Faculty of Engineering
Department of Chemical Engineering
Master Program in Health Safety and Environmental Engineering

OCCUPATIONAL SAFETY AND ENVIRONMENT IN OPERATIONS AT MAPUTO PORT DEVELOPMENT COMPANY. THE CASE OF TIRES DAMAGE IN TERMINAL TRACTORS AND TRAILERS

Research Author: Narciso Soares Narciso

Maputo, April 2023

Faculty of Engineering

Department of Chemical Engineering

Master Program in Health Safety and Environmental Engineering

OCCUPATIONAL SAFETY AND ENVIRONMENT IN OPERATIONS AT MAPUTO PORT DEVELOPMENT COMPANY. THE CASE OF TIRES DAMAGE IN TERMINAL TRACTORS AND TRAILERS

Research Author:

Narciso Soares Narciso

Supervisor :

Prof. Doutor Orlando Zacarias

Maputo, April 2023

AUTHENTICITY STATEMENT

Originality Statement

I declare that this dissertation has never been presented for any degree or in any other scope and that it is the result of my individual work. This dissertation is presented in partial compliance of the requirements for obtaining a master's degree from Eduardo Mondlane University.

(Narciso Soares Narciso)

DEDICATION

To my father Augusto Narciso (in memory) to all learning, valuing education, and life instruction. Father this achievement is for you.

ACKNOWLEDGMENT

Thanks for God for the gift of life and health during the master's course.
To all Mozambican and French teachers for the commitment sharing the knowledge and experience during the course.
To Prof. Doctor Orlando Zacarias for supervision, guidance, patience, and shared knowledge during development of my dissertation. To all companies which together created all conditions to become reality this master's course.
To the coordinator of the Master's program Professor Marcelino Rodrigues & Professor Raed Kouta for their support during my training.
To my wife Ana Sueel Mário, sons Valney Narciso and Oziel Narciso for patience and understanding to accept my absence and lack of attention on days that was dedicated to study and research works.
To my company to accept to give me the availability to attendee the class on worktime, for Maintenance team for support to develop my researching and specially to my boss Eng. Marla Calado to believed me, full understanding, support, and freedom given to me to dedicate my study time whenever necessary.
To classmates for moments of friendship and support.

RECOMMENDATION OF THE BOARD OF EXAMINERS

The undersigned certify that they have read and recommend to the Faculty of Engineering a thesis entitled “**OCCUPATIONAL SAFETY AND ENVIRONMENT IN OPERATIONS AT MAPUTO PORT DEVELOPMENT COMPANY. THE CASE OF TIRES DAMAGE IN TERMINAL TRACTORS AND TRAILERS”.** Submitted by NARCISO SOARES NARCISO, in partial fulfillment of the requirements for the degree of Master’s in HEALTH, SAFETY AND ENVIRONMENT ENGINEERING.

____

Prof. Doutor Orlando Zacarias

Supervisor

____

Doutor Marcelino Januário Rodrigues, Arq.to

Course Coordinator

RESUMO

A Segurança Ocupacional e Meio Ambiente numa empresa, garantem o bem estar físico e psicológico dos trabalhadores durante a execução do trabalho, bem como a preservação do meio ambiente. Este trabalho de pesquisa pretende estudar a segurança ocupacional e meio ambiente nas operações da *Maputo Port Development Company* (MPDC), considerando o caso da danificação de pneus dos tractores de terminal e atrelados. Deste modo pretende-se determinar as causas da danificação de pneus de tractores de terminal e atrelados, propondo medidas de controle e garantir as condições de segurança para os trabalhadores na área operacional. Por outro lado, o estudo é complementado, pela verificação das alternativas de reaproveitamento de pneus danificados, que constituem um grave problema ambiental para gestão e destino dos mesmos.

Para o alcance dos objectivos da pesquisa, foi feita uma abordagem metodológica qualitativa com uso da revisão bibliográfica e colecta de dados operacionais da MPDC. Na análise dos dados foi aplicada a ferramenta de Análise de Modos e Efeitos de Falha (FMEA). Para melhor estruturar o FMEA, utilizou-se as ferramentas da qualidade, tais como: *Brainstorming*, Diagrama de Ishikawa, Diagrama de Pareto e plano de acção 5W1H.

Pela análise quantitativa usando metodologia FMEA para deteriminação do *RPN (Risk Priority Number)* e posterior ilustração gráfica pelo Diagram de Pareto, foi possível identificar os factores "poucos vitais" (que merecem mais atenção), e constituem as principais causas para danificação dos pneus dos tractores de terminal e atrelados que correspondem a 80% dos problemas, e factores "muitos úteis" (embora úteis conhecer tem, têm um efeito relativamente menor). Identificou-se que as causas prioritárias para danificação dos pneus no estudo em causa estavam relacionadas com os falhas C1, C8, C11, C10, C6, C4 e C5 (segundo tabela 9). Usando a ferramenta 5W1H, foi elaborado um plano de ação correctiva e preventiva, para mitigação das causas que contribuem significativamente para a danificação dos pneus.

A geração de quantidades significativa de resíduos dos pneus é um desafio para o mundo e Moçambique em particular. Portanto, a limitação de alternativas para reutilização e reciclagem de pneus estão relacionadas a falta de industrias de regeneração de resíduos de borracha, bem como a complexidade no processo para exportação. Como alternativas de reutilização de pneus danificados, a MPDC usa pneus interiros para protecção contra errosão costeira e delimitação de áreas.

PALAVRAS-CHAVE: HSE, Operações MPDC, perda de pneus, tractor de terminal, FMEA, pneus sucatas, reuso e reciclagem**.**

ABSTRACT

Occupational Safety and Environment in a company ensures physical and psychological well-being for employees while they are performing their duties as well as preserves the environment. This research work aimed at studying the occupational safety and environment at Maputo Port Development Company (MPDC) Operations considering a case study of tires damage in terminal tractors and trailers. In this way, the aim is to determine the causes of damage to tires on terminal tractors and trailers proposing control measures and guaranteeing safety conditions for workers in the operational area. By other side the study is complemented by the verification of alternatives for reuse of damaged tires, which present a serious environmental problem for their management and destination.

