of Risk Assessment

Risk assessment approaches may be qualitative, quantitative, or both, depending on the nature of the data available and the questions to be answered (Jacxsens *et al*., 2015). A quantitative risk assessment is an analysis of the highest priority risks, to which a numerical rating is assigned to develop a probabilistic analysis of the project (Santos *et al*., 2018). A quantitative analysis quantifies the possible outcomes for the project and assesses the probability of achieving specific project objectives. It provides a quantitative approach to making decisions when there is uncertainty, and it creates realistic and achievable targets (Basu, 2017). According to Marhavilas *et al*. (2011), there are seven quantitative risk assessment techniques outlined as follows:

1. **The Proportional Risk-Assessment (PRAT)** technique refers to "a proportional formula for calculating the quantified risk due to hazard. The risk is calculated considering the potential consequences of an accident, the exposure factor, and the probability factor" (Marhavilas *et al*., 2011).
2. **The Decision Matrix Risk-Assessment (DMRA)** is a quantitative technique and a graphical method that can create liability issues and help risk managers to prioritize and manage key risks (Chen *et al*., 2012).
3. **Quantitative Risk Measures of Societal Risk (QRMSR**) are the societal risk associated with an operation of a given complex technical system, where risks are evaluated and an accident is determined and the frequency is measured along with the consequences (Marhavilas *et al*., 2011).
4. **The Quantitative Risk-Assessment (QRA)** allows a site operator to quantify and determine the acceptability of risks arising from major process hazards on an industrial site. QRA is suitable for industrial plants with explosive hazards (Marhavilas *et al*., 2011).
5. **Quantitative Assessment of Domino Scenarios (QADS)** is based on a systematic methodology for the identification of domino scenarios and for the assessment of consequences and expected frequencies of the escalation events (Marhavilas *et al*., 2011).
6. **The Clinical Risk and Error Analysis (CREA)** is based on techniques that are well established in the industry and have been adapted for the medical domain. Hence, it is a

quantitative method that supports analysis related to organizational vulnerabilities within healthcare settings (Matr, 2011).

7. **The Weighted Risk Analysis (WRA)** is a tool that can compare different risks such as investments, economic losses, and the loss of human lives in one dimension (Marhavilas *et al*., 2011; Matr, 2011).

Qualitative assessment is important because it provides support for further investigation of quantitative, but can also provide the information needed for risk management (Jacxsens *et al*., 2016). This assessment is often used when numerical data is inadequate, unavailable, resources are limited, and when time allowed is reduced. Furthermore, the qualitative assessment begins with obtaining information on risk factors, followed by risk classification in terms of "acceptable" or "unacceptable", or classifications such as "low", "medium", and "high" (Radu, 2009). There are seven qualitative risk assessment techniques, ranging from Experience-based Judgement, Checklists, What-if Analysis, Task Analysis, Safety Audits, and STEP techniques, to HAZOP (Dusane and Bhangale, 2014). These are outlined as follows:

1. **Experience-Based Judgements** is a technique in which experts use their judgments that may rely on knowledge and information retrieved from memory (information-based judgments) and they heavily rely on their subjective feelings (Nussinson & Koriat, 2008).
2. **Checklists**, when well conceptualized can be an effective tool for assessing hazards and implementing safe work practices. An important benefit of the checklist methodology is its ability to quantify risk and provide scalability across an organization. This allows the researcher and the organization to conduct a comparative risk assessment to identify specific processes or research operations that present higher degrees of risk to the organization (American Chemical Society, 2015).
3. **What-if Analysis** consists of structured brainstorming, to determine what can go wrong in a given scenario, and then judging the likelihood and consequences that things will go wrong (American Chemical Solutions, 2017). This method aims to identify sources of risks and this is done by analyzing the potential consequences of deviations in a system (Alverbro *et al*., 2010).

4. **Task Analysis** entails various methods that have been developed for the analysis of specific types of tasks such as cognitive tasks or system designs. Organizations choosing to implement task analysis should determine which method is most appropriate to the task in question (Alverbro *et al*., 2010; Nussinson & Koriat, 2008).
5. **Safety Audits** are procedures by which the operational safety programs of an installation, a process, or a plant are inspected. Safety audits identify equipment conditions or operating procedures that could lead to a casualty or result in property damage or environmental impacts (Marhavilas *et al*., 2011).
6. **The Sequentially Timed Event Plotting (STEP)** technique is an important part of the safety management and accident prevention process. STEP provides a comprehensive systematic process for accident investigation from the description of the accident process (Herrera & Woltjer, 2010).
7. **The hazard and Operability technique (HAZOP)** is a systematic and detailed method that was developed in the process industry. Different guidewords (such as 'no', 'less', 'higher', and 'instead') are used to identify potential deviations in a system. The method is qualitative and the aim is to find potential problems in a system. Consequences, causes, current protection, and recommended actions are usually described and displayed in a table (Alverbro *et al*., 2010).

When choosing what type of risk assessment to follow, organizations must decide whether to conduct a self-risk assessment (internal) or an independent risk assessment (external) (Alverbro *et al*., 2010). According to Msomi (2018), "conducting a self-risk assessment is an excellent first step in broadening awareness about risk and risk management within the organizations. The main differences between quantitative and qualitative risk analysis are shown in Table 1.

Table 1. Differences between quantitative and qualitative risk analysis

Qualitative Risk Assessment	Quantitative Risk Assessment
Consider all the risks identified in the identification process	Consider the risks which are marked for further analysis
Doesn't analyze the risks mathematically to identify the probability and distribution rather, stakeholder's inputs (expert judgment) are used to judge the probability and impact	Uses probability distributions to characterize the risk's probability and impact, it also uses a project model (e.g. schedule, cost estimate), mathematical and simulation tools to calculate the probability and impact
Usually applied in most the projects	May not be applied to many simple or moderately complex projects
This predicts likely project outcomes in terms of money or time based on the combined effects of risks and estimates the likelihood of meeting targets and contingencies needed to achieve the desired level of comfort	The individual risks are assessed by assigning the numeric ranking of probability and impact, usually, the rank of 0 to 1 is used where 1 demonstrates high

Source: Msomi (2018)

2.3.3. Risk assessment in Supply Chain

Risk management, in the supply chain, has gained a growing interest from practitioners as a response to the massive disruptions supply chains experienced (e.g., pandemics, protests, floods, etc.), and thus several pieces of research conducted (Dolgui & Ivanov, 2021; Ivanov & Das, 2020; Mohammed, Harris, *et al*., 2021). Supply chains might experience poor performance due to poor risk management approaches Dolgui & Ivanov, 2022; Mohammed, Yazdani, *et al*., 2021). This would negatively impact productivity performance, forecasting, business reputation and continuity, and customer satisfaction, in addition to management issues among firms' stakeholders (Ganguly & Kumar, 2019). Therefore, managers are forced to incorporate robust risk management in their supply chains to tackle risks and consequences (Abdul Rahman *et al*., 2021).

From a supply chain risk management (SCRM) point of view, the risk is sometimes interpreted as unreliable and uncertain resources creating supply chain interruption, whereas uncertainty can be explained as matching risk between supply and demand in supply chain processes (Kumar *et* *al*., 2019). Therefore, warehouse processes in supply chain operations contain risks that deteriorate supply chain performance and customer satisfaction. Risk management of warehousing, as suggested by Lam *et al*. (2015), features important risk sources through conceptualizing with modern specialists, which fall into nine classifications, namely, physical environment risk, operational risk, human risk, market risk, resource risk, managerial risk, financial risk, security risk, and regulatory risk.

Accordingly, to Dolgui & Ivanov (2022) there are four types of errors or risks in the supply chain of warehouse operations: (1) The permanent shrinkage in the physical stock due to embezzlement or destruction; (2) The misplacement, which is temporary shrinkage in the physical stock that can be replaced after material handling or counting after every period; (3) The more or less production capacity of supplier which is the long-lasting deficit or surplus in the physical inventory due to supplier failure or errors; (4) The most significant fourth one is the transaction type error that affects the management information system differently than the first three errors, which modify the physical inventory.

2.4. Description of the FMECA method

Failure mode, effects, and criticality analysis (FMECA) is an extension of Failure Modes and Effect Analysis (FMEA). FMEA is a bottom-up, inductive analytical method that may be performed at either the functional or piece-part level. FMECA extends FMEA by including a criticality analysis, which is used to chart the probability of failure modes against the severity of their consequences (Elbadawi *et al*., 2018a).FMEA consists of an inductive tool to identify and analyze potential failures that may occur in a given piece of equipment, product, or process and determine their causes and effects on its operation, as can be seen in Figure 3. This methodology can be used to define the best actions to be taken to identify, prevent and correct potential failures, problems, and errors of a system, project, or product before it reaches the consumer (Guiochet, 2003; Villemeur, 1992).

Figure 3 represents the flow chart of the procedure to be applied in the FMECA methodology. The preliminary step in implementing an efficient risk analysis is the creation of an FMECA working group. Choosing the right people to perform the analysis is critical and should ensure that all key aspects of the process under analysis will be properly considered from a technical as well as a quality management perspective (Lopez *et al*., 2010). To begin an FMECA analysis it is important to perform a functional analysis, which consists of identifying the functions that the system must perform to satisfy customer requirements. At this stage, the main constituent assemblies of the system to be analyzed are listed. Each set is then divided into subsets and their components (Doddagoudar & Shetty, 2018).

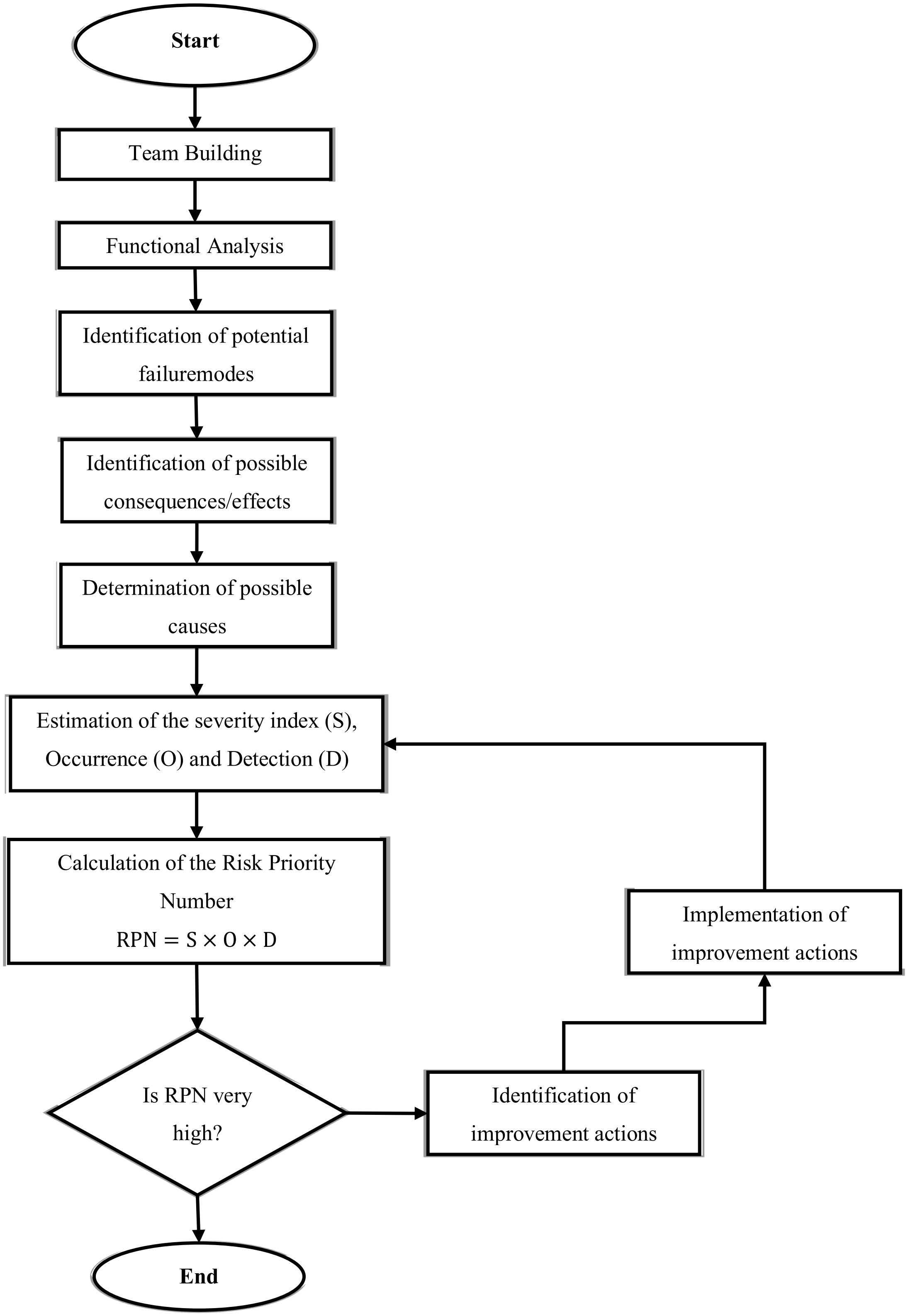

Figure 3. FMECA analysis procedure. **Source:** adapted from Soares (2015)

Analogously, for each failure mode, the consequences/effects are identified, as well as the causes that may cause them. Subsequently, an estimate of the Risk Priority Number (RPN) is made. RPN is a measure used when assessing risk to help identify critical failure modes associated with design or process and is given by Eq (1).

$$\mathrm{RPN} = \mathrm{S} \times \mathrm{O} \times \mathrm{D} \qquad \mathrm{Eq.}\,(1)$$

where S is the Severity, O is the Occurrence and D is the Detection. The RPN attributes weight to each failure mode under consideration. This parameter makes it possible to classify failures in order of importance. The higher the RPN of a failure mode, the greater risk for product reliability and, thus the need to be reexamined. Subsequent modifications have the purpose of lowering the RPN to avoid a failure's occurrence or repetition (Carmignani, 2009). The Occurrence is the frequency of the failure. Severity is the seriousness (effects) of the failure. Detection is the ability to detect the failure before it reaches the customer. There are many ways to define the value of these components. A useful way is to use numerical scales (called critical guidelines) (Elbadawi *et al*., 2018a). The ranking for the criteria can have any value. There is no standard for such value; however, there are two-way common rankings used in all industries today. One is ranked based on a 1 to 5 scale and the second, a 1 to 10 scale (Elbadawi *et al*., 2018b).

The scored scale of 1 to 5 is limited in nature but offers expediency and ease of interpretation. It does not provide for sensitivity (accuracy) of specific quantification, because it reflects a uniform distribution. On the other hand, a ranking of 1 to 10 is used widely and is highly recommended because it provides ease of interpretation, accuracy, and precision in the quantification oh the ranking. Other rankings, above 1 to 10 scales are not recommended (even though they can be very precise and accurate) because they are difficult to interpret and lose their effectiveness (Elbadawi *et al*., 2018a). Table 2 shows the ranking of S- Severity where 1 is considered negligible and 10 catastrophic.