To reach the research objectives, a qualitative methodological approach was employed using a bibliographical review and collection of operational data from the MPDC. In the data analysis, the quantitative tool Failure Modes, and Effects Analysis (FMEA) was applied. For better structuring the FMEA, was used the quality tools, such as: Brainstorming, Ishikawa Diagram, Pareto Diagram and 5W1H action plan.

Through the quantitative analysis using FMEA methodology to determine the RPN (Risk Priority Number) and subsequent graphic illustration by the Pareto Diagram, it was possible to identify the "few vital" factors (the factors that warrant the most attention), and which constitute the main causes for the damage of tires in terminal tractors and trailers which correspond to 80% of the problems, and "very useful" factors (while useful to know, have a relatively minor effect). It was identified that the priority causes for the damage of tires in the case study were related to failures C1, C8, C11, C10, C6, C4 and C5 (according to table 9). Using tool 5W1H, was developed a corrective and preventive action plan, to mitigate the causes that contribute significantly to tire damage.

The generation of significant amounts of tire waste is a challenge for the world and Mozambique in particular. Therefore, the limitation of alternatives for reusing and recycling tires are related to the lack of rubber waste regeneration industries, as well as the complexity in the process for export. As alternatives for reuse of damaged tires, MPDC uses whole tires to protect against coastal erosion and to delimit areas.

KEY WORDS: HSE, MPDC Operations, tire losses, terminal tractor, FMEA, scrap tires, reuse and recycling**.**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXES

LIST OF ABBREVIATION AND ACRONYMS

HSE - Health Safety & Environment

OHS – Occupational Health & Safety

MPDC - Maputo Port Development Company

CFM – Caminhos de Ferro de Moçambique

FMEA - Failure Modes and Effects Analysis

ETA – Event Tree Analysis

QC - Quality Control

P - Probability

S – Severity

ALARP - As Low as Reasonably Practicable

RV – Risk Value

O - Occurrence

D – Fault Detection

RPN – Risk Priority Number

HIRA - Hazard identification and risk assessment

DEFINITIONS:

Terminal tractor: a special truck used in port terminal.

Skips: recipients where the ore placed to be carried trailer of terminal tractor.

Slab: place in the open sky where the ores are stored in the form of piles.

Jersey block: barriers built in concrete for area protection and containment of cargo in stockpiles.

Stockpile: cargo of ore stored in the form of mountains.

1. INTRODUCTION

1.1.Context

The present study deals with the Health, Safety and Environment in MPDC Operations, with case study of tires damage in tractors and trailers.

A tire is a ring-shaped component that wraps around the rim of a wheel to transfer a vehicle's load from the axle through the wheel to the ground and provide traction on the surface over which the wheel travels. Most tires are pneumatically inflated structures that also function as a flexible cushion that absorbs shock as the tire rolls over rough features on the surface. (Tire - Wikipedia).

There are three most relevant operating costs in the provision of logistics services: fuel supply, vehicle maintenance and tire maintenance. It is important to refer that the mentioned costs largely depend on how the vehicles are used by drivers, that is, the how more correct the vehicle is driven, the better the tire maintenance conditions will be, with a consequent reduction in operating costs (Dario et al., 2014).

Based on the previous situation, MPDC is greatly affected by the costs related to maintenance and/or replacement of tires, due to significant losses for different factors during loading and unloading operations, mainly in the shipment of iron ores.

In a cargo transport company, one of the subjects that draws the most attention is the tire, as it is normally the second item with the highest maintenance cost in a company of this profile, being only behind the cost of fuel (diesel oil) (Pecorari, 2020).

Maintenance plays a fundamental role for any company’s business, especially when one of its components is unavailable due to failure or anomaly, which leads to non-production/operation costs. It is evident that in the current times, minimizing costs and increasing efficiencies is one of the strategic assumptions of companies to be able to better compete in the market.

In a logistics company such as MPDC, tires for terminal vehicles, which become a consumable, have relative financial importance, to which their contribution must be optimized, and their operating cost reduced. Effective tire management can significantly prolong the life-cycle of tire before changing or retreading. Associated with the significant losses of tires, a major environmental problem arises, related to the correct destination that is given to waste tires.

MPDC has as one of the values the Occupational Safety and the impacts of tires losses in terminals tractors and trailers has been compromising the safety for operators, other workers around as well as environment. In addition to the analysis of tires impacts, it will also be a priority of study in this research, propose the control measures to reduce or eliminate events and impacts, ensuring the continuous improvement of MPDC’s business as well as alternatives for the reuse of scrap tires. Events resulting from tire damage not only bring the risk of material damage, but also human and environmental damage. Among the material risks can be highlighted, tire explosion, collision of the terminal tractor with other mobile equipment or infrastructure and for human risk injury to the operator or other work around.

On the other hand, damaged tires bring several and significant impacts to the environment if the correct treatment is not followed, as: potential for tire fires which produce acid smoke harmful to humans and the environment as well as leaves behind an oil waste, ground for mosquitoes and take up landfill space.

To avoid high investment in tires, it is necessary to understand the reasons for the damage of each tire. This study will lead to cost savings by providing guidance and help on the following points:

- Identify the causes of tire damages and propose control measures.
- Improve the tire maintenance and selection system.
- Identify tire reuse alternatives.

1.2. Justification

All companies are responsible to ensure the health and safety conditions for their employees and other parties that may be affected by their activities.

The promotion of occupational health and safety culture is intended to enable the companies to provide safe and healthy workplaces, prevent injuries and other losses related to the work and continuous improvement for health and safety performance indicators.

During MPDC operations is being highlighted the occurrence that result in tires damages, conditions that opened any opportunities to study and understand this fact.

Any loss in a company brings different impacts, but tire damage for logistic business, as MPDC the impacts are significative, affecting directly on availability of operational resources as the combination of terminal tractor and respective trailer, compromising negatively on the productivity during the operations of loading iron ores to ships and environmental impacts.

Terminal tractors are a type of machine used in port terminals, for cargo transport, and therefore widely used in MPDC Operations. Like any other type of road vehicle, terminal tractors need tires for their movement.

The tire is an essential component for any road vehicle, for the study in question terminal tractors and trailers.

Traction, braking and steering forces are generated between the road and the tires and control the vehicle's motion. Tires, however, wear down, causing dispersal of unhealthy wear particles as well as disposal of old tires, which is harmful to the environment (Wang, 2017).