Table 2. Ranking of the Severity Index

Severity index	Classification
1-2	Secondary
3-5	Important
6-7	Very important
8-9	Critical
10	Catastrophic

The Occurrence indicates the probability that the failure will occur, that is, it determines the probability that once the cause occurs, it will cause the failure mode. Table 3 represents the values assigned to the occurrence index.

Table 3. Ranking of the Occurrence Index

Occurrence Index	Classification	Frequency
1	Remote	Once per two years
2	Very Low	Once a year
3	Low	Once per semester
4	Moderate	A few times a year
5		A few times per semester
6		Once in quarter
7	High	A few times per quarter
8		Often in quarter
9	Very High	Often in a month
10		Often a week

Source: Carmignani (2009)

The Detection estimates the probability that the control means detecting the cause or effect of the failure mode before the customer is affected (Carmignani, 2009). Table 4 represents the values assigned to the cause/effect detection index.

Table 4. Ranking of the Severity Index

Detection index	Classification	Criterion
1-2	Almost certain	Very high probability of detecting the error: Inspections and checks will almost certainly detect the error
3-5	High	High probability of detecting the error: Inspections and checks will most likely detect the error
6-7	Moderate	Moderate probability of detecting the error: Inspections and checks are likely that inspections and checks will detect the error
8-9	Very Low	Low probability of detecting the error: Inspections and checks are unlikely that inspections and checks will detect the error
10	Remote	Very low probability of detecting the error: Inspections and checks fail to detect the error; there is no detection system

Source: Carmignani (2009)

After evaluating each index, the RPN (risk priority number) is calculated. RPN assigns a weight to each failure mode under consideration. This parameter allows researchers to rank failures in order of importance. The higher the RPN of a failure mode, the greater the risk to the reliability of the product/system and thus the need for reexamination. Subsequent changes aim to decrease the RPN to avoid its occurrence or repetition (Carmignani, 2009). After the changes are made, the same procedure is performed again to understand if the implemented action measures had any effect.

For this work, based on Antunes (2009) approach, the RPN calculation was slight modified. The Severity was broken into two components: Quantification of the hazard (QH) and Extent of the impact (EI). The occurrence was also broken into Exposure/frequency (EF) and Performance of prevention and control systems (PC). Additionally, the cost and technical complexity of measures to prevent/correct the measures to prevent/correct hazard was considered. That said, the RPN was calculated using the modified equation.

$$\mathrm{RPN} = (\mathrm{Q_H} + \mathrm{L_H}) \times \mathrm{E_I} \times \mathrm{EF_H} \times \mathrm{PC} \times \mathrm{C} \qquad \text{Eq. (2)}$$

where RI is the Risk index; S stands for Severity; Q_H corresponds to the Quantification of the hazard; L_H means the Hazard level; E_I denotes the Extent of impact (Risk); EF_H expresses the Exposure/frequency of occurrence of the hazard; PC signify Performance of prevention and control systems and; C is Cost and technical complexity of measures to prevent/correct the hazard.

With the RPN value calculated, and according to its score range, the RI is evaluated according to the categories shown below (see Table 5).

Table 5. Scoring Ranges and the Meaning of Risk Index

Risk Priority Number	Score range
Low	1–90
Medium	91–250
High	251–500
Very High	501–1800

Source: Antunes (2009)

2.5. Description of the FTA method

Fault Tree Analysis (FTA) is a deductive analysis that graphically models how logical relationships among equipment failures, human errors, and external events can combine to cause a specific hazard of interest (a “Top Event”). Fault Tree Analysis uses Boolean logic symbols (i.e., And gates, Or gates) to break down the causes of the Top Event into basic equipment failures, human errors, or external events (i.e., basic events). Top events are typical events identified from other hazard identification techniques (e.g., HAZID, HAZOP, FMECA) that need more detailed analysis. For very complex systems, Fault Tree Analysis is useful to identify the failure pathway that leads to the failure of the top event (American Bureau of shipping [ABS], 2020).

The outputs of a Fault Tree Analysis include:

- ✓ Graphical representation of the fault tree demonstrating how the failure of the top event can occur;
- ✓ The probability of failure of the top event;
- ✓ The list of the minimal cut sets that can cause the failure of the top event and/or the probability of the occurrence of the cut sets;
- ✓ Lists of the recommended risk control measures to mitigate risk and the evaluation of the recommendations;

CHAPTER III: APPLIED METHODOLOGY

This chapter has as its objective, a presentation of the detailed description of the methods that were used during this study.

3.1. Research Purpose

According to Saunders *et al*. (2012), a research study may have three different research purposes, explanatory, descriptive, or exploratory. Cargan (2007) supports these three but also presents "evaluative" as a fourth alternative. The explanatory research purpose is used when there are two or more variables that the researcher is trying to establish a cause-and-effect relationship (Saunders *et al*., 2012). Cargan (2007) claims that a requirement for explanatory research is that variables are known before the research begins. Therefore, to answer the third specific objective an explanatory purpose was used.

Saunders *et al*. (2012) state that the purpose of a descriptive study is to gain accurate knowledge about the included variables in a phenomenon. The authors stress the importance of the researcher having a clear picture of the studied phenomenon before beginning the study, which was not the case in this study. This study aimed to contribute to risk assessment in the warehouse without prior methodologies and hence could not have a clear picture of the phenomenon in advance. Consequently, the study did not have a descriptive research purpose.

Cargan (2007) describes evaluative research as studying the implementation of a policy or a particular problem to evaluate how successful the implementation is in achieving its goal. Since this study did not include any such implementation the evaluative research purpose could easily be dismissed. When conducting exploratory research, the goal is to increase the knowledge about a relatively unexplored topic (Saunders *et al*., 2012). Cargan (2007) clarifies that in exploratory research the main task involves producing analytical or conceptual generalizations that later can be tested and verified. No prior study of warehouse operations in company A was conducted, hence this research study had an exploratory research purpose.

It can be argued that the first research question of this study had descriptive characteristics as it essentially aimed to describe how manufacturing company A warehouse works, and how it potentially can threaten workers and company properties. However, the overall aim of the study was to assess the occupational health and safety risks in the warehouse, which lacks descriptive characteristics.

3.2. Research Approach

According to Saunders *et al*. (2012), a researcher can choose between two main approaches when conducting a research study; induction and deduction. Furthermore, they all agree that the researcher also has to decide whether to adapt a quantitative or qualitative approach. The choice of whether to adapt a quantitative or qualitative approach concerns what type of data the researcher intends to use (Holme & Solvang 1997). Creswell (2002) means that the quantitative approach involves the collection, analysis, interpretation, and writing of especially numerical data. A qualitative approach, on the other hand, involves mainly working with non-numerical data. Considering the study's general objective a quantitative research approach was used.

3.3. Research Strategy

To achieve the aim of a research study Saunders *et al*. (2012), state the importance of choosing a research strategy to follow - a plan of action. The choice is highly dependent on the research purpose and the chosen research approaches. The research methodology (Figure 4) was divided into 4 phases: identification of risks and application of semi-quantitative FMEA/FMECA through the risk matrix, probability analysis through FTA, and application of 5W1H preventive measures. Alongside the functional analysis, the effect of temperature and humidity on Beetle growth was performed through Pearson correlation and Linear regression.

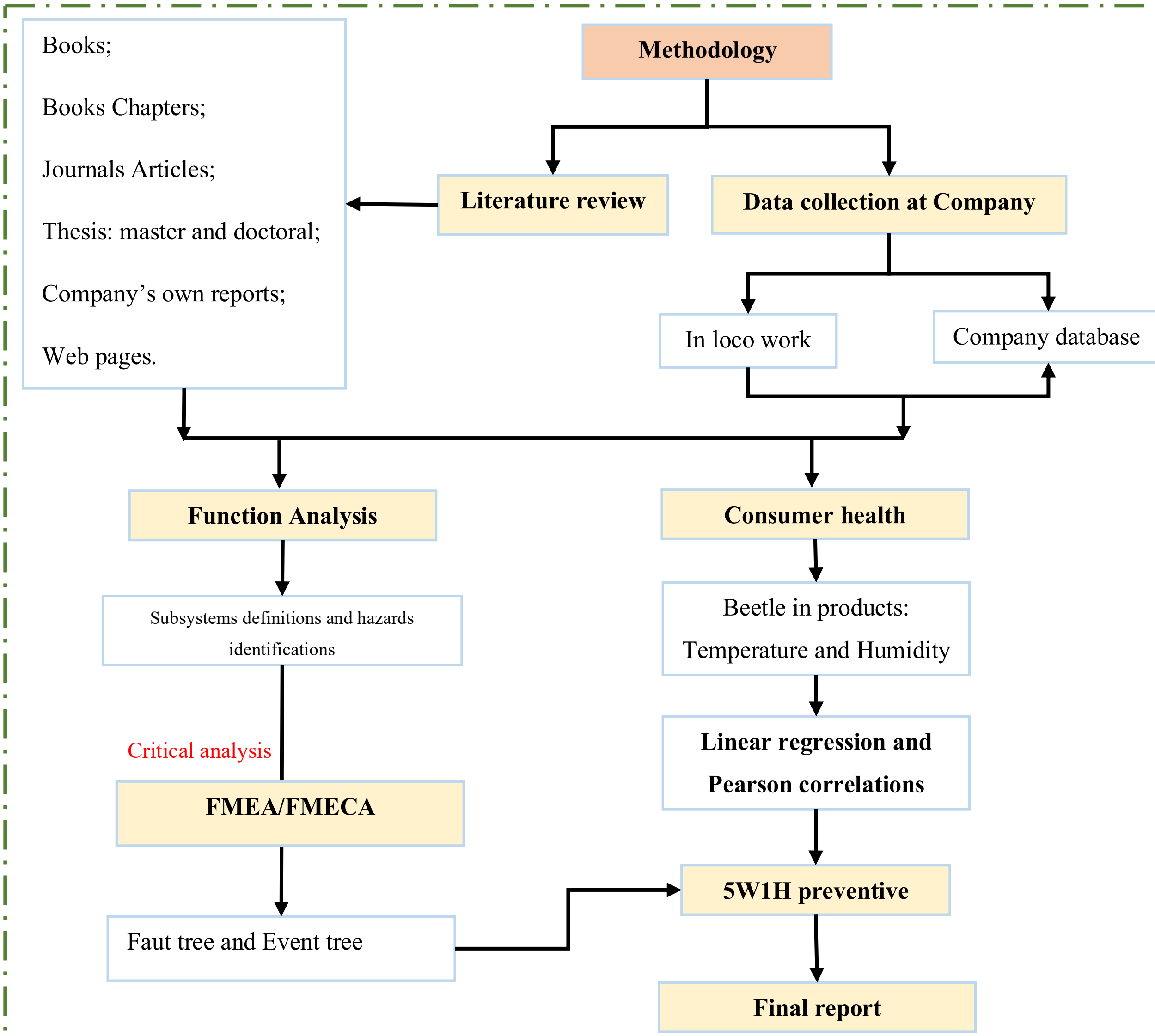

Figure 4. Flowchart of the work methodology

3.4. Company description

Company A is an industry that can be classified as a class A manufacturing industry. Company A is dedicated to the production and marketing of cigarettes. Company A is a well-renowned successful industry and has proved its standing in counting prominent industries in Mozambique. Company A is part of one of the largest multinational companies operating in Mozambique and has been operating for over 120 years in more than 180 markets around the world.

Company A is a leading tobacco group, with brands sold in around 180 markets. Its production is supported by more than 55,000 people and with a portfolio containing over 200 brands. The company sought and seeks to compensate for the increased competition with new investments aimed at the production of new products, as well as the reduction in energy consumption, maintenance costs, quality improvement, and the incorporation of greater added value to the products it produces. The Company A structure is much decentralized with the parent company retaining authority for the overall strategic direction of the Firm and financial control. Company A operates in the following functional areas:

- ✓ Operations (Production, Supply Chain, and Quality);
- ✓ Finance;
- ✓ Human Resource;
- ✓ Marketing (Brand and Trade Marketing- Demand Chain);
- ✓ LEX.

Overall activities of the tile company are governed by the "Board of Directors" and Executive. The "Board of Directors" is composed of 6 members headed by a chairman. Chief Executive of Company A is called the "Managing Director" who is normally appointed by "Company A Holdings". The Managing Director of the company is the chairman of the executive committee. This committee includes the head of all the functional departments. The decision making, infrastructure are participatory to a very high extent. All the plans and decisions that are made are communicated from the top level of the organization and the decisions are made after discussing the issue with the related authority and the grass root level. Every possible input from every relevant level of the workforce is taken before getting to any decision.

3.4.1. Company A: operations department

The Company A factory has a production capacity of 3 billion cigarettes per year. Organizationally, the building is divided into the following areas:

- ✓ Raw material storage area;
- ✓ Cigarette filters manufacture area;
- ✓ Tobacco Feeder area;

- ✓ Cigarette manufacturing and packaging
- ✓ Finished product storage area;
- ✓ Finished product and raw materials loading and offloading area;
- ✓ Tobacco waste recovery Area;
- ✓ Compressors and powder extractors Area for.

Regarding the HSE Department (Health, Safety, and Environment), the company is aligned with the strategy of the Excellence System with the HSE Policy, aiming to develop its activities respecting the environment and promoting the safety of its employees. Therefore, it is committed to implementing an Integrated Management System of Health, Safety, and Environment following the requirements of the Standards OHSAS 18001:2007 and ISO 14001:2015. Figure 5 shows the main PPEs used in the factory.

Figure 5. Main PPEs used in the factory

In the scope of OHS and fire risk, the company has been guided by a set of rules and guidelines imposed on all employees. Therefore, Company A has created a set of self-protection measures consisting of a prevention plan, an internal emergency plan, and safety records. In the period of no occupation, there is no occupation of the establishment, and only security guards are present at the establishment. There is a security team, belonging to a security services company, which is present in the establishment 24h/days. The company ensures the continuous presence by shifts of a security guard during the day, night, and weekends, which ensures the access, and control of people, visitors, vehicles, and rounds to the establishment.

This study specifically covers the finished good warehouse, which receive and distributed locally produced products and imported products from other markets.

3.4.2. Warehouse

The finished goods warehouse (FGW) is located on the factory premises. In the warehouse, there are 18 employees allocated to different tasks, as can be seen in the organization chart. 15 workers are from subcontracted companies: facility management (company B) and cleaning and facilities maintenance company (company C). The 12 workers from company B work in a single daily shift and 3 workers from company C work for over 10 hours a day.