The objective of this study is to analyze and identify the possible causes that result in the damage of tires, to reduce this impact, which will bring beneficial from an economic and ecological point of view.

The incidents that result in tire damage are what appear to be the main ones that have contributed to the reduction in the availability of operational resources, in this case terminal tractors, compromising productivity in the operations of loading iron ore to ships and adding additional costs, for outsourcing the platform trucks services.

MPDC has been making large investments for the growth of its business, from infrastructure, equipment, Occupational Health Safety and Environment and automation of systems.

The port activity and other transport systems are under great pressure to meet the wishes of their customers and users in increasingly shorter deadlines. In this way, due to the dynamics in its activities and pressure to meet the wishes of its customers, shareholders and users, there is an urgent need to create a work environment that allow workers to perform their tasks in safe conditions with the least possible risk to their lives and on the other hand guarantee customer satisfaction by offering quality services.

Furthermore, due to the increase in activities and services at the port, there is a need for the MPDC to increase its fleet of terminal tractors, the cargo storage areas, specifically minerals and labor. The last reinforcement of terminal tractors was accompanied by a significant number of damages to tires and at the same time an increase in purchase demand. The increase in the number of tire damage events worried MPDC's management, as it contributes negatively to the reduction of the equipment resource (combination of terminal tractors and trailer) that has impacted with the increase in the turnaround time of ships.

The problem of amounts waste generation may be associated with industrial and technological development, which focuses on the comfort and well-being of employees, in the production of disposable materials, which after use are not used, becoming harmful to the health of the man and the environment. For Mozambique in special, a broader awareness is needed regarding the final disposal of solid waste, particularly tires, working mainly on reducing their generation. In addition, to insert a philosophy of reusing, recycling, or reusing the material at hand, before completely discarding it.

1.3.Research Objectives

1.3.1. General Objectives

The general objective of this research relates to:

- Determine the main causes that result in tire damages of the terminal tractors in MPDC operations.

1.3.2. Specifics Objectives

Specific objects are listed as:

- Propose improvements to the Health, Safety and Environment system at the MPDC, in relation to the damage of tires on terminal tractors and trailers.
- Propose an action plan to minimize the event with damage tires on terminal tractor and trailer in MPDC Operations.
- Identify possible solutions for the correct treatment of waste tires from the point of view of environmental preservation.
- Demonstrate the life cycle of tires used in MPDC's operations.

1.4.Company Presentation

Maputo Port Development Company (MPDC) is a national private company, which results from the partnership between Caminhos de Ferro de Moçambique - CFM (Mozambique Railway Company) and Portus Indico, comprised by Grindrod, DP World and local company Mozambique Gestores. On 15th of April 2003 MPDC was given the concession of Maputo’s Port for a period of 15 years, with an extension option of another 15. In June 2010, the concession period was extended for another 15 years, with an option of an additional ten years of operations after 2033.

MPDC holds the rights to finance, rehabilitate, construct, operate, manage, maintain, develop, and optimize the entire concession area. The company also holds the powers of a Port Authority, being responsible for maritime operations, piloting towing (tugboats), stevedoring, terminal, and warehouse operations, as well as port’s planning development.

a) MPDC Organogram

The MPDC organogram as illustrate in the organogram flow chart (figure 1, on the next page), the HSE area is represented in two directions:

- Operations Direction: where the main responsibility is handling cargos. The process of handling cargos consists in reception of mineral via trucks or wagons, store in stockpile and then shipping in vessel, in order side offloading cargos coming from vessel. The case study on this research is managed in the Operations Department.

- Port Authority Direction: the main responsibility is establishing, regulating and monitor the compliance of Port rules (HSE and Security) in common areas and sub concession.