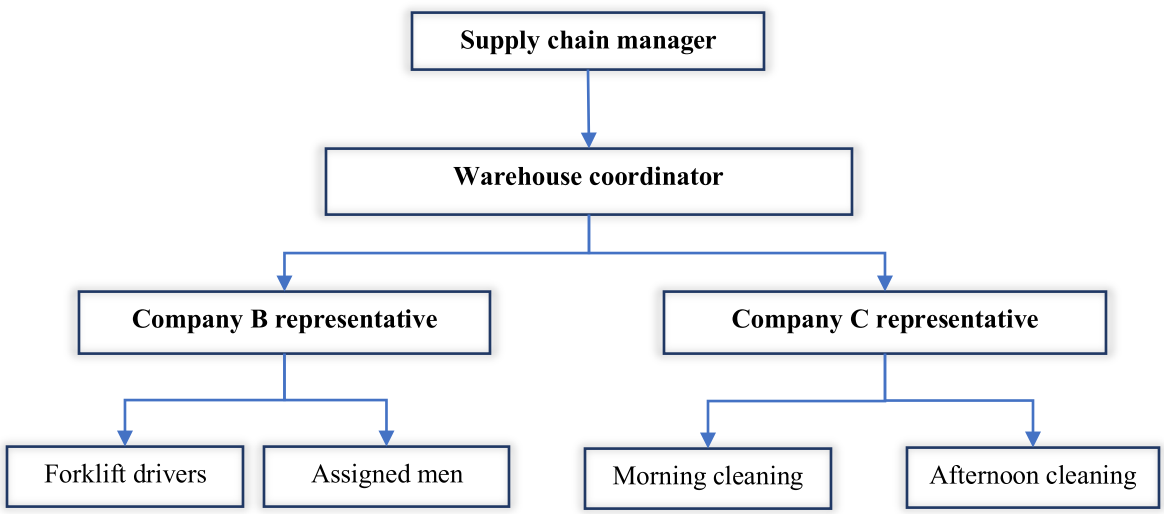

Figure 6. Warehouse organization chart

The finished product warehouse occupies an area of 1375 m^2, with a height of 21 m and a length of about 55 m. It has in its constitution two large construction groups. The warehouses have a capacity of ten thousand boxes of products and are arranged in a system of shelves with an aisle between them. This aisle is divided into two zones (A and B), and zone A is where the products with the highest probability of leaving are located, in other words, they are closer to the exit zone. The warehouse is operated according to FIFO (first in first out) standards.

The products stored in the warehouse must meet certain characteristics concerning weight, height, and shape. Thus, the pallet must not exceed approximately 750 kg, 1.4 meters in height, or exceed the margins of a Euro pallet. All products that meet these characteristics are stored in this facility.

3.5. Functional analysis

3.5.1. Warehouse operations system

A system is a set of components, humans, machines, or both, which have certain functions and acts and interact, one concerning another, to perform some task or tasks in a particular environment or environment. Figure 7 shows the map of the Company A warehouse system.

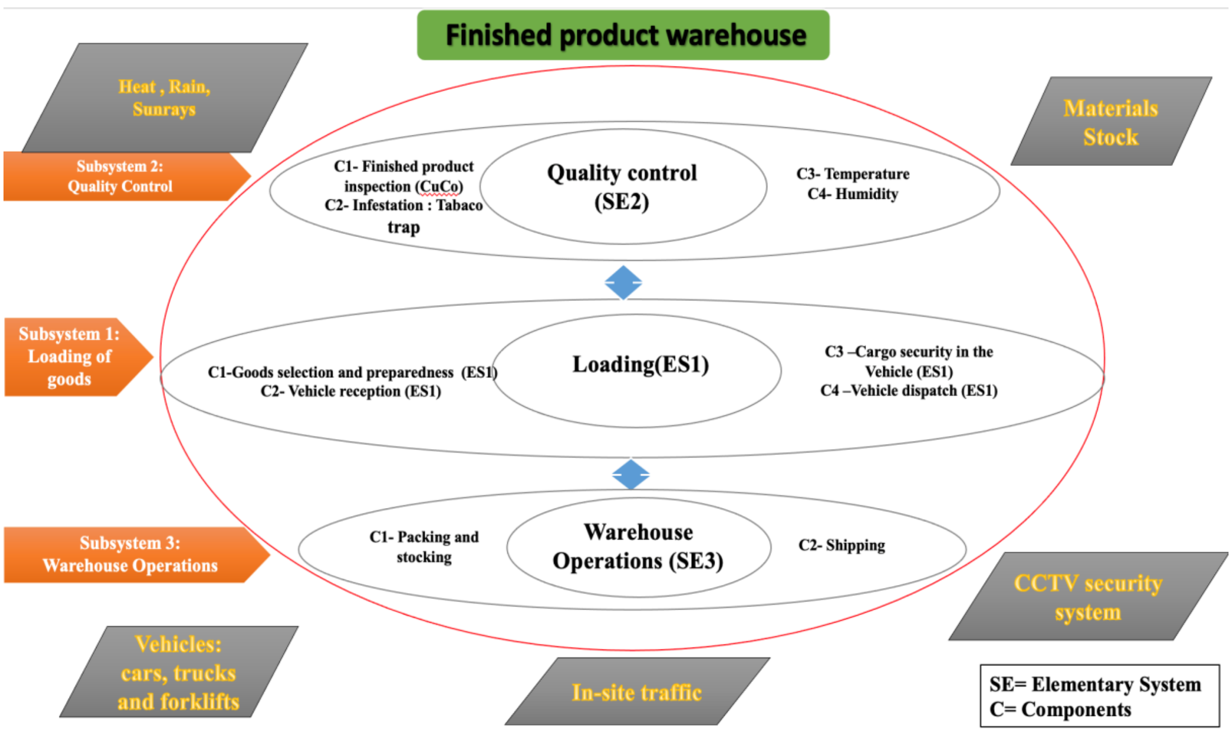

Figure 7. Warehouse operations system

The Figure 7 system consists of subsystems and components that work under certain environmental conditions. The designed system expresses the main processes and work procedures in company A FGW. The different subsystems are interconnected, and the different components guarantee the continuous functioning of warehouse operations.

3.5.2. Elementary System

The warehouse is used for the loading of vehicles, which can be done manually and/or with a forklift, as well as handling goods employing pallet trucks and/or forklifts. The vehicles to be loaded can range from light goods vehicles (rigid vehicles), with loose volumes to be stored in the loading space, to heavy goods vehicles (articulated vehicles), normally with volumes divided by pallets. For an efficient system, it is necessary to know all the processes of the system as well as the external limits and the surrounding environment. Within this department, quality control, packaging, and finished product shipment activities are also carried out.

3.5.3. Interface

The interface consists of the connection between the different procedures in the warehouse a fact that influences the occupational safety and environmental impacts of the processes developed in the warehouse.

3.5.4. Subsystems

The set of components of the 3 subsystems will ensure increased occupational safety in the warehouse and reduced environmental impacts associated with this activity.

The main components of subsystem 1 are Goods selection and preparedness, Vehicle reception, Cargo security in the Vehicle, and Vehicle dispatch.

The main components of subsystem 2 are Finish product inspection, infestation control, and temperature and humidity measure.

The main components of subsystem 3 are Packing, Stocking, and Shipping.

3.5.5. External limits and Environment

Climate conditions – influence the state of the operator and the working environment and the quality of storage finish product.

Intense heat – increases fire dispersion in case of fire and decreases the air quality in the Warehouse.

Windstorm – dispersion of materials and application of more force on the part of operators in the handling of goods

Rain – in addition to damaging the health of operators and the quality of goods when exposed to rain, the water can moisten the floor, increasing the hazard of slipping and tripping people and equipment.

Vehicles cars, trucks, and forklifts: compromise the mobility of operators in the factory yard, emit gases during operation, and oil and fuel spillage. When not properly parked, they are a sliding hazard - compromising the property and safety of operators.

In-site traffic: the circulation of trucks and cars in the vicinity of the warehouse represents an occupational hazard to workers due to exposure to the same means of circulation.

Materials Stock: Poorly stacked goods, unsound shelving, the handling of loads at height and impacts at ground level are all responsible for objects falling from different heights.

CCTV security system: The video surveillance systems allow the security teams to follow all the movements in an optimized way, for effective and agile management of the events inside and outside the warehouses.

3.5.6. Service Functions

sF1: The system Finish Good Warehouse is more efficient when it has an integrated method of occupational safety and environment assessment.

sF2: The system Finish Good Warehouse must consider the different processes they include in their functions.

sF3: The system Finish Good Warehouse must contain a procedure for occupational risk and environment assessment.

sF4: The system Finish Good Warehouse is more efficient when the quality control is efficiency.

sF5: The system Finish Good Warehouse must ensure occupational health and safety to prevent workplace injuries.

3.5.7. Constrains Functions (cF)

cF 1: The system Finish Good Warehouse is stable when it takes into the warehouse operations components.

cF 2: Failure to control infestation reduces the quality of the finished product and provides an unsafe working environment for operators.

cF 3: The lack of individual and collective protection equipment increases the risk of accidents inherent to warehouse workers.

cF 4: Unsafe packaging and storage conditions of the finished product in the warehouse put the health and safety of operators at risk.

cF 5: The absence of loading procedures provides an unsafe condition for warehouse operators and occupants**.**

cF 6: Warehouse services can result in the emission of gases, falling objects on different levels, and the generation of solid waste which compromises the environment.

3.5.8 Functional specification

The Functional Specification is a tool that formalizes a need, detailing the expected functionalities, as well as the restrictions. It presents in a detailed and structured way the specifications (see Table 6), and the services to be provided that will give structure to the project. The first step is to establish an importance grid, ranging from 1 to 4, and flexibility classes, ranging from 0 to 3.

Table 6. Functional Specification

Observation	Importance	Class F	Flexibility
1	Desirable	F0	Level needed
2	Required	F1	Low - difficult to negotiate
3	Important	F2	Good - negotiable
4	Very important	F3	Strong- very negotiable

Table 7 presents the relationship between the service functions (sF) and the constrains functions (cF), which were detailed in the previous section (see sections 3.2.5 and 3.2.6).

Table 7. Relationship between cF and sF

Type	Function	Criteria	Level	Importance	Flexibility
sF4	Condition the finished product before it is sent to the distributor	Temporary storage	Inspections control	4	F0
sF4	Ensuring that the finished product goes to the market within the desirable standards and compliances	Opening box by box for observation and inspection	Inspections control	4	F0
sF4	Prevent the finished product from being infested and compromising the final quality	Constant cleaning in the warehouse; implantation of traps, disinfection, and pest control	Daily beetle count	2	F1
sF1	Prevent collision between person and machine	Safe movement in the warehouse	Lack of procedures	4	F0
sF3	Ensuring specific and sufficient manpower	Prevent overstress and ergonomic disease resulting from repetitive exercise	Safe work - shift work	2	F1
sF1	Facilitate cargo transport	Fewer gas emissions and increased productivity	Lack of equipment inspections and maintenance	3	F0
sF5	Ensuring proper and safe working conditions	Protection of the safety of the finished product and operators	Lack of procedure s	4	F1
sF2	Measures protection of the finished product and encouraging compliance with warehouse policies	Monitoring of operators and different stakeholders by the security system in the warehouse	Lack of procedures	3	F2

3.6. Data Collection

As outlined, the characterization of the process was carried out in a phased manner. Thus, the first phase consisted of a preliminary diagnosis of the process, where the main processes were identified and characterized. Table 8 are presented the details of the loading and warehouse operations of finished products and raw materials at Company A warehouse. In this section, all the steps involved in the processes described above are presented.

Table 8. Company A warehouse operations

Steps	Operations	Observations
1	Storage of finished product	The boxes are stored in stacks of max 3 m high on wooden pallets
2	Finished product inspection and surveillance	
3	Quality control of the finished product	Boxes are opened one by one to check the conformity
4	Warehouse pest and infestation control	

The process of loading goods (Figure 8) is started with the selection and preparation of the goods to be loaded (Figure 9). Then, the vehicle to be loaded is received in the warehouse. Once the vehicle arrives, the load to be loaded is secured on the vehicle using the appropriate means for this purpose, in the case of goods on pallets (Figure 10), the forklift is used to place the goods on top of the truck, and a pallet truck is used on top of it for better securing. In case the load consists of loose volumes, it is done manually, and a pallet truck is used to place the goods close to the vehicle, and the loading is done manually. Finally, the vehicle is dispatched (Figure 11).

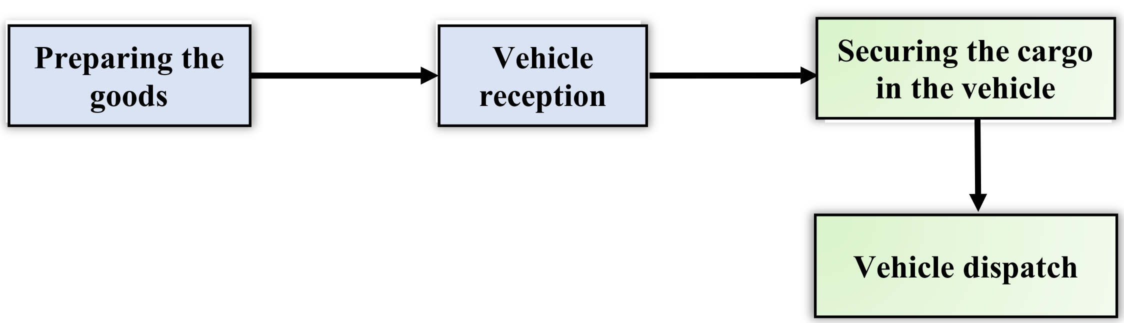

Figure 8. Process diagram: Loading Vehicle

Figure 9. Preparing the goods to be loaded

Figure 10. Forklift driver maneuvering cargo at the loading area

Figure 11. Vehicle dispatching area

3.6.1. Machines and equipment used

In this section, an analysis of the main components used in the warehouses of Company A is performed. Table 9 presents the identification of mechanical and electrical components that are involved in the process of loading and unloading goods. However, no electrical components were identified as being used during the process of receiving and unloading goods at the Company A warehouses.

Table 9. Machines and equipment used in the process of Loading of finish product in Company A Warehouse

Identification of mechanical components						
Identifying the component	**Source of noise (Y/N)**	**Source of vibrations (Y/N)**	**Source of mechanical hazards (Y/N)**	**Surface temperature (ºC)**	**Maintenance Plan (Existence/Compliance)**	**Observations**
Forklift	Yes	Yes	Yes	Room temperature	Not regularly	-
Pallet jack	No	No	Yes	Room temperature	No	-
Identification of electrical components						
Identifying the component	**Voltage (V)**	**Intensity current (I)**	**Existence of protections (Y/N)**	**Surface temperature (ºC)**	**Maintenance plan (Existence/Compliance)**	**Observations**
There is no	-	-	-	-	-	-

3.6.2. Means of protection

The mechanisms present in the loading area of goods at the Company A warehouses are presented in Table 10. During the operations, all workers involved are required to wear safety boots and reflective clothing and the operators also wear gloves for manual handling of loads. However, no collective protection system used for the operations described above was identified.

Table 10. Collective/Individual protection procedures in Company A warehouse

Collective protection procedures		
Identification of the procedure	**Verification of the effectiveness of the protection measures**	**Evaluation of the degree of implementation of the procedures**
None	-	-
Individual protection procedures		
Identification of the procedure	**Verification of the effectiveness of the protection measures**	**Evaluation of the degree of implementation of the procedures**
Use of protective protection boots	Suitable	Used by all employees
Use of protective gloves	Suitable	Used by few employees

3.6.3. Hazards identification in Warehouse operations

After the visits to the Company warehouse, and to enrich the realization of the study, some photographs were taken to illustrate and better identify the hazards and risks to which workers are exposed. The classification of Hazards and Risks, referred to by (Cabral and Veiga, 2010), was adopted. The hazards and risks identified in the Company A warehouse were summarized in Table 11.