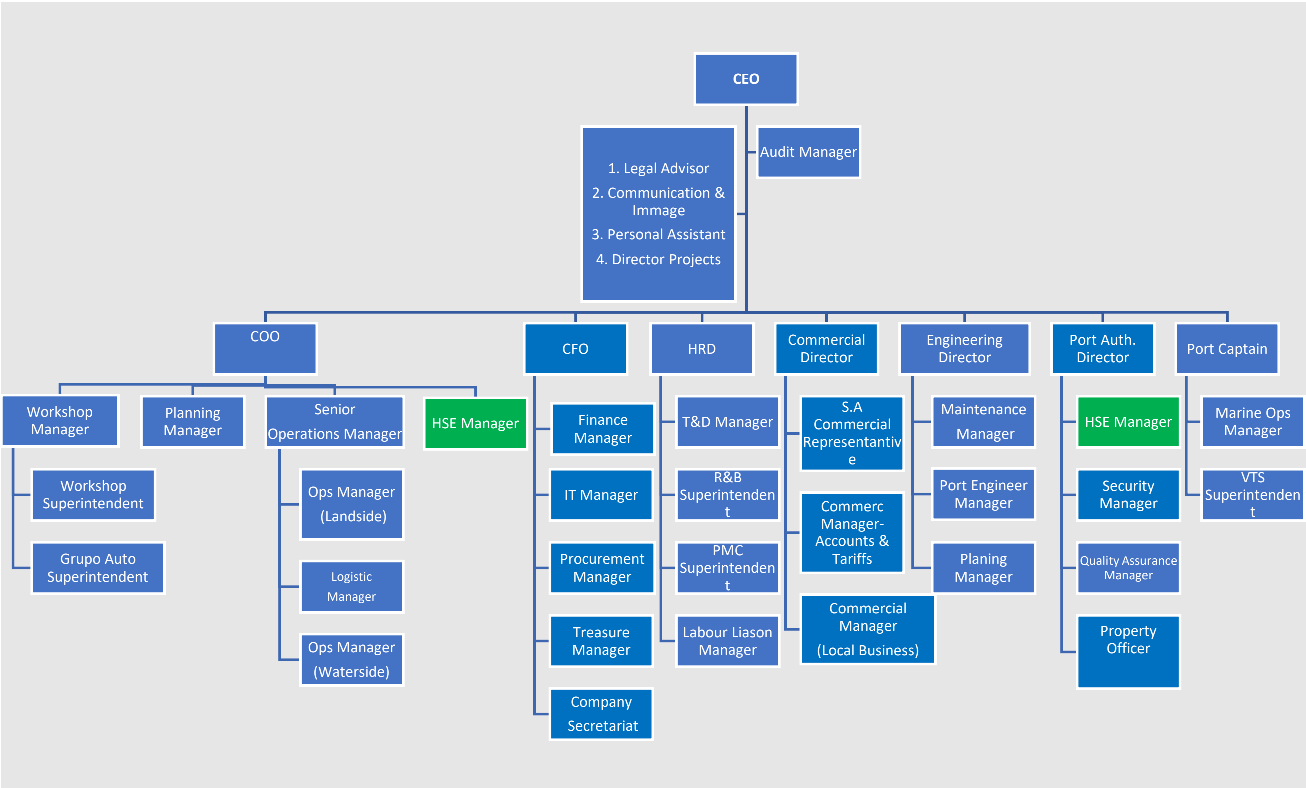
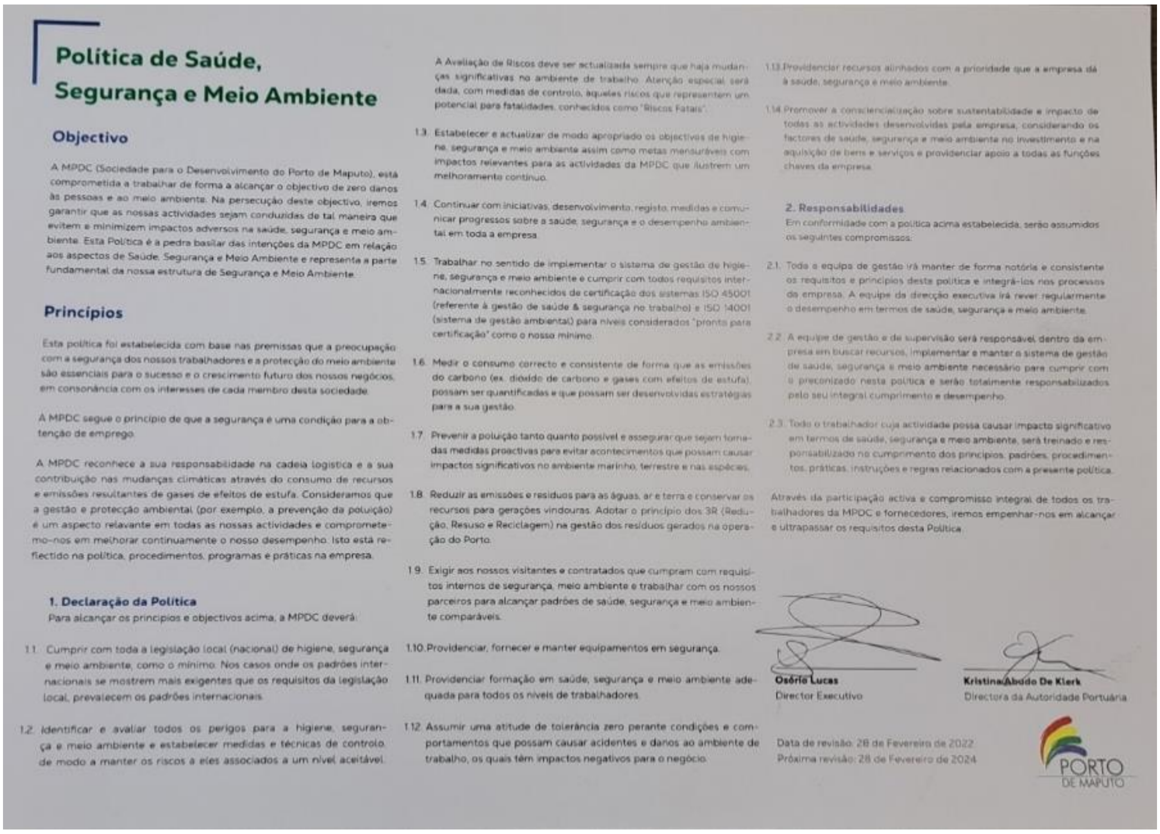


Figure 1: MPDC Organogram

Source: MPDC

b) **MPDC HSE Policy**

MPDC has established the HSE Policy whose main commitment is to ensure zero harm to people and the environment. See figure 2 below:



Política de Saúde, Segurança e Meio Ambiente

Objectivo

A MPDC (Sociedade para o Desenvolvimento do Porto de Maputo), está comprometida a trabalhar de forma a alcançar o objectivo de zero danos às pessoas e ao meio ambiente. Na persecução deste objectivo, iremos garantir que as nossas actividades sejam conduzidas de tal maneira que evitem e minimizem impactos adversos na saúde, segurança e meio ambiente. Esta Política é a pedra basilar das intenções da MPDC em relação aos aspectos de Saúde, Segurança e Meio Ambiente e representa a parte fundamental da nossa estrutura de Segurança e Meio Ambiente.

Princípios

Esta política foi estabelecida com base nas premissas que a preocupação com a segurança dos nossos trabalhadores e a protecção do meio ambiente são essenciais para o sucesso e o crescimento futuro dos nossos negócios, em consonância com os interesses de cada membro desta sociedade.

A MPDC segue o princípio de que a segurança é uma condição para a obtenção de emprego.

A MPDC reconhece a sua responsabilidade na cadeia logística e a sua contribuição nas mudanças climáticas através do consumo de recursos e emissões resultantes de gases de efeitos de estufa. Consideramos que a gestão e protecção ambiental (por exemplo, a prevenção da poluição) é um aspecto relavante em todas as nossas actividades e comprometemo-nos em melhorar continuamente o nosso desempenho. Isto está reflectido na política, procedimentos, programas e práticas na empresa.

1. Declaração da Política

Para alcançar os princípios e objectivos acima, a MPDC deverá:

1.1. Cumprir com toda a legislação local (nacional) de higiene, segurança e meio ambiente, como o mínimo. Nos casos onde os padrões internacionais se mostrem mais exigentes que os requisitos da legislação local, prevalecem os padrões internacionais.

1.2. Identificar e avaliar todos os perigos para a higiene, segurança e meio ambiente e estabelecer medidas e técnicas de controlo de modo a manter os riscos a eles associados a um nível aceitável. A Avaliação de Riscos deve ser actualizada sempre que haja mudanças significativas no ambiente de trabalho. Atenção especial será dada, com medidas de controlo, àqueles riscos que representem um potencial para fatalidades, conhecidos como "Riscos Fatais".

1.3. Estabelecer e actualizar de modo apropriado os objectivos de higiene, segurança e meio ambiente assim como metas mensuráveis com impactos relevantes para as actividades da MPDC que ilustrem um melhoramento contínuo.

1.4. Continuar com iniciativas, desenvolvimento, registo, medidas e comunicar progressos sobre a saúde, segurança e o desempenho ambiental em toda a empresa.

1.5. Trabalhar no sentido de implementar o sistema de gestão de higiene, segurança e meio ambiente e cumprir com todos requisitos internacionalmente reconhecidos de certificação dos sistemas ISO 45001 (referente à gestão de saúde & segurança no trabalho) e ISO 14001 (sistema de gestão ambiental) para níveis considerados "pronto para certificação" como o nosso mínimo.

1.6. Medir o consumo correcto e consistente de forma que as emissões do carbono (ex. dióxido de carbono e gases com efeitos de estufa), possam ser quantificadas e que possam ser desenvolvidas estratégias para a sua gestão.

1.7. Prevenir a poluição tanto quanto possível e assegurar que sejam tomadas medidas proactivas para evitar acontecimentos que possam causar impactos significativos no ambiente marinho, terrestre e nas espécies.

1.8. Reduzir as emissões e resíduos para as águas, ar e terra e conservar os recursos para gerações vindouras. Adotar o princípio dos 3R (Redução, Resuso e Reciclagem) na gestão dos resíduos gerados na operação do Porto.

1.9. Exigir aos nossos visitantes e contratados que cumpram com requisitos internos de segurança, meio ambiente e trabalhar com os nossos parceiros para alcançar padrões de saúde, segurança e meio ambiente comparáveis.

1.10. Providenciar, fornecer e manter equipamentos em segurança.

1.11. Providenciar formação em saúde, segurança e meio ambiente adequada para todos os níveis de trabalhadores.

1.12. Assumir uma atitude de tolerância zero perante condições e comportamentos que possam causar acidentes e danos ao ambiente de trabalho, os quais têm impactos negativos para o negócio.

1.13. Providenciar recursos alinhados com a prioridade que a empresa dá à saúde, segurança e meio ambiente.

1.14. Promover a consciencialização sobre sustentabilidade e impacto de todas as actividades desenvolvidas pela empresa, considerando os factores de saúde, segurança e meio ambiente no investimento e na aquisição de bens e serviços e providenciar apoio a todas as funções chaves da empresa.

2. Responsabilidades

Em conformidade com a política acima estabelecida, serão assumidos os seguintes compromissos:

2.1. Toda a equipa de gestão irá manter de forma notória e consistente os requisitos e princípios desta política e integrá-los nos processos da empresa. A equipe da direcção executiva irá rever regularmente o desempenho em termos de saúde, segurança e meio ambiente.

2.2. A equipe de gestão e de supervisão será responsável, dentro da empresa em buscar recursos, implementar e manter o sistema de gestão de saúde, segurança e meio ambiente necessário para cumprir com o preconizado nesta política e serão totalmente responsabilizados pelo seu integral cumprimento e desempenho.

2.3. Todo o trabalhador cuja actividade possa causar impacto significativo em termos de saúde, segurança e meio ambiente, será treinado e responsabilizado no cumprimento dos princípios, padrões, procedimentos, práticas, instruções e regras relacionados com a presente política.

Através da participação activa e compromisso integral de todos os trabalhadores da MPDC e fornecedores, iremos empenhar-nos em alcançar e ultrapassar os requisitos desta Política.

Osório Lucas
Director Executivo

Kristina Abudo De Klerk
Directora da Autoridade Portuária

Data de revisão: 28 de Fevereiro de 2022
Próxima revisão: 28 de Fevereiro de 2024

PORTO DE MAPUTO

Figure 2: MPDC HSE Policy

Source: MPDC

1.4.1. MPDC HSE System

MPDC developed, implemented, maintaining, and continually improves your OHS management system based on international standard ISO 45001. In this moment MPDC is working on process for certification on this standard ISO 45001. One of the requirements of this standard is the compliance of legal requirement. The HSE Mozambican legal requirement that MPDC has as support in their system are listed below:

a) Labor Law 23/2007 of 1st August 2007:

On this law specifically on chapter VI approaches about Hygiene, Safety and Health of Employees where the matters described follow are full complied in MPDC:

- Work safety commissions (Article 217): MPDC stablished a work safety committee composed by HSE representative for each area, union representative, Department managers, HSE team, HSE officers of the service providers companies and Chief

Operations Officer (as chairperson), This committee meet on monthly base and all matter discussed are compiled on minutes.

- Medical examinations (Article 221): on an annual basis the employees are submitted on medical surveillance in order to monitor health conditions. Most of the examinations are conducted in internal MPDC clinic except X rays and blood examination.
- Concept of Work Accident (Article 222): was developed and implemented a procedure to manage the incident/accident, where is mandatory to report and investigate all accidents.

b) Legislative Diploma 48/73: Approves the General OHS Regulation in Industrial Establishments

c) Decree 62/13, 04 of December: Regulation establishing the legal regime for accidents at work and occupational diseases.

1.4.2. High risk activities at MPDC Operations

Based on MPDC activity risk matrix, due to magnitude of the risk level, being high, these activities were classified as high risk. To ensure that these activities being conducted in safe conditions, were established specific control measures as described, as below:

a) Shipping of minerals.
b) Working at Height.
c) Hot Working (Welding).
d) Discharge of general cargos from the vessel.
e) Manual housekeeping in the slabs.
f) Gas bottle moving, storage & utilization.
g) Fuel Supply by mobile tank.

In the table below is presented the potential risks and preventives control measures to the high-risk activities:

Table 1: Risk analysis of activities with high risk and control measures

Activity	Potential Risks	Preventive Measures
Shipping of minerals **(Using ship crane and mobile crane)**	• Injury on stevedores' hands during connections chains on the skips. • Respiratory diseases due to dust inhalation. • Running over with mobile equipment's (forklift and tractors).	• Allocation of stevedores with adequate training on this tasks. • Definition of traffic flow for mobile equipment and pedestrian. • Use of PPE (safety boots, dust mask, helmets with chain streps, gloves, glasses). • Installation of alert signs on mobile equipment (reverse alarm and rotating light).