Table 11. Identification of hazards and risks in the activities of the Company A warehouses

Activity	Risk identified	Activity representation
Forklift driving and maneuvering goods.	1. Fall of detached, suspended objects; 2. Fall of people on a gradient; 3. Run over by machines/vehicles; 4. Collision; 5. Compression by or between objects (crushing); 6. Road crash or rollover.	 **Figure 12.**Forklift driver maneuvering load
Use of stepladder to place light loads on the rack	1. Fall of people on unevenness; 2. Fall of objects in manipulation; 3. Compression by or between objects (crushing); 4. Personal injury, property losses. 5. Tripping/falling at the same level; 6. Collision.	
Temporary storage on pallets for shipment		 **Figure 13.**Forklift driver maneuvering load
Others	1. Cutting; 2. Exposure to poor or poorly designed light; 3. Shocks against immovable objects.	

CHAPTER IV: EVALUATIONS AND RESULTS

This chapter presents and discusses the results of the application of the FMEA/FMECA and FTA methodologies.

As already mentioned, the FMEA/FMECA analysis technique was applied to make a general sweep of the hazards, i.e., covering the occupational risk aspect, more specifically the risks inherent to loading and unloading tasks and products, and the operational risk aspect, i.e., the risk intrinsic to the equipment and facilities. Subsequently, the FTA methodology was applied for a more specific analysis of the operational risk, and in this way to complement the deviation analysis methodology. The process that shows the highest RPN raking for loading/unloading operations, warehouse procedures, and product quality control, was used to define the feared elements for the rest of the analysis and probabilistic study. Additionally, measures of temperature and humidity were performed to investigate the correlation between them and finished good Beetle. The analysis of the Beetle was performed to clarify if the warehouse conditioning contributes to the growth of Beetles in the FGW of Company A. The data from the daily measurements of temperature, humidity, and amounts of Beetles were analyzed through descriptive statistics using the Statistical Package for the Social Sciences (SPSS) V21. To understand if there is an association between the variables under study, Pearson correlation coefficients were performed. And, wanting to understand if the variations in temperature and humidity affect the development of Beetles, a Multiple Linear Regression was also performed. So, to generate the model, the temperature and humidity of the finished product warehouses are the predictor variables of the model (equation 3) and the number of Beetle is the response variable. To use linear regression and Pearson correlation, the data must follow a normal trend, therefore, prior normality test (Shapiro-Wilk) was performed and the results are shown in Table B-2 (Annex B).

$$\mathrm{Beetle} = \alpha_o + \alpha_1 \mathrm{T}_{\mathrm{FGW}}[°\mathrm{C}] + \alpha_2 \mathrm{T}_{\mathrm{FGW}}[\%\mathrm{H}] + \varepsilon_t \qquad \text{Eq. (3)}$$

The significance of the model will be assessed using a two-factor Analysis of variance (ANOVA) with the following hypotheses:

- ✓ H_0: the linear regression model is not significant: it is accepted if (p-value <0.05)
- ✓ H_a: The linear regression model is significant: Accepted if (p-value >0.05)

4.1. Assessment of Identified Risks

Once the identification phase was completed, it was time to characterize the aspects that could cause occupational health, safety, and environmental impacts. In this phase, the FMEA methodology was applied to describe and evaluate the hazards. The results obtained were summarized in Tables 12 to 14.

Table 12. Application of FMECA methodology of risk assessment for vehicle Loading operations

Sub-process	Hazard	Hazard description	Risk	Significance Assessment					RPN
				(QH + LH)S	EI	EFH	PC	C	
Vehicle reception	Carbon monoxide concentration	Vehicle entry to the loading area	Inhalation of harmful or toxic substances	2	3	1	5	1	30
	Vehicle Circulation	The arrival of the vehicle to proceed with the loading of the merchandise	Running over	5	2	1	5	1	50
	Equipment Maneuvering	Putting the vehicle in a position to perform the loading of the goods		3	2	1	5	1	30
Forklift usage	Transportation of materials	Transporting goods by forklift	Falling objects	5	3	2	5	1	150
	Goods lifting operations	Placing the goods on the vehicle		3	2	2	5	1	60
	Work on the radius of fixed or mobile structures	Parallel activities when using the forklift	Collision with objects	2	2	2	5	1	40
	Using equipment with moving parts moving parts	Forklift Forks		3	2	2	5	1	60
	Use of mobile equipment	Forklift use	Crushing/Scrapping	3	3	2	5	2	180
	Heavy load handling	Handling of goods to be loaded		5	2	2	5	2	200
	Incorrect gestures or work postures	Forklift driver leaning over the steering wheel	Overstressing	2	1	3	5	2	60
	Carbon monoxide concentration	Trucks working inside the warehouse	Inhalation of harmful or toxic substances	2	3	1	5	2	60
	Use of bottled gas equipment	Gas-powered Forklift	Fire/Explosion	10	4	1	5	1	200
	Machine Circulation	Forklift	Run over	3	2	1	5	1	30

Table 12. Cont.

Sub-process	Hazard	Hazard description	Risk	Significance Assessment					RPN
				(QH + LH)S	EI	EFH	PC	C	
Pallet jack Usage	Transportation of materials	Transporting goods by pallet jacks	Falling objects	5	3	2	5	1	150
	Goods lifting operations	Using the pallet jack for moving goods		2	3	1	5	1	30
	Work on the radius of fixed or mobile structures	Parallel activities when the use of the pallet truck	Falling objects	2	2	2	5	1	40
	Use of mobile equipment	Pallet Jack use		2	2	2	5	1	40
	Heavy load handling	Handling of goods to be loaded	Crushing/Scrapping	3	2	2	5	2	120
	Incorrect gestures or work postures	The pallet jack driver does the wrong postures when pushing the pallet jack	Overstressing	2	1	3	5	2	60
	Heavy load handling	Using the pallet jack		2	1	3	5	2	60
	Carbon monoxide concentration	Trucks working inside the warehouse	Inhalation of harmful or toxic substances	2	3	1	5	1	30
Load goods (Forklift)	Usage of the support bases	Pallet transported by forklift	Falling to a different level	5	1	1	5	1	25
	Top Quota Access	Truck bed to be loaded		5	1	1	5	1	25
	Transportation of materials	Stowing the goods in the truck with the aid of the pallet jack	Falling objects	2	3	2	5	1	60
	Goods lifting operations	Using the forklift to place goods on the truck		3	2	2	5	1	60
	Using equipment with moving parts	The operator on top of the truck can suffer a collision of goods	Collision with objects	2	2	2	5	1	40
	Use of mobile equipment	Forklift and/or pallet jack	Crushing/Scrapping	3	3	2	5	2	180
	Heavy load handling	Handling of goods to be loaded		5	2	2	5	2	200
	Excessive weight movement	Using the pallet jack	Overstressing	2	1	3	5	2	60
	Incorrect gestures or work postures	Use of pallet jack and goods storage		2	1	3	5	2	60
	Carbon monoxide concentration	Trucks working inside the warehouse	Inhalation of harmful or toxic substances	2	3	1	5	1	30

Table 12. Cont.

Sub-process	Hazard	Hazard description	Risk	Significance Assessment					RPN
				(QH + LH)S	EI	EFH	PC	C	
Load goods (Manual)	Obstacles in transit areas	Stowed objects in transit areas	Falling to the same level	2	4	3	5	1	120
	Poor storage/organization of the workplace	Boxes distributed on the floor without MSDS		2	4	3	5	1	120
	Work on the radius of fixed or mobile structures	Forklift and/or pallet jack handling in the warehouse	Collision with objects	2	2	2	5	1	40
	Poor goods handling	Placing boxes from vehicle bed level to vehicle bed to ground level	Overstressing	2	3	3	5	2	180
	Machine Circulation	Forklift circulation in the warehouse	Run over	3	2	1	5	1	30
Vehicle departure	Carbon monoxide concentration	Vehicles leaving the warehouse	Inhalation of harmful or toxic substances	2	3	1	5	1	30
	Vehicle Circulation	Vehicles leaving the warehouse	Run over	5	2	1	5	1	50

Table 13. Application of FMECA methodology of risk assessment for Warehouse procedures

Sub-process	Hazard	Hazard description	Risk	Significance Assessment					RPN
				(QH + LH) S	EI	EFH	PC	C	
Packing and Stocking	Weight of boxes	The operator can exert excessive force to load the boxes	Ergonomic	3	2	2	5	3	180
	Opening and take-off of the boxes	The glue can exhale strong smells and particulate material	Inhalation of harmful or toxic substances	5	2	2	5	3	300
		The Chissat knife can cut the operator's fingers	Finger and hand cut	3	2	2	5	3	180
	Manual loading of boxes	The box can fall on the operator's feet and body	Operator crushing	3	2	1	5	1	30
Shipping	Transportation of materials	Transporting goods by forklift	Falling objects	5	3	2	5	1	150
	Goods lifting operations	Placing the goods on the vehicle		3	2	2	5	1	60
	Work on the radius of fixed or mobile structures	Parallel activities when using the forklift	Collision with objects	2	2	2	5	1	40
	Using equipment with moving parts moving parts	Forklift Forks		3	2	2	5	1	60
	Use of mobile equipment	Forklift use	Crushing/Scrapping	3	3	2	5	2	180
	Heavy load handling	Handling of goods to be loaded		5	2	2	5	2	200
	Incorrect gestures or work postures	Forklift driver leaning over the steering wheel	Overstressing	2	1	3	5	2	60
	Carbon monoxide concentration	Trucks working inside the warehouse	Inhalation of harmful or toxic substances	2	3	1	5	2	60
	Use of bottled gas equipment	Gas-powered Forklift	Fire/Explosion	10	4	1	5	1	200
	Machine Circulation	Forklift	Run over	3	2	1	5	1	30

Table 14. Application of FMECA methodology for quality control in Warehouse operations

Sub-process	Hazard	Hazard description	Risk	Significance Assessment					RPN
				(QH + LH)S	EI	EFH	PC	C	
Finish good inspections (CuCo)	Use of chissat	The sealed boxes are opened to check the conformity of the packages	Finger / Hand cutting	3	4	2	3	3	216
			Injuring another operator	3	4	2	3	3	216
	Inhalation of particulate matter	Exposure to particulate matter resulting from clutch disengagement	Contracting respiratory diseases	2	4	2	5	2	160
			Contracting allergies in the eyes	2	4	2	3	2	96
	Manual weight loading	The boxes are opened and inspected one by one on a table.	Falling objects and operator	5	1	3	4	2	120
			Ergonomic stress	3	3	2	5	2	180
Infestation control	Preparing the traps	Skin contact and smell of poison from the trap glue.	Inhalation of toxic substances	2	1	2	5	2	40
			Adhesion of the glue on other objects	2	1	2	5	2	40
	Setting the traps	Allocating traps to high points	Falling objects on a different level	2	1	2	5	1	20
			Operators falling in different level	3	1	3	4	2	72
	Inspection of trapped beetles	Frequent contact of the operator with the piles of the finished product in the warehouse	Falling objects on different levels	5	4	2	3	3	360
			Crushing/Scrapping	5	3	1	3	3	135
	Treatment and disposal of trap waste	The material contains a harmful product	Exposure of Beetle to the operator	5	4	1	3	1	60
			Contaminate the environment (the receiving body)	2	1	2	3	3	36
Temperature & humidity control	Damage to the stock of the finished product	Uncontrolled oscillations of temperature and humidity in the warehouse	Loss of productivity and company breakdowns	2	4	3	2	1	48
			Rapid deterioration of the finished product	3	4	3	2	1	72
	Inadequate working conditions	Hot zones with humid air for the execution of the operations in the warehouse by the operators	Ergonomic stress	5	4	3	5	1	300
			Asphyxiation	5	3	3	2	2	180
	Installation of sensors	Sensors installed in high points to provide better accuracy of the readings	Falling into different levels	5	3	1	3	3	135
			Poor data visibility	5	3	1	3	3	135
	Proliferation of Beetle	Temperature and humidity have a direct influence on the multiplication of the Beetle	Rapid deterioration of the finished product	5	4	3	2	2	240
			Low quality of finished product	5	4	3	1	2	120

After the analysis of the FMEA/FMECA tables (tables 12 to 14), it was possible to synthesize the results, the frequencies relative to the degrees of risk obtained indicated in Table 15. Of the 266 risks analyzed, 42 present a low-risk grade, 29 present a moderate-risk grade and only 3 present a high-risk grade.

Table 15. Number of risks according to the ranking of RPN

	Frequency	**%**
Low risk	42	56.76
Moderate risk	29	39.19
High Risk	3	4.05
Total	**74**	**100,0**

From Table 15, it is possible to observe the percentages of incidence according to the degree of risk, with the high-risk degree having an incidence of 4.05% of all the risks, 39.19% the moderate risk degree, and the low-risk degree with 56.76% of all the risks. These results are in line with the results obtained by Pedrosa (2014) when applying the FMEA method to assess the occupational risks that exist in industrial dryer operations (the list of risk indexes can be found in Annex C). The results obtained are in line with the notion of risk that is associated with the execution of this process. The most relevant aspects were identified and the risk index score conveniently evaluated the situations that from the occupational safety and hygiene point of view will require more attention.

The results obtained are in accordance with the functions performed by employees, which is not considered a risky job, but some risks are inherent to certain functions, although they are not very high. Most of the risks with significant results, result from:

The use of forklifts and pallet trucks, as well as lifting heavy loads. These are risks that, in the event of an accident, can lead to serious harm to the worker, these have already occurred on the premises but never with consequences for the workers, even though there are no preventive measures in place for this purpose;

The manual handling of loads, either with excessive weight or by wrong postures when lifting them. When the pallets are broken at the bottom, during the loading/unloading of goods, the forks cannot remove the entire pallet, or when removing the pallet, they hit the damaged area, pushing it. In this case, the consequence will be that the pallet or the adjacent pallet will fall. The risk of an accident occurs because there is the movement of people on the side of the aisle. If the pallet falls in the aisle, the worker may suffer multiple injuries, serious fractures, or even fatal injuries;

The risk of inappropriate behavior more specifically by forklift and jack pallet operators happens predominantly concerning violations of safety rules and work procedures;

The risk of operators' cuts during the opening of boxes for inspection of product quality, the risk has a high RPN value, also due to the operators' poor adherence following the safety rules and work procedures. Operators justified, essentially, by the lack of comfort of using safety equipment and that certain work instructions are impractical to follow. An example of the operator's violation of the safety rules is the non-use of gloves when opening the boxes;

The risk of collision between forklift trucks and people happens because there are no specific areas for forklift traffic inside the warehouse, and it is necessary to place physical barriers to limit the contact between the forklift trucks and the people occupying the warehouse. The severity of the consequences of this event is very high since any collision with an occupant can cause multiple injuries, serious fractures, or even fatal injuries. Forklifts are driven by humans, so there is always the risk of faults. With repeated maneuvering of the forklift, the operator is more likely to miss the stop timing, because there is no physical barrier to prevent the forklift from colliding with the trucks receiving the product, with people, and with the pallet entry and exit areas. In the study conducted by Pinheiro & Martins (2020), it was found that the parameter that contributes most to the percentage of the number of existing deviations was the attention parameter (53.85%).

4.2. Criticality analysis

The FMECA approach served to provide the relevant information for the Fault Tree Analysis. It provided a starting point for a root cause analysis. It was convenient to start the registration of the aspects following the flow of the studied process being complemented with the aspects of a general character.

4.2.1. Fault tree analysis

Fault Tree Analysis (FTA) is a top-down probabilistic risk assessment technique. It is a deductive method that investigates the factors and conditions that contribute to adverse events in a system. The strength of the FTA is that it is a visual model that depicts the cause-and-effect relationship between the root cause events to provide both qualitative and quantitative results (Altabbakh *et al*., 2013). In this study, both qualitative and quantitative approaches were used to analyze the probability of the feared events in the Company A warehouse.

By using FMEA/FMECA analysis, two events were extracted for analysis using the FTA technique. These events or top events were:

- ✓ Top event (1): Accident at work
- ✓ Top event (2): Quality control

In figures 14 and 15, we can see the fault tree of the top feared event with all defined intermediate and basic events connected by OR gates. The fault tree under study comes with the respective weight of criteria and alternatives.

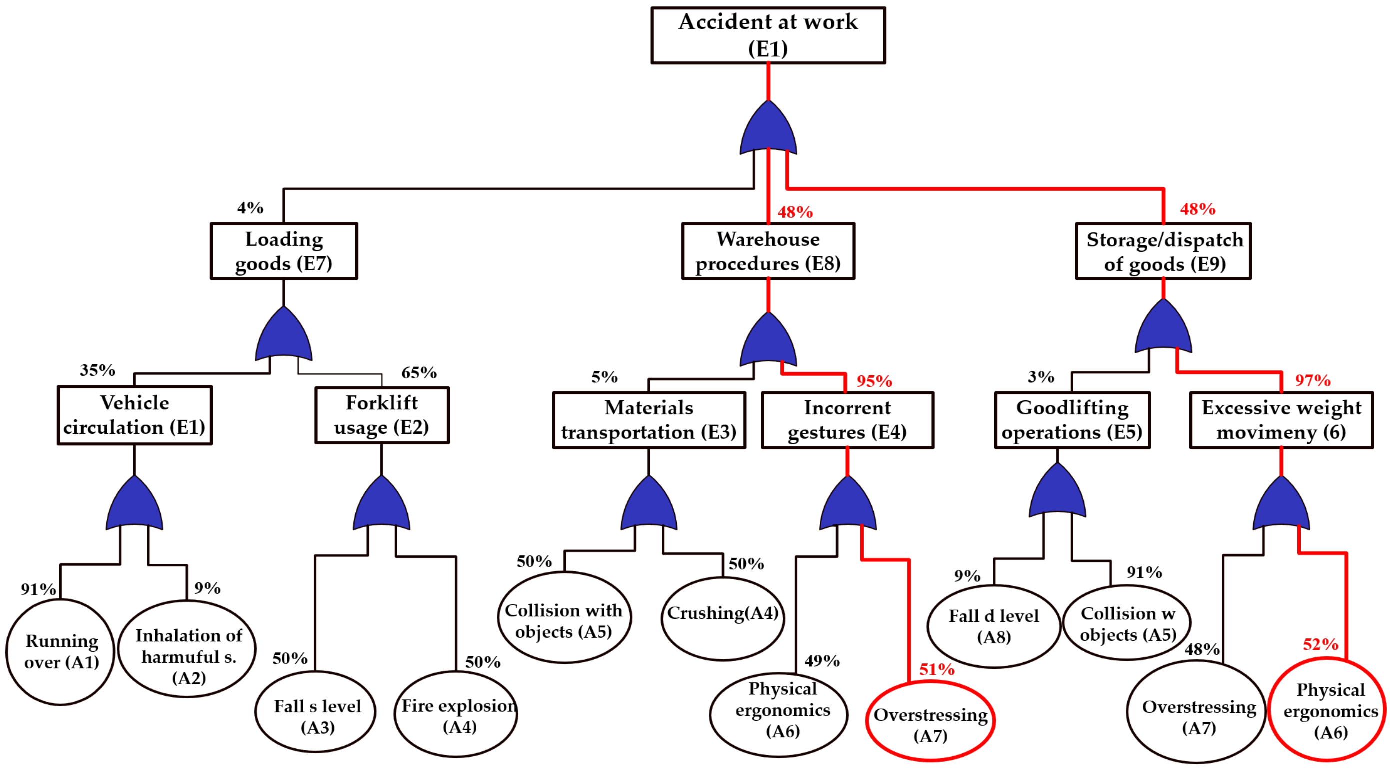

Figure 14. Fault tree diagram of accident occurrence at work

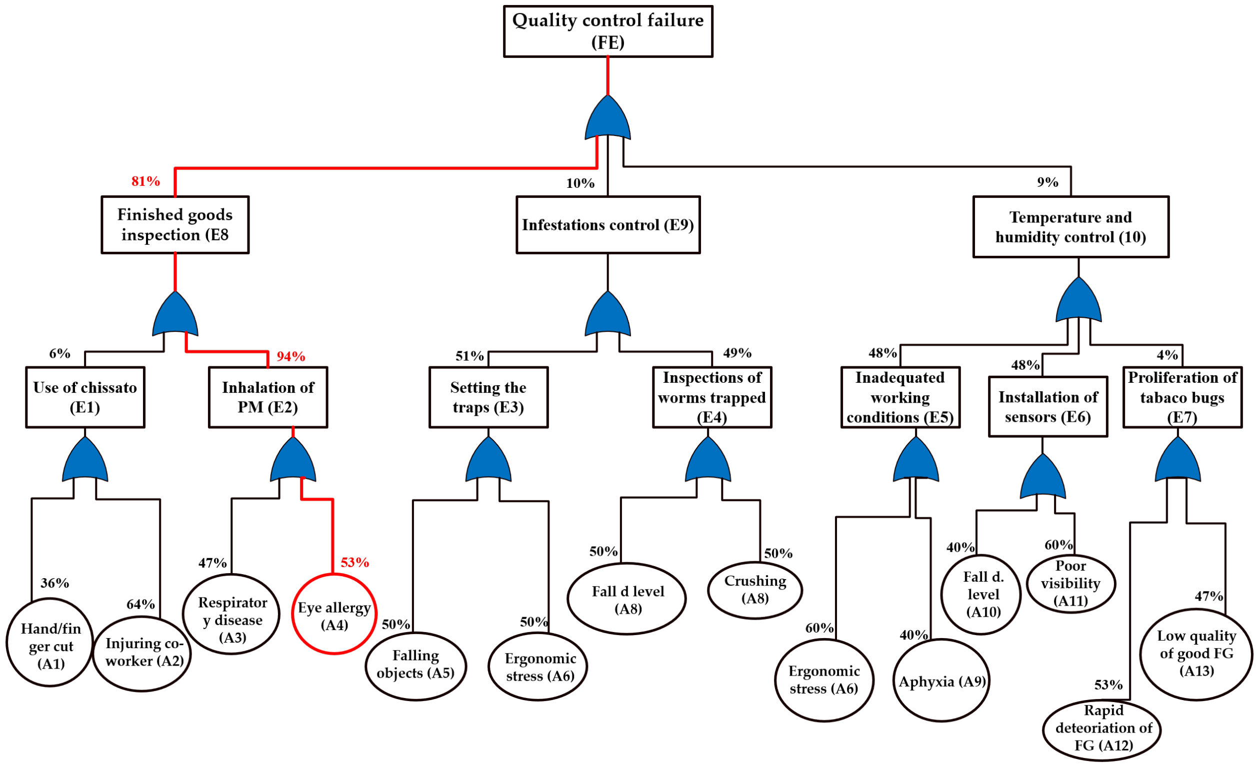

Figure 15. Fault tree diagram of quality control procedures leading to an accident at work

The faults and relationships for each top event have been identified and a logical combination of incidents has been deduced that can trigger unwanted events. In this way, each tree contains information about how the combination of certain faults leads to overall failure. Once the fault trees have been made, the mathematical expressions are defined and the probability values are calculated according to the Boolean algebra related to FTA (Tables 16 and 17).

Table 16. Top event failure frequencies (1)

Identity card	P(E1)	P(E2)	P(E3)	P(E4)	P(E5)	P(E6)	P(E7)	P(E8)	P(E9)	P(E)
Min	5.E-03	1.E-02	1.E-02	6.E-08	5.E-03	8.E-08	2.E-02	1.E-02	6.E-03	4.E-02
Max	1.E-02	2.E-02	2.E-02	7.E-01	1.E-02	7.E-01	3.E-02	7.E-01	7.E-01	9.E-01
Mean	8.E-03	1.E-02	1.E-02	2.E-01	8.E-03	3.E-01	2.E-02	3.E-01	3.E-01	5.E-01
Stand deviation	1.E-03	1.E-03	1.E-03	2.E-01	1.E-03	2.E-01	2.E-03	2.E-01	2.E-01	2.E-01
v_x (PE)	0.16	0.08	0.08	0.73	0.16	0.71	0.07	0.69	0.69	0.40
v_x (PE)*	0.48	0.35	0.34	0.73	0.47	0.71	0.37	0.72	0.71	0.44
Asymmetry	0.85	0.31	0.12	0.36	0.99	0.28	0.31	0.36	0.28	-0.15
Kurtosis Normalized (G2)	1.09	0.45	-0.07	-0.93	1.45	-0.96	0.40	-0.93	-0.96	-0.67

Classification of homogeneity:

Homogeneous when: $-1,5 < G1 < 1,5$

$0 < G2 < 9$

$0,1 \leq vx < 0,2$

Table 17. Top event failure frequencies (2)

Identity card	P(E1)	P(E2)	P(E3)	P(E4)	P(E5)	P(E6)	P(E7)	P(E8)	P(E9)	P(E10)	P(E)
Min	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.05
Max	0.02	0.65	0.02	0.06	0.04	0.04	0.01	0.66	0.07	0.01	0.67
Mean	0.01	0.22	0.01	0.01	0.01	0.01	0.00	0.23	0.03	0.01	0.27
Stand deviation	0.00	0.17	0.00	0.01	0.01	0.01	0.00	0.17	0.01	0.01	0.16
v_x (PE)	0.08	0.80	0.08	0.81	0.62	0.63	1.30	0.75	0.40	0.01	0.61
v_x (PE)*	0.34	0.80	0.39	0.83	1.06	1.14	1.30	0.79	0.74	0.01	0.73
Asymmetry	0.13	0.47	0.24	1.00	1.74	1.77	1.83	0.47	1.00	0.01	0.46
Kurtosis Normalized (G2)	-0.06	-0.92	-0.15	0.65	2.09	2.32	3.28	-0.92	0.66	0.01	-0.92

Classification of homogeneity:

Homogeneous when: $-1,5 < G1 < 1,5$

$0 < G2 < 9$

$0,1 \leq vx < 0,2$

It can be seen in Figures 14 and 15 that in the two Fault trees presented the failures are very similar to each other. This fact results from the loading and unloading of goods and the quality control processes are performed by the same employees, for this reason, all the processes occurring in the warehouse of Company A, work in an interconnected way. It is noteworthy, the fragility of the whole process is enough for a single event to occur for the top event to appear.

Analyzing Figure 14, for the occurrence of an accident at work two critical events were determined. The proportion of occurrence of an accident at work for the normal procedures in the warehouse and storage of goods had a probability of 48%. The occurrence of an accident at work during operations in the warehouse of company A has a lifetime as a factor (cause). The event of an accident is the result of the combination of Overexertion (physical ergonomics) and excessive movement of loads. Lifting or moving products and materials can cause repetitive strain. Even seemingly light loads can result in repetitive motion injuries.

On the other hand, the occurrence of accidents due to bad work posture with the basic event (a situation that generates the whole chain of events) overstressing is caused by mechanical stress. The activities developed in the warehouse sector in Company A are developed essentially manually, without any automation, therefore, the repetition of the same work every day, leads to extreme fatigue in the workers, consequently, altering their state of attention for the execution of their tasks. Thus, the two critical events that were identified have a relationship because they can be related to time without task rotation and the execution of activities in the same position for a long time.

In the study conducted by Pinheiro & Martins (2020), distraction, stress, execution of routine work on automatic, and excess or accumulation of work are the main causes of accidents in a product warehouse. Therefore, to get around this situation it is necessary to take preventive measures to minimize this situation, especially when events of overloaded workers occur, it is necessary to adjust the load and create a rotation plan for workers. The events of ergonomic origin that are repeated along the fault tree are always the same and can always happen for the same reasons, they are due to the repetition of work for long periods and execution of tasks with inadequate posture.

According to Figure 15, there are three (3) ways to generate a top event (2): the first is during "finished good inspection" operations with a probability of 81%, the second is during "infestation control" with the importance of 10% and the third is related to possible failures in the conditions of the warehouse itself which represents 9% of importance.

The analysis of the basic events shows that the human factor is the main cause of the occurrence of the top event (2), as can be seen in Figure 15. The only extreme event, most likely to lead to the occurrence of an accident at work, during the product quality control process, is the inspection of the finished product, and it has a probability of 81%, when combined with the possibility of inhaling particulate matter, with 94%. Comparing the contraction of respiratory diseases with the contraction of eye allergies, the latter has a high probability of occurring at 53%, this fact can be explained by the fact that the operators use protective masks and do not wear goggles at any time. Restuputri & Sari (2015), analyzing the cases of accidents at work in the manufacturing industry, also detected that the lack of use of personal protective equipment, especially, safety goggles, is responsible for eye disorders due to chemicals and glass shards and, the causative factor is the attitude of workers (human factor). Also, Fuentes-Bargues *et al*. (2017), in their study through a fault tree previously analyzed by HAZOP in two companies, in the port of Valencia (Spain), concluded that human errors are one of the main causes of accidents at work in product unloading and loading environments and storage facilities.

Analyzing the top two events it is observed that the most significant risk source for the overall failure sequence is "finished product inspection" in the top event (2) "failures in quality control processes" (with a failure frequency of 0.22 events). This event occurs after inhalation of particulate matter (caused by the fine tobacco particles that are produced during product inspection) resulting from human factors: no use of safety goggles.

On the other hand, the event with the lowest probability of occurrence, are the failures that lead to accidents during product loading operations in the top event (1), with an importance of 4% and a frequency of 0.02 events, because it is one of the most complex operations and involves very strict protocols, which are followed by operators with high rigor.

The procedure for calculating the top event (1) and (2) is shown in Annexes A. The homogeneity test (Figures 16 to 19) was performed to gauge whether the calculation of the probability of the feared event has uniformly distributed values or not. Figures 20 and 21 show the histogram and hazard event curve for the top event (1), respectively.

At first sight, the data seem homogeneous, however, we can distinguish some problems on the histogram as well on the curve. The first one has a more important zone than the others (elements circled in green in Figure 16). As for the curve, we can observe fluctuations in the curve that are not representative of the homogeneity of the data. The data are then governed by different laws. However, the results show that the data comply with the homogeneity requirements.