	• Seriou's injury due to fall of suspended cargo. • Contamination of water sea with ore. • Collision between mobile equipment or physical structures.	• Safety procedure "Not work under suspending load". • Barricade and sign around the workplace. • Stablished speed limit. • Inspect all lifting equipment's. • Allocation of certified operators and winchman.
Work at height	• Fall from height and fall from the same level (slips and trips). • Struck against rigid structure, sharp or rough objects. • Struck by falling objects. • Caught in, on or in between objects. • Electrocution. • Fire.	• Barricade the area around and define "no go zone". • Tools fitted with a lanyard. • Use helmet with chin strap. • Use safety harness in good conditions. • Allocation of a standby person. • Issue the PTW. • Use of suitable equipment and tools for task. • Person trained.
Welding (Hot Working)	• Injury due to burns. • Respiratory diseases due fumes inhalation. • Eye injury from debris. • Hearing damage due to noise. • Electrocution. • Fire. • Explosion.	• Issue a Permit to work. • Provide a fire extinguisher. • Barricade the area. • Remove from the workplace all combustible material. • Use of PPE (safety glasses, gloves, uniform wit long sleeve, mask, and face shields). • Supervision on activity. • Qualified welders.
General Cargo discharging	• Injury on stevedore's hands during connections chains on the skips. • Running over with trucks. • Serious injury due to fall of suspended cargo. • Collision between mobile equipment or physical structures.	• Allocation of stevedores with adequate training on these tasks. • Definition of traffic flow for mobile equipment and pedestrian. • Use of PPE (safety boots, helmets with chain streps, gloves, glasses). • Installation of extension or barricade on trailer truck to avoid fall of cargo. • Safety procedure "Not work under suspending load". • Barricade and sign around the workplace. • Stablished speed limit. • Inspect all lifting equipment's. • Allocation of certified winchman.
Cleaning in the slab	• Injury on stevedore's hands due to manuals tools. • Respiratory diseases due to dust inhalation. • Running over with mobile equipment's (payloaders, tractors and trucks); • Contamination of drainage water with ore.	• Allocation of stevedores with adequate training on these tasks. • Definition of traffic flow for mobile equipment and pedestrian. • Use of PPE (safety boots, helmets with chain streps, gloves, glasses). • Installation of alert signs on mobile equipment (reverse alarm and rotating light). • Safety procedure "Not work under suspending load". • Barricade and sign around the workplace.

	• Collision between mobile equipment or physical structures.	• Stablished speed limit. • Allocation of certified operators and winchman.
Gas bottle moving, storage & Utilization	• Injury due to burns. • Fire due to gas leakage. • Serious injury due to explosion. • Faulty equipment / connections. • Explosion. • Injury due to fall of cylinder.	• Store full and empty cylinders separately. • Provide a fire extinguisher. • Installed signs on storage area (no smoke, no fire). • Remove from the storage or workplace all combustible material. • Use of PPE (safety glasses, gloves, uniform wit long sleeve and face shields). • Maintain the valve on safe position. • Store cylinders in a dry, well-ventilated area. • Cylinders is transported standing up and firmly secured by chains. • Developed suitable emergency response procedure in place;
Fuel Supply by mobile tank	• Fire due to fuel spillage. • Soil contamination due to fuel spillage. • Gas inhalation. • Explosion. • Vapours dispersion;	• Installed emergency fuel cut offs. • Provide a fire extinguisher. • Barricade the area. • Installed signs on storage area (no smoke, no fire). • Remove from the workplace all combustible material. • Avoid breathing in vapours or mists. • Use of PPE (safety glasses, gloves, gas mask. • Turn off all sources of ignition (engine) • Use of absorbent materials to clean up and prevent the spill from spreading.

Source: Author

1.4.3. MPDC Operations Context

Tire damage events happen during shipping operations, mainly when iron ore is shipped.

MPDC as logistic company where the business comprises in handling load on the following categories:

a) Reception of cargos (ores) via trucks and wagons. These cargos when arrive in the Port are stored in slabs in different stockpiles and warehouses. See the flow in figures 3 and 4, on the next page.

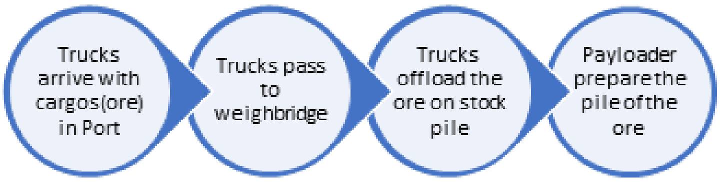


Figure 3: Process flow of reception cargo via truck

Source: Author

Figure 4: Process flow of reception cargo via wagon

Source: Author

b) Unloading general cargos from the vessel

The unloading of general's cargo is made in direct manner or undirect.

- Direct unloading consists in discharge of the cargos from the vessel directly to the trucks and the truck take the cargos for destination out of the Port.
- Undirect unloading consists in discharge of the cargo from the vessel to the truck or directly on floor (quay) and then the cargos are stored temporarily in the Port. See the flow in figure 5.

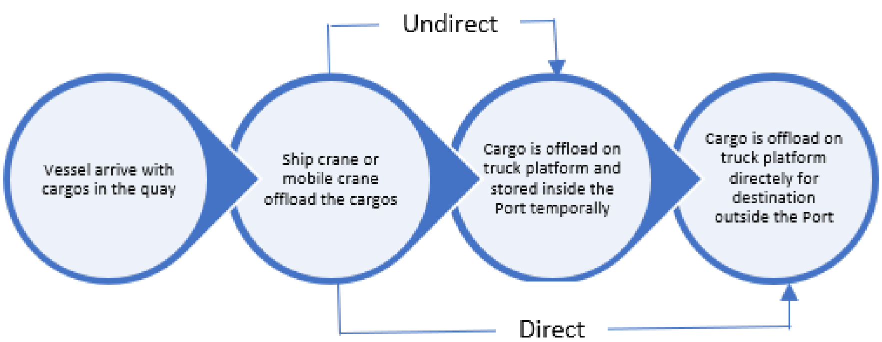


Figure 5: Process flow of general cargo unload operation

Source: Author

c) Loading the minerals from the stockpiles to the vessel. The minerals which are handling in the Port are most of them iron ore, that represent cargos of greater volumes handled. See the flow in figure 6, on the next page.

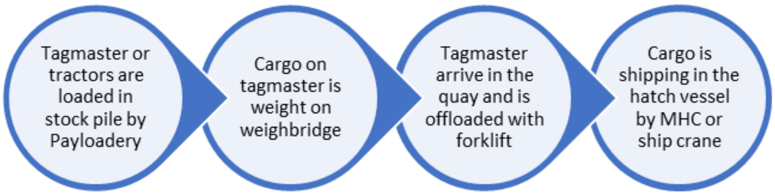


Figure 6: Process flow of shipping ore

Source: Author

For operations of iron ore shipping, it involves a series of logistics in terms of machines, including:

- **Terminal tractors:** whose function is to load the cargo (iron ore) from the stockpiles to the quay where the cargo will be loaded in the vessel**.**
- **Payloader:** its function is to load the ore from the stockpile to the skips on trailer of terminal tractor.
- **Forklifts:** it has the function of unloading and loading skips, from the trailer of the terminal tractors to the quay, when they are full of ores and from the quay to the trailers, when empty. The forklifts used to load full skips, their capacity ranges from 28ton to 40ton and the forklifts used to load empty skips range from 7ton to 15ton.
- **Mobile Cranes (Mobile Harbor Crane) or ship crane:** whose function is to carry out the loading of skips with ore into the ship's hatch.

The problem in research is verified more frequently in the iron ore shipment operation, where the terminal tractors and trailer are exposed in all operation areas, since the slabs, main road, weighbridge and berth.

2. LITERATURE REVIEW

2.1. Structure and tire composition

The tire, with a hollow toroidal shape, is essentially made of rubber and filled with air. The figure 7 following illustrates the constitution of a tire.

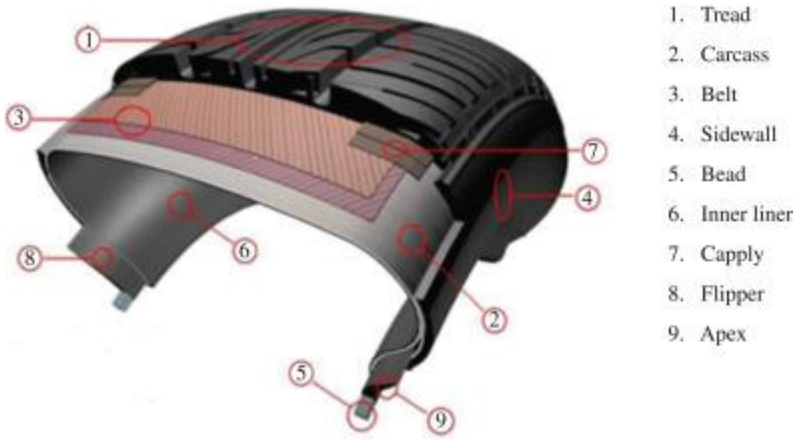


Figure 7: Basic structure of tire

Source: Radiation Technology for Advanced Materials (2019)

According to The Maintenance council (1994), the components of tire structure are presented and its functions description below:

1. **Tread** – composed of rubber, provides the interface between the tire structure and the road. The primary purpose is to provide traction and wear.

2. **Carcass -** The radial ply, together with the belt plies, contains the air pressure of the tire. The ply transmits all load, braking, and steering forces between the wheel and the tire tread.

3. **Belt** - Belt plies, especially steel, provide strength to the tire, stabilize the tread, and protect the air chamber from punctures.

4. **Sidewall -** The sidewall rubber is specially compounded to withstand flexing and weathering while providing protection for the radial ply.

5. **Bead Bundle** - Made of continuous high-tensile wire wound to form a high-strength unit, the bead bundle is the anchor foundation of the casing which maintains the required tire diameter on the rim.

6. **Liner -** A layer of rubber in tubeless tires specially compounded for resistance to air diffusion. The liner in the tubeless tire replaces the innertube of the tube-type tire.

7. **Capply -** Is a layer of rubberized parallel nylon cords that is wrapped circumferentially over the steel belts and under the tread.

8. **Flipper -** A ply laid over the radial ply turnup outside of the bead that reinforces and stabilizes the bead-to-sidewall transition zone.

9. **Apexes -** Rubber pieces with selected characteristics are used to fill in the bead and lower sidewall area and provide a smooth transition from the stiff bead area to the flexible sidewall.

2.2.Tire function

Tires are a fundamental component of the vehicle and have several functions, including:

- The tires carry and/or support the entire load of the vehicle.
- Ensure generation of pulling force and braking forces are through friction in the longitudinal direction between the tire and the road.
- Enable the generation of steering forces and provide directional stability through friction between the tire and the road in the lateral direction.
- Absorbs the impact of the road and cushions the vehicle on the irregularities of the road surface, through its characteristics of vertical elasticity.

According to their functions, tires must be able to carry heavy loads and be resistant to wear and heat. As tires cushion the vehicle on bumps in the road surface, they must provide a comfortable ride.

To carry out transport safely, maintenance and tires must have a structured company activity, integrated with all operational sectors, which provide solutions to maximize the expected results (Pinto & Xavier, 2001).

The tire must also offer satisfactory durability, and provide safety for vehicle performance, in addition to the satisfaction of transport professionals, such as:

- Low rolling resistance and fuel economy.
- Low noise level.
- Possibility of repairs.
- Possibility of retreading.
- High speed capability within technical and legal standards (Goodyear, 2018).

The factors that significantly reduce tire life are based on five as given below (Bridgestone, 2018).

a) Incorrect Alignment

Reduces mileage by up to 25%. The alignment of the front axle is an existing condition by the traffic legislation, according to the National Traffic Council - CONTRAN (558/80), under penalty of fine and seizure of the vehicle, where it determines the exclusive use of new tires.

b) Incorrect Balancing

Reduces mileage by up to 20%. Balances can be of three types:

- ✓ Static imbalance.
- ✓ Dynamic imbalance.
- ✓ or both, static and dynamic together.