Figure 17 shows that the hazard event curves for the top event (1) the correlation coefficient, R, is 0.97. This signifies that the obtained curve is not perfectly homogeneous (in the end it is noticed a gap). However, it can also note that the behavior of the sample data is not heterogeneous either. Thus, we validate this analysis, then the distribution of the sample is approximated by a statistical law.

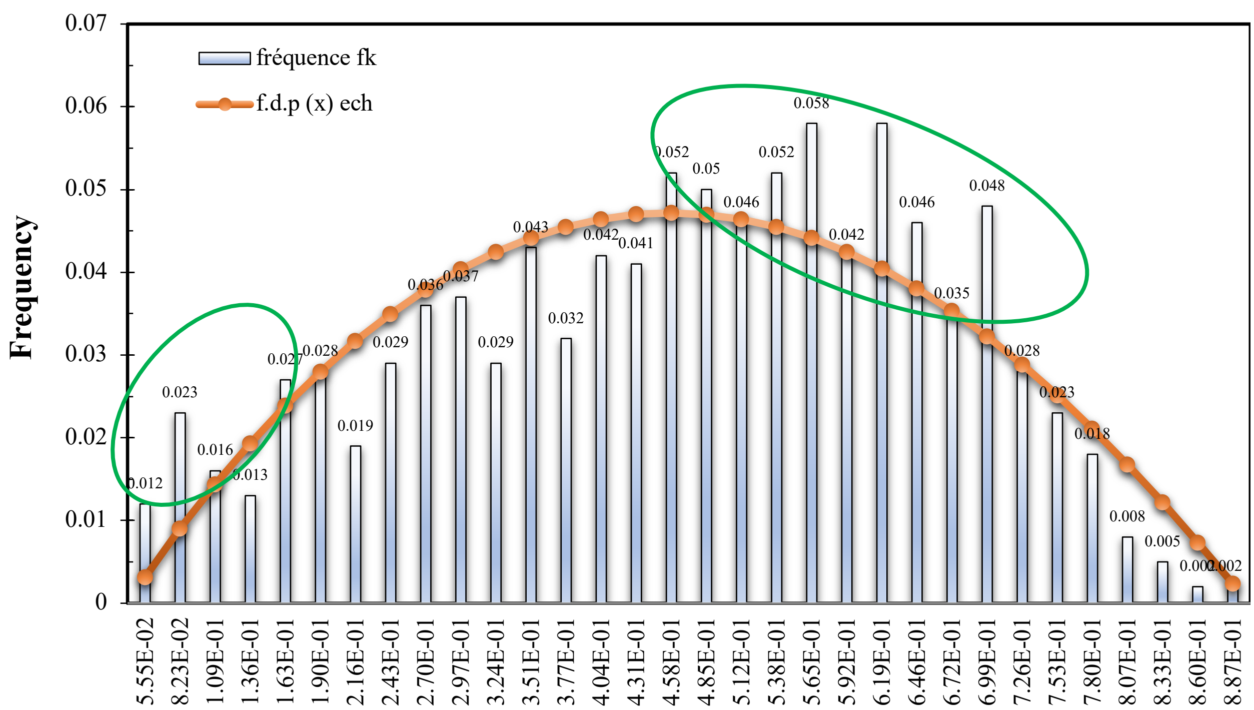

Figure 16. Histogram of the feared event for the top event (1)

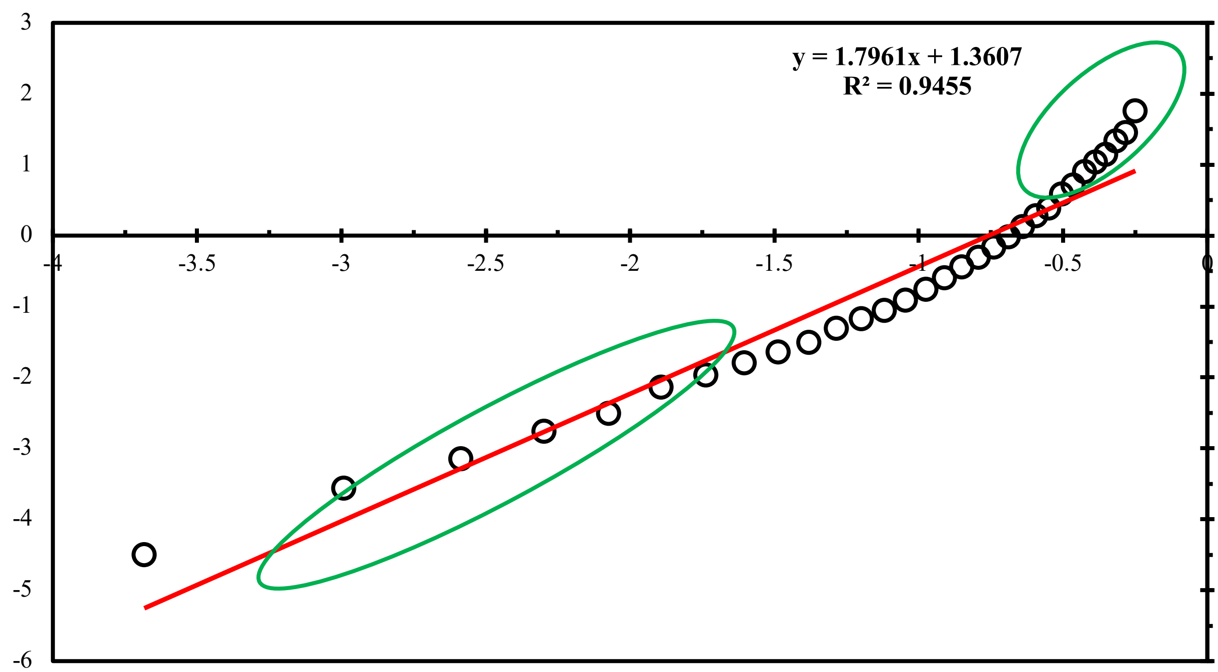

Figure 17. Hazard event curve for the top event (1)

Figures 18 and 19 show the histogram and hazard event curve for the top event (2), respectively. At first sight, the data seem homogeneous; however, we can distinguish some problems on the histogram as well as on the curve. The first one has a more important zone than the others (elements circled in green in Figure 18). As for the curve, we can observe fluctuations in the curve that are not representative of the homogeneity of the data. The data are then governed by different laws. However, the results show that the data comply with the homogeneity requirements. The correlation coefficient, R, is 0.98 for the hazard event curve in the top event (2), as can be seen in Figure 19. This means that the obtained curve is not perfectly homogeneous (in the end it is noticed a gap). However, it can also note that the behavior of the sample data is not heterogeneous either. The top event (2) data are more homogenous than the top event (1) since has 96.3 % of R^2 against 94.55%, suggesting that this data can be modeled by a straight line (linear regression).

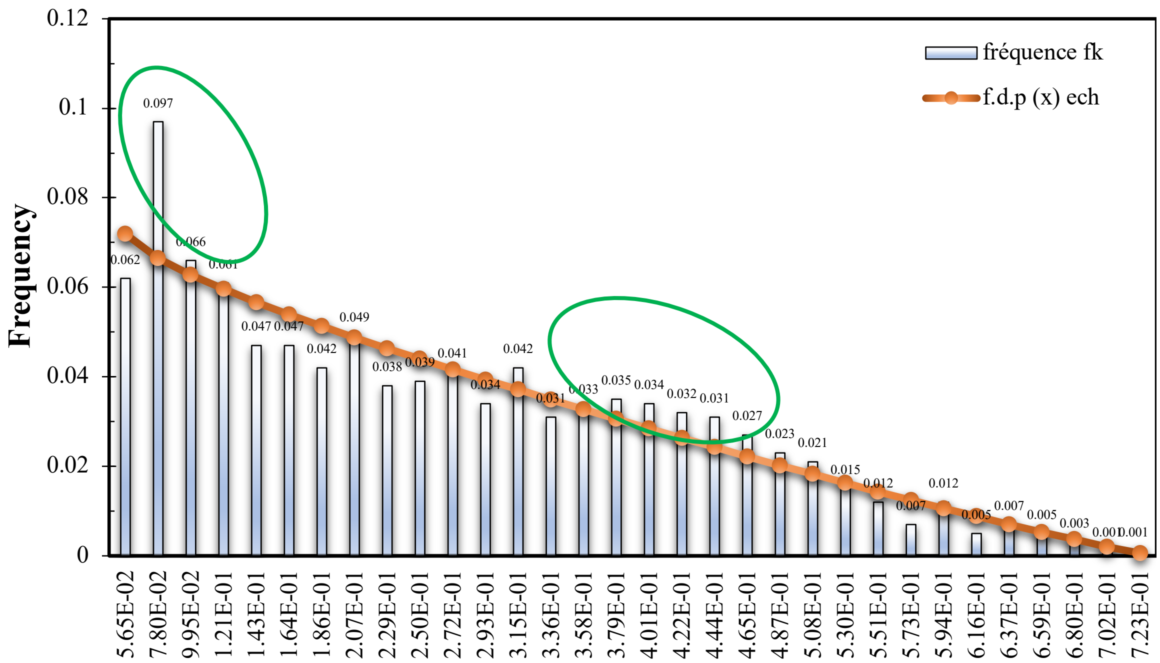

Figure 18. Histogram of the feared event for the top event (2)

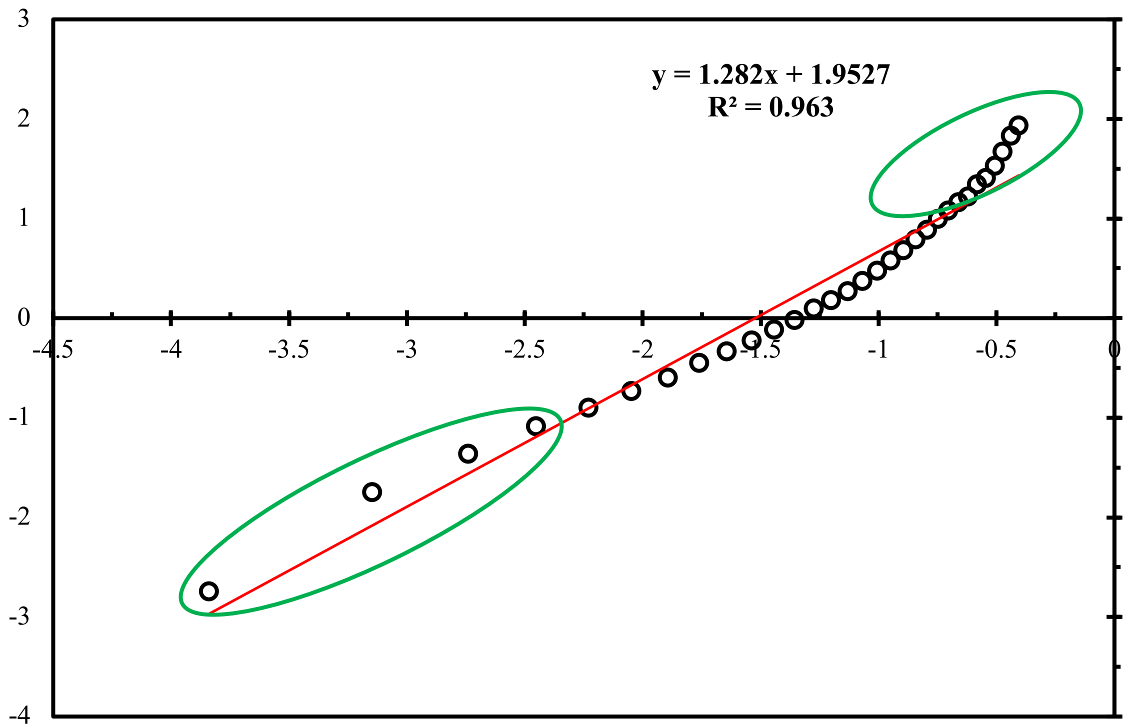

Figure 19. Hazard event curve for the top event (2)

4.3. Health concern in FGW

As evidenced in the risk assessment inherent to quality control activities, there is a need to assess the presence of beetles in the finished product to analyze the influence of temperature and humidity on the growth of these worms. In the FWG of Company A, temperature and humidity are monitored using the digital Mini data logger and Beetle is monitored by Tobacco insect trap (equipment's specifications found in Tables D-1 and D-2, Annex D). Company A FGW Mini data logger and Tobacco insect trap are shown in Figure 20.

Figure 20. Equipment used to monitor physical parameters of FGW in company A. a) Tobacco insect trap; b) Mini data logger.

The average Temperature, Humidity, and Beetle presence from January to December 2022 in company A FGW is presented in Table 18.

Table 18. Monitoring results for FGW

Month	Jan	Feb	Mar	Apr	My	Jun	Jul	Aug	Sept	Oct	Nov	Dec
T_{FGW} [°C]	28.14	28.49	27.80	25.56	23.60	21.06	21.57	22.18	24.58	25.66	27.86	26.17
H_{FGW} [%rH]	69.91	68.65	64.14	69.40	70.47	63.28	69.27	62.49	63.63	62.35	64.56	62.56
T. worms	8.00	7.00	6.00	5.00	2.00	1.00	1.00	2.00	3.00	2.00	6.00	3.00

4.3.1. The relationship between temperature, humidity, and Beetle

To understand if there is an association between the variables under study, Pearson correlation coefficients were performed. The results are shown in Table 19. The values in brackets represent the p-value of the significance test for each relationship.

Table 19. Pearson correlation coefficients

	FGW [°C]	FGW [%rH]	Beetles
FGW [°C]	1.00		
FGW [%rH]	0.18 (0.57)	1.00	
Beetles	0.92 (0.00)	0.34 (0.28)	1.00

According to Montgomery (2013), if the value of Pearson correlation coefficients is in the range from 0 to 0.3 the correlation is negligible, from 0.3 to 0.5 the correlation is weak, and above 0.9 it is very strong. Thus, the data presented in Table 19 shows that there is a negligible correlation between temperature and humidity, and a weak correlation between humidity and the number of Beetle found. However, the correlation between temperature and the number of Beetle is very strong. On the other hand, if the Pearson coefficient values are positive it means that there is a direct proportionality. Thus, the data presented is positive for all variables. The amounts of Beetle in the warehouses of the company under study is significantly and directly correlated to the temperature of the warehouse since the coefficient is 0.92, i.e., the higher the temperature the higher the number of Beetle. Similarly, an increase in warehouse humidity increases the number of Beetle, however, this increase is not significant (p-value > 0.05).

4.3.2. Effect of temperature and humidity on the number of Beetle

The results of the multiple linear regression are presented in Table 22. The objective of this analysis was to quantify the effect of the variable’s temperature and humidity on the number of Beetle. Table 20 presents the coefficients used to evaluate the quality of the linear regression model.

Table 20. Model Quality Coefficients

S	R	R-sq	R-sq(adj)	R-sq(pred)
1.02440	92.5%	85.62%	82.42%	73.11%

The coefficients R, R^2, R^2-adjusted (R^2-adj), and R^2-predicted (R^2-pred) for the applied model, according to Table 3 is equal to 0.925, 0.856, 0.824, and 0.731, respectively. These coefficients evaluate the quality of the empirical multiple regression model and are determined using the formulas presented in Table B-1 (Annex B). From the significance of the R, it can be stated that, with 95% confidence, 92.5 % of the Beetle detected in the warehouse are simultaneously associated with the factors temperature and humidity. On the other hand, R^2 of 0.856 shows that the applied model explains up to 85.62 % of the values of the Beetle found through temperature and humidity.

According to Montgomery (2013), a high R^2 value does not necessarily mean that the regression model is very good, because it increases whenever new variables (significant or not) are added to the model. For this reason, it is preferable to analyze the quality of the model through R^2-adj, whose numerical value is strictly dependent on the significance of the model terms, that is, the expression of R^2-adj includes the fraction $(n - 1)/(n - p)$ which is the smaller the more significant the model terms are (that is, the smaller the value of p). Thus, by the value of R^2-adj, 82.42% of the Beetle values found are strictly associated with temperature and humidity.

The R^2-pred measures the predictive ability of a model (Frost, 2013), that is, the fraction of the total variation in the response that can be accurately predicted by the model. The latter authors add that, an R^2-predicted ≥ 0.5 is acceptable and excellent when it is greater than 0.8. The relationship between temperature and humidity is well described by the model analyzed, since it can explain about 73.11% of new observations of Beetle can be explained by variations in temperature and humidity.

In addition to analyzing the quality coefficients of the model, it is necessary to verify the results of the ANOVA, and these results are presented in Table 21. It is shown in this table that the p-value for the model is equal to 0.00 ($p <0.05$) demonstrating that the model is significant. Also, the temperature variations are significant with a p-value equal to 0.00 ($p < 0.05$), however, the humidity variation does not affect the model significantly. Thus, it can be concluded that the model is significant [$F(2, 11) = 26.79$; $p < 0.05$; $R^2 = 0.856$], and only the temperature has a significant effect on the amount of Beetle detected in the warehouse of the company under study.

Table 21. Analysis of variance for the model

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	56.222	28.111	26.79	0.000
T_{FGW} [°C]	1	48.899	48.899	46.60	0.000
H_{FGW} [%rH]	1	3.259	3.259	3.11	0.112
Error	9	9.445	1.049		
Total	11	65.667			

The regression equation for this model is shown in equation (4) and the coefficients and their significance are shown in Table 22.

$$\text{Beetle} = -27.36 + 0.804T_{FGW}[°C] + 0.1658H_{FGW}[\%H] \qquad \text{Eq. (4)}$$

Table 22. Coefficients of the regression model

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
	(Constant)	-27.359	6.535		-4.186	0.002		
1	T_{FGW} [°C]	0.804	0.118	0.870	6.826	0.000	0.984	1.016
	H_{FGW} [%rH]	0.166	0.094	0.225	1.762	0.112	0.984	1.016

Regarding the results of the regression equation. The coefficients presented in Table 22 and equation (4) can be understood as follows:

- ✓ The values of the coefficients in the linear regression model equation for the variables temperature and humidity are equal to 0.804 and 0.166, respectively, and demonstrate that a unit increase in warehouse temperature and humidity, on average, increases the number of Beetle by 0.804 and 0.166 units respectively.

- ✓ The calculated t-value for the relationship between temperature and quantity of Beetle is equal to 6.826, with an associated p-value of 0.00. Since the p-value is less than 0.05 at the 5% significance level, it is concluded that temperature has a positive and significant impact on the number of beetles detected. On the other hand, the t-value for the humidity vs. n° Beetle relationship is equal to 1.762, with an associated p-value of 0.112. Once the p-value is greater than 0.05, it is concluded that humidity has a positive, weak, and non-significant impact on the number of beetles detected in the warehouse.

Therefore, FGW temperature is the variable with the most weight on the development of Beetle in the finished product during its storage time.

4.4. Preventive measures to reduce the probability of occurrence of identified risks

After the analyses were conducted using the FMECA and FTA methods and risk maps, preventive mechanisms were developed as a method of risk management. Corrective actions relate to a particular risk factor by considering the results obtained from the methods used. Their implementation may reduce the likelihood of the occurrence of a given risk factor, thus making the effect of the hazard less severe for company A.

For the implementation of corrective actions, 5W1H preventive measures were created detailed in Table 23. It was planned and specified the preventive measures and activities to be developed to obtain the improvement in process health and safety conditions, and consequently, eliminate and/or reduce risks. The 5W1H preventive measures proved to be of great relevance because its elaboration took into consideration not only the results achieved with the risk analysis, but also the immediate needs of company A warehouse. Table 23 presents the preventive measures for identified risks in the company A warehouse.

Table 23. 5W1H Preventive measures

Hazards	5W					1 H	Status
	WHAT?	WHO?	WHEN?	WHERE?	WHY?	HOW?	
Inhalation of harmful or toxic substances	Guide the use of PPEs	The company's HSE team	Immediately	In company Warehouse	To ensure the health and protection of the worker, minimizing exposure to risks in occupational	Performing presentations about the importance of the use of PPEs and inspecting use.	Not started
Crushing/Scrapping	Replacing wooden pallets with plastic pallets	Warehouse manager	Immediately	In company Warehouse	Avoid the use of broken pallets below	Purchase a new shipment of pallets	Not started
Collision with objects	Periodic checking and maintenance of racks and other supports	Warehouse manager	Immediately	In company Warehouse	To ensure health and protection and protection, minimizing exposure to risks occupational	Performing daily inspections	Not started
	Use of protective footwear (steel toe cap)	The company's HSE team	Immediately	In company Warehouse	To ensure the health and protection of the worker, minimizing exposure to risks in occupational	Making Presentations about the importance of the use of PPEs and inspecting use.	Not started
	Keeping circulation/passag e routes free and clear of objects/goods;	The company's HSE team	Immediately	In company Warehouse	To ensure the health and protection of the worker, minimizing exposure to risks in occupational	Performing site walk every two hours	Not started
Contracting allergies in the eyes	Guide the use of PPEs: safety goggles	The company's HSE team	Immediately	In company	To ensure the health and protection of the worker, minimizing exposure to risks in occupational	Performing presentations about the importance of the use of PPEs and inspecting use.	Not started

Table 23. Cont.

Hazards	5W					1 H	Status
	WHAT?	WHO?	WHEN?	WHERE?	WHY?	HOW?	
Contracting respiratory diseases	Guide the use of PPEs: safety goggles	The company's HSE t team	Immediately	In company	To ensure the health and protection of the worker, minimizing exposure to risks in occupational	Performing presentations about the importance of the use of PPEs and inspecting use.	Not started

Ergonomic stress or Overstressing	Conduct training on safety operation	The company's HSE team	Immediately	In the company	Enable the workers for working in good positions	Planning the days that will the training	Not started
	Occupational safety exercises	Operators	Immediately	center aisle in the Company Warehouse	Enable the workers for working with relaxed muscles	Every operator should relax every 2 h	Not started
Beetle presence	Control Temperatures level	Quality control manager	Immediately	In company Warehouse	Enable the control of temperature to avoid Beetle growth	Acquisition of new air conditioners	Not started
Cutting risk	Guide the use of PPEs	The company's HSE team	Immediately	In company Warehouse	To ensure the health and protection of the worker, minimizing exposure to risks in occupational	Performing presentations about the importance of the use of PPEs and inspecting use.	Not started
	Awareness Campaigns	The company's HSE team	Immediately	In company Warehouse	To Make workers aware of this issue.	Performing presentations about the importance of the use of PPEs and inspecting use.	Not started

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Company A employees, especially the HSE team are committed to the occupational health and safety safeguards of their co-workers and have established an HSE policy that highlights the importance of safety above any other interest within the organization. After the detailed analysis of the topic under study, and the results interpretation of the risk assessment of the company's warehouse operations, it can be concluded that:

The application of the FMEA/FMECA and FTA methods was found to be crucial since they complement each other. According to the FMECA analysis and identified situations of hazard, near misses, unsafe behavior, and conditions generated, in the general, low-risk event (56.76%). The moderate risks comprise 39.19% and high-risk 4.05%of all the risks. The deviations found (Hazard situations) that contributed most to the occupational risk are in order of importance: use of forklifts and pallet trucks, as well as lifting heavy loads, packing and stocking, and Infestation control.

Through the FTA, it was possible to identify the different basic events that can be associated to result in an accident in FGW. The quantitative analysis of the FTA points to 0.5 and 0.27 probability of occurrence of an accident during loading/unloading procedures and quality control process. The probabilistic risk study predicts that human factors are the main factor that drives the occurrence of the Feared events.

The linear regression analysis showed that Temperature variation is a parameter that determines the presence of Beetle in the FGW of the Company, therefore, the temperature should be more controlled during stored of goods in the warehouse.

For the implementation of some of the safety measures a cost-benefit analysis is required. As a result of the application of the 5W1H preventive measures method and from the FMECA analysis it can be concluded that some of the suggested recommendations entail an excessively large investment for the benefit they bring.

5.2. Recommendations

The present study was limited to the analysis of occupational risks that compromise occupational safety in the FWG of Company A.

However, it is recommended to continue the study to analyze other departments of the company, especially the manufacturing area (the area of greatest and constant occupation by the operators), to understand how they can also contribute to the occurrence of the undesired event and to find ways to prevent such risks. An in-depth study on the effect of beetles proliferation in the warehouse and their influence on occupational health.

The study of the influence of physical parameters (temperature and humidity) on the air quality in warehouses.

It also recommended to study the influence of the quality of the air in the warehouse on the physical effort made by the workers during the exercise of their functions in the warehouse.

Before applying the recommended controls for the different hazards, it is necessary that Company A conducts a cost-benefit analysis of each proposal, as this type of analysis is relevant for decision-making in health and safety management in organizations.

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ANNEXES

ANNEX – A. PROBABILISTIC ANALYSIS CALCULATION

Step 1. Fault Tree Construction

Figures A-1 and A-2 present the initial Fault trees drafted for analysis.

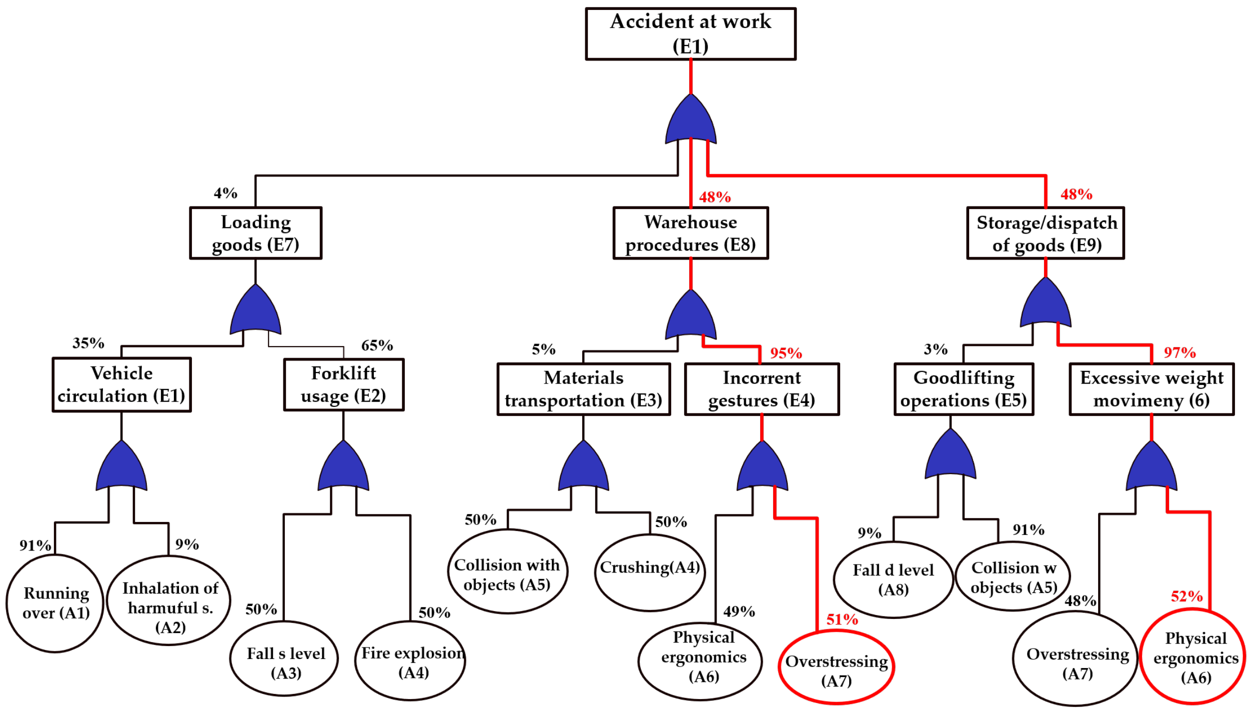

Figure 21. Initial fault tree for the event (1)

Feared event 1: This relates to the risks associated with the work of loading finished products into the dispatch vehicles in the warehouse

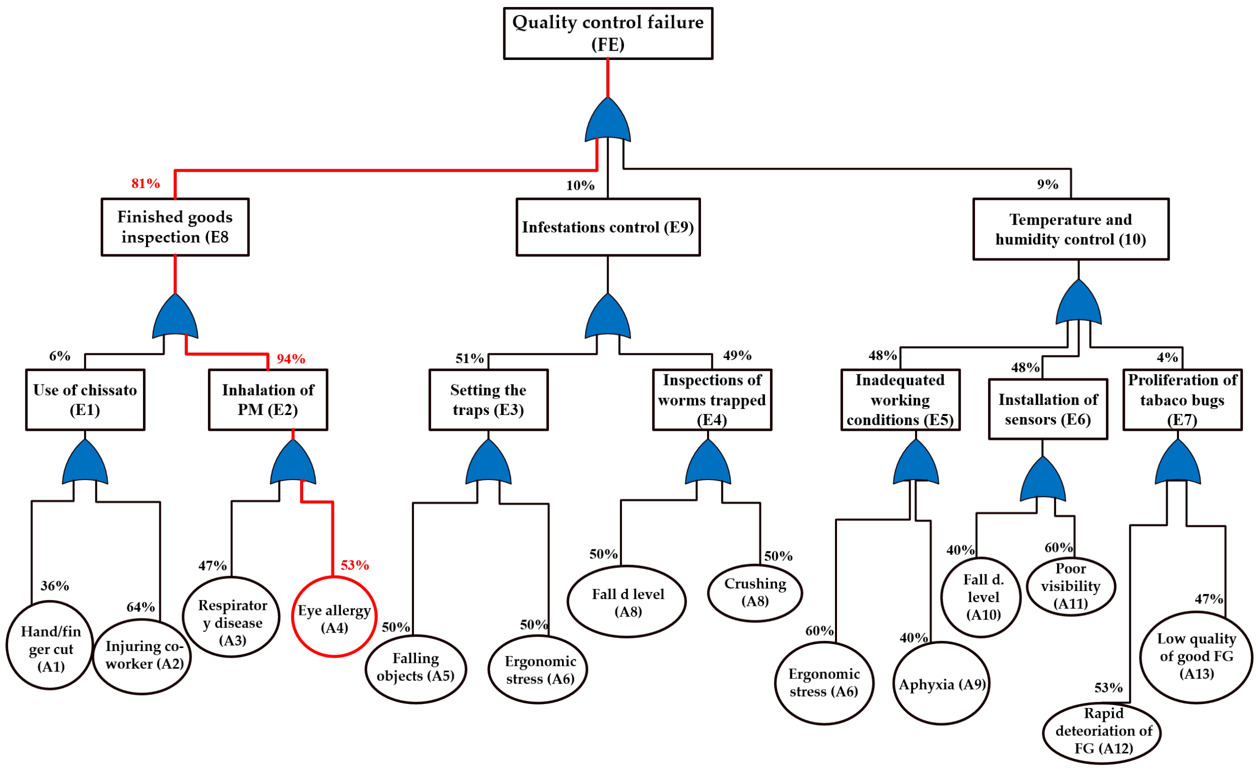

Figure 22. Initial fault tree for the event (2)

Feared event 2: This is related to the risks associated with the procedures performed by the operators for inspection and quality control of the finished product in the warehouse.

Step 2. Basic model

The set of values needed for the calculation of probabilities was chosen arbitrarily according to own interpretation of the problem. Table A-1 shows the statistical laws used.

Table 24. Basic model general characteristics – Feared event 1

ID	Causes	Factor	Law	Questions
A1	Running over	Human factor	BETA 1	The probability of the operators colliding with the forklift due to the absence of barriers for circulation within the warehouse
A2	Inhalations of harmful toxic substances	Mechanical stress	GAMMA	The likelihood of forklift trucks and vehicle mechanics emitting noxious gases
A3	Falling objects	Human factor	BETA 1	The probability of falling objects and products when loading and unloading the product in the warehouse

A4	Crushing / Scrapping	Human factor	BETA 1	The probability of the forklift operator not being able to observe the obstacles due to the height of the load on the vehicle
A5	Collision with objects/ operator cut-off	Human factor	BETA 1	The probability of the operator cutting himself and injuring his hand when opening and closing boxes in the process of product inspection in the warehouse
A6	Physical ergonomics	Lifetime	WEIBULL	The probability of operators developing ergonomic disorders due to the continuous repetition of movements in warehouse activities
A7	Overstressing	Lifetime	WEIBULL	The likelihood of operators developing ergonomic complaints due to the nature of the heavy warehouse work
A8	Falling objects from a different level	Mechanical stress	GAMMA	The probability of materials falling from different levels due to forklift truck lift system failure

Table 25. Basic model general characteristics – Feared event 2

ID	Causes	Factor	Law	Questions
A1	Finger / Hand cutting	Human factor	BETA 1	The likelihood of operators cutting their fingers or hands using the chisato while opening boxes
A2	Injuring another operator	Human factor	BETA 1	The likelihood of operators cutting another operator using the chisato while opening boxes
A3	Contracting respiratory diseases	Lifetime	WEIBULL	The probability of the operator contracting respiratory diseases by inhaling dust from tape and box material
A4	Contracting allergies in the eyes	Lifetime	WEIBULL	The probability of the operator contracting allergic eyes diseases by exposition of dust from tape and box material
A5	Falling objects and operator	Human factor	BETA 1	The probability of falling objects and products during the loading and unloading of the product in the warehouse
A6	Ergonomic stress	Human factor	BETA 1	The likelihood of operators becoming fatigued by high warehouse temperatures and poor indoor air quality
A7	Falling objects on different levels	Mechanical stress	GAMMA	The probability of the operators falling from the top level to the floor while doing the beetle's insertion round
A8	Crushing/Scrapping	Mechanical stress	GAMMA	The likelihood of the operator being crushed over by the load when trying to set the traps
A6	Ergonomic stress	Human factor	BETA 1	The probability of operators becoming fatigued by high warehouse temperatures and poor indoor air quality
A9	Asphyxiation	Mechanical stress	GAMMA	The probability of the warehouse accumulating too much heat, compromising air quality
A10	Falling into different levels	Mechanical stress	GAMMA	The probability of the operators falling from the top level to the floor, while doing the beetle sweep
A11	Poor data visibility	Human factor	BETA 1	The probability of the operator not accurately checking the data on the temperature and humidity control equipment due to the height of the fixture
A12	Rapid deterioration of the finished product	Mechanical stress	GAMMA	The likelihood of the finished product being returned from the market as being of poor quality due to storage
A13	Low quality of finished product	Mechanical stress	GAMMA	The probability of the product losing quality due to storage conditions

Step 3: Probabilistic calculations

From the designations above, it was then possible to make the study the root causes of the tree of failures. These causes were listed from A1 to An and analyzed according to the causes assigned in the dashboard and analyzed in a representative sample of 1000 values to assess the best results. Figure A-3 shows part of these calculations for factor A2.

A2

A lifetime which must not be less than a given threshold t0. We assume t0 is between aT and a P% of the lifespan mean (p between 5 and 10%). So P (A2) = P (T <t0). But the average lifespan is variable between mT1 and mT2. We assume that T follows a WEIBULL law with a beta between beta (inf) and beta (Sup). Also the minimum service life varies between aT1 and aT2. Please note that the average (mX) is always> at the minimum (aX).

aT1	aT2>aT1	mT1	mT2>mT1	beta (INF)	beta (SUP)	p%min	p%max	seuil t0
0	1	1.5	2.5	1.5	5	0.01	0.05	according to the simulations

aT	mT	"beta" Weibull parameter	p%	"eta" Weibull parameter	Standard deviation	v*	g(beta)	t0	Average P(A6)	
0.078453024	2.172179717	3.191490057	0.015936121	2.33795335	0.719871909	0.343823247	0.343823247	1.386700026	0.14510406	0.1266101
0.671326154	2.338929514	4.004274866	0.043646157	1.839692742	0.467385183	0.280273592	0.280273592	0.916045546	0.00031037	
0.464801534	2.274244093	3.459340996	0.024320655	2.012296876	0.578666281	0.31980362	0.31980362	1.653392417	0.14939178	
0.134957457	2.447845888	1.59385249	0.033053691	2.578773176	1.485252248	0.642163378	0.642163378	0.432545753	0.03150337	
0.773598942	1.664312451	2.606657496	0.011829445	1.002741484	0.367151735	0.412199581	0.412199581	1.326959208	0.19130189	
0.743448077	1.833516214	4.344019751	0.035501527	1.196944919	0.283788368	0.260340027	0.260340027	1.06651196	0.00337636	
0.437402302	1.664180421	3.665994574	0.01864491	1.36006966	0.372355262	0.303522908	0.303522908	0.62294136	0.00067345	
0.787121613	1.859451735	4.460263611	0.034717911	1.175667027	0.272555807	0.254171548	0.254171548	1.487993348	0.09475102	
0.563844657	2.147936532	4.08280975	0.032598624	1.745627998	0.436245093	0.275391282	0.275391282	1.845578052	0.24672008	
0.340468169	2.352874504	4.136127373	0.0206688	2.215971472	0.547727202	0.272175252	0.272175252	1.590602672	0.08944184	
0.908440619	2.239109622	2.724369288	0.018560517	1.495873364	0.527236266	0.396218943	0.396218943	1.427657609	0.05444126	
0.210412637	2.319445157	2.471598254	0.020391191	2.377652303	0.911748782	0.432306649	0.432306649	1.099980274	0.08428006	
0.748186016	2.259150132	3.891924117	0.038467215	1.669576575	0.434518423	0.287576931	0.287576931	0.901475132	9.1978E-05	

Figure 23. Example of calculation of basic model probabilistic analysis

Since this is a case of an event linked to its causes utilizing an OR and not an AND, we used the formula:

$$P(A) + P(B) - P(A) * P(B)$$

The causes directly linked to the feared event are connected by 3 root causes. However, the formula applied was:

$$P(A)+P(B)+P(C)-P(A)*P(B)-P(A)*P(C)-P(B)*P(C)+P(A)*P(B)*P(C)$$

To calculate the events of higher levels (0, 1, and 2), the forms presented above were used from the values calculated in the preceding events. However, we used the statistical series and the calculated probabilities of the cause of each lower level to establish that of the corresponding higher level until reaching level 0 (Feared Event).

Step 4 and step 5 correspond to the Homogeneity test and calculation of probabilities of occurrence and critical path design, presented within the main text.

ANNEX – B. STATISTICAL TREATMENT

Table 26. Lists of formulas used for statistical treatment

Parameter	Equation	Legend
Standard deviation (SD) and relative standard deviation (RSD)	$s = \sqrt{\frac{\sum_{i=0}^{n}(x_i - \bar{x})^2}{n-1}}$ $\%RSD = \frac{s}{\bar{x}} \times 100\%$	$\bar{x}$- the average result of x x_i – the individual value of x n – Sample size
Coefficient of correlation (R^2)	$R^2 = 1 - \frac{SS_E}{SS_T}$ $SS_E = \sum_{i=0}^{n}(y_i - \hat{y})^2$; $SS_T = \sum_{i=0}^{n} y_i{}^2 - \frac{\left(\sum_{i=0}^{n} y_i\right)^2}{n}$	SS_E – the sum of squares of the errors SS_T – the sum of the total squares P – significance probability.
The adjusted coefficient of correlation (R^2-adj)	$R^2{}_{adj} = 1 - \frac{SS_E/(n-p)}{SS_T/(n-p)} = 1 - \left(\frac{n-1}{1-p}\right)(1 - R^2)$	
Predict coefficient of correlation (R^2-pred)	$R^2{}_{pred} = 1 - \frac{PRESS}{SS_T}$ $PRESS = \sum_{i=0}^{n}(y_i - \hat{y}_i)^2$	PRESS – the sum of squares of the predicted residuals $\hat{y}$– the value of y predicted by the regression model obtained from n-1 observations
Test F for ANOVA	$F = \frac{SS_{Treatment}/(I-1)}{SS_E/(I-1)}$ $SS_E = \sum_{i=1}^{I}\left[\sum_{j=0}^{n}(y_{ij} - \overline{y_{\blacksquare}})^2\right]$ $SS_{Tratamentos} = n\sum_{i=1}^{a}(\overline{y_{\blacksquare}} - \overline{y_{\blacksquare\blacksquare}})^2$	SSTreatment– Sum of squares due to the factor I – number of groups being compared N – total number of data n – number of replicates for each group ▪ y_{ij}– the sum of observations under i treatments ▪ $\overline{y_{\blacksquare}}$ – average of observations under i treatments $\overline{y_{\blacksquare\blacksquare}}$– an average of all observations

Table 27. Equipment specification data

Variables	**Kolmogorov-Smirnov**			**Shapiro-Wilk**			**Test Meaning**
	χ^2_{cal}	**Degree of freedom**	**t-value**	χ^2_{cal}	**Degree of freedom**	**t-value**	
Beetle	0.217	12	0.125	0.898	12	0.149	Normal
Humidity	0.240	12	0.055	0.821	12	0.057	Normal
Temperature	0.168	12	0.200	0.917	12	0.264	Normal

All the data from, temperature, humidity, and tobacco beetles follow a normal trend, therefore, linear regression and Pearson correlation can be used for analyzing this dataset.

ANNEX – C. IDENTIFIED RISK INDEX CLASSIFICATION

As can be seen, most of the risks encountered can be classified as moderate to low. In general, the hazard-identified situations have RPN values below 90, except for the following situations:

1. For vehicle Loading/unloading:

a) Transport of goods in forklift, RPN equal to **150 – Medium;**
b) Use of forklift, RPN equal to **180 – Medium;**
c) Movement of loaded goods by forklift, RPN equal to **200 – Medium;**
d) Gas-powered forklift, RPN equal to **200 – Medium;**
e) Movement of loaded goods by pallet jack, RPN equal to **120 –Medium;**
f) Using a forklift and/or pallet jack to unload/load goods, RPN equal to **180 – Medium;**
g) Handling of goods to be unloaded, RPN equal to **200 –Medium;**
h) Objects stowed in passageways during manual unloading, RPN equal to **120 – Medium;**
i) Boxes distributed on the floor as a way to organize the merchandise per customer, RPN equals **120 –Medium;**
j) Placing boxes from vehicle bed level to ground level, RPN equal to **180 –Medium;**
k) Handling of oversized and overweight packages, RPN equal to **180 – Medium;**

2. For warehouse operations:

a) Excessive use of force to unload/load boxes, RPN equal to **180 –Medium;**
b) Release of strong smells (chemicals) and particulate material from glue, RPN equal to **300 – High;**
c) Hand Cuts due to handling of chisato knives, RPN equal to **180 –Medium;**
d) Transport of goods in forklift, RPN equal to **150 – Medium;**
e) Use of forklift, RPN equal to **180 - Average**
f) Movement of goods to be loaded by forklift, RPN equal to **200 - Average**
g) Gas-powered forklift, RPN equal to **200 – Average**

3. For warehouse quality control:

a) Self-Hand Cuts due to handling of chisato knives, RPN equal to **216–Medium;**
b) Hand-cuts to another co-worker, RPN equal to **216–Medium;**
c) Contracting respiratory diseases, RPN equal to **160–Medium;**
d) Contracting allergies in the eyes, RPN equal to **96–Medium;**
e) Falling objects and operator, RPN equal to **120–Medium;**
f) Ergonomic stress, RPN equal to **120–Medium;**
g) Frequent contact of the operator with the piles of the finished product in the warehouse, RPN equal to **360–High;**
h) Hot zones with humid air for the execution of the operations in the warehouse by the operators, RPN equal to **300–High;**
i) Asphyxiation, RPN equal to **180–Medium;**
j) Sensors installed in high points to provide better accuracy of the readings, RPN equal to **135–Medium;**
k) Rapid deterioration of the finished product, RPN equal to **240–Medium;**
l) Low quality of finished product, RPN equal to **240 – Medium;**

ANNEX – D. TABACO TRAP AND MINI DATA LOGGER SPECIFICATION

Table 28. Equipment specification data

DATA LOGGER General Specs	
Weight	34 g
Dimensions	60 x 38 x 18.5 mm
Operating temperature	-20 °C to + 70 °C
Housing	Plastic
Protection class	IP20
Channels	2 Internal
Standards	2011/65/EU-guidelines 2014/4/30/EU
Measuring rates	1 min – 24 h
Battery type	2 x 3 V button cell (CR2032)
Battery life	1 year (15 min measuring cycle, +25°C
Memory	16,000 measuring values
Storage temperature	-20 °C to + 70 °C

Tobacco Insect trap: The Tobacco Beetle

Table 29. Tobacco Insect trap

The Tobacco Beetle	The reddish brown, almost hemispherical beetle has a size of 2-4 mm, is covered with fine hairs, and can be found all over the world. The pest infects leaf tobacco and tobacco products but also dried fruits, peanuts, cocoa, maize, wheat, and spices.
Application and Advantages	Store the capsules in a chilly place below 20°C. The pheromone capsule will remain active for 4-6 weeks. The application is versatile: ✓ To recognize and localize infestation at an early stage(monitoring) ✓ To monitor population density ✓ To check the success of other control measures
Container monitoring	**Storage monitoring:** The trap is positioned 15 –20 m apart from each other in storage or production areas. Place the trap on a wall, pale, or the backside of a machine at 1.20 m height. Record the number of caught beetles regularly, at least once a week, or daily if there is an infestation. If their number increases faster than proportionally, further pest control measures should be considered.