The lack of balance, in addition to being uncomfortable at the wheel, causes irregular and premature wear of the tires, hub bearings and shock absorbers.

c) Inadequate pressure control

Reduces mileage by up to 30%. Improper pressure control leads to an average damage of 50% in your tire life. Already with an excess of 30% of weight, 15% of the useful life is lost. Tires must be calibrated fortnightly, always cold, using the appropriate pressure for the type of tire and weight carried, stipulated by the manufacturers. There is a recommended pressure table for load-related tires, which is the correct basis for tire inflation.

Tire calibration is also of paramount importance and can neither be below nor above the ideal. In case of low pressure, the following can occur:

- ✓ Excessive wear on the tires.
- ✓ Higher fuel consumption.
- ✓ Lower vehicle stability and more discomfort when driving.

In the situation of excess pressure, it is likely to have excessive wear in the center of the tire and less stability in curves.

d) Inadequate tread design

Reduces mileage by up to 40%. The different tread designs must be respected, due to the wide variety found on the market. Tires with different designs and brands should not be mixed on the same axle, as the original matrices of these tires are not the same, even though they are of the same size.

e) **Improper pairing**

Reduces mileage by up to 25%. Incorrect or improper pairing of tires, unpaired tires result in uneven load distribution, due to the variation in tire diameter, as they rotate at the same speed, as a result will have, rapid and irregular wear of the design and overloading of one of the tires will result, associated to the factors such as: pressure difference, the bulging of the roads prevent the correct pairing of the double wheels.

Regardless of the customs and practices adopted by operators of terminal tractors, notes that a better performance of tire management is linked to the way the organization relates to tire manufacturers and suppliers, who provide support and solutions for possible problems (Dario, 2012).
Therefore, it is encouraged to always seek strong partnerships with these market participants.

2.3.Quality management tools

The use of quality management tools has been used more frequently in organizations, as it is easier to apply. Quality tools help to identify what is happening in a process, establishing the probable causes, as they allow the analysis of facts and structured data for decision-making with a greater probability of adequacy to the analyzed situation (Almeida, 2016).

Quality tools are instruments to identify opportunities for improvement, assist in the measurement and presentation of results, generating support for decision-making by managers (Behr et al., 2008).

2.3.1. Ishikawa's Cause and Effect Diagram

The cause-and-effect diagram, also known as the Ishikawa Diagram, is used to identify likely causes that contribute to an effect (Martins & Laugeni, 2015).
The cause-and-effect diagram is a tool for representing the possible causes that lead to a given problem. The causes are grouped into six items, where each one will be analyzed to see if there is any factor that could generate the problem. A general cause may have more than one influencing factor, and a general cause may not have any factors.

The Ishikawa diagram can be used to investigate a negative effect, and then correct it, as well as take a positive effect, and incorporate it into the process. When identifying a problem, looking for the cause that generated it, an analysis of the process under study is carried out. After the end of the process analysis, the main cause that originated the problem is located and a new procedure must be carried out, that is, a standardization of the execution of the process. With the standardization established, the control points must be instituted to make sure that the new procedures (standardization) are being complied with (Barreto & Lopes, 2005).

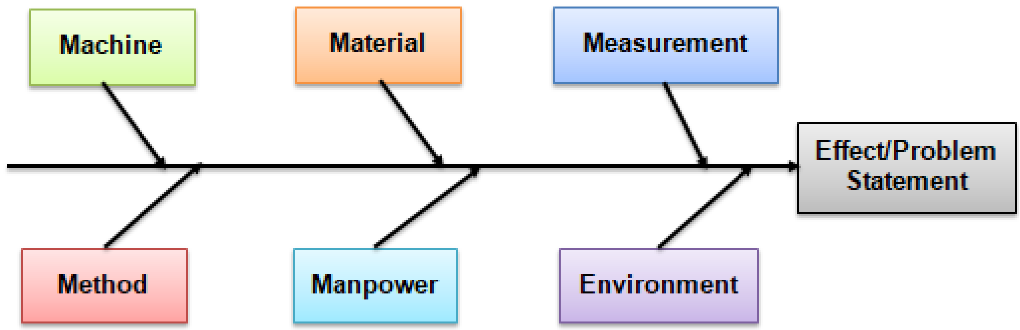


Figure 8: Ishikawa Diagram

Source: Campos, 1999

The Ishikawa diagram is a graphical tool used by administration for management and quality control (QC) in different processes, during phases of analysis of information obtained through surveys or brainstorming.

The Ishikawa Diagram was one of the analysis tools included in the research to:

- Enable to visualize the many "causes" as possible.
- Sort the information in different groups established of the tool.
- Obtain a synthetic and shared vision.

2.3.2. Brainstorming

Brainstorming is a quality tool, carried out in groups, where members freely discuss ideas, without the possibility of criticizing the different opinions that arise. Its objective is to exhaust the possibilities for solving possible problems and identify which are the most applicable to the solution (Marshall Junior et al, 2006). The tool is developed in three stages:

- Presentation of the subject to be discussed, this must be clear and objective.
- Generation and documentation of ideas.
- Analysis and selection.

To conduct a Brainstorming analysis with success the following rules must be considered:

- Do not criticize the ideas expressed.

- Encourage original and exaggerated ideas.
- Focusing on quantity over quality.
- Bounce on other participants' ideas.
- Consider all ideas and people at the same level.

2.3.3. 5W1H Tool

The problems in the organizations must be analyzed, investigated, and controlled, implementing controls measures linked to the root cause of the problem.

Oftentimes we believe know the failure behind a problem’s manifestation but may not be following the problem all the way to its root cause.

The 5W1H method is a questioning technique used to explore the cause-and-effect relationships underlying a particular problem. Five W's (who, what, where, when, why) and the one H (how) is great to comprehend the details, analyze inferences, and get to the fundamental facts to solve issues.

The 5W1H method in this research will allow to understand the tire damage problem situation by asking the right questions.

- What: description of the problem.
- Who: the responsible parties.
- Where: the location of the problem.
- When: temporal characteristics of the problem (at what point in time, how often)
- How: the effects of the problem?
- Why: reasons, cause of the problems?

For the problem of the research is demonstrated the scheme of 5W1H on figure 9, illustrated on the next page.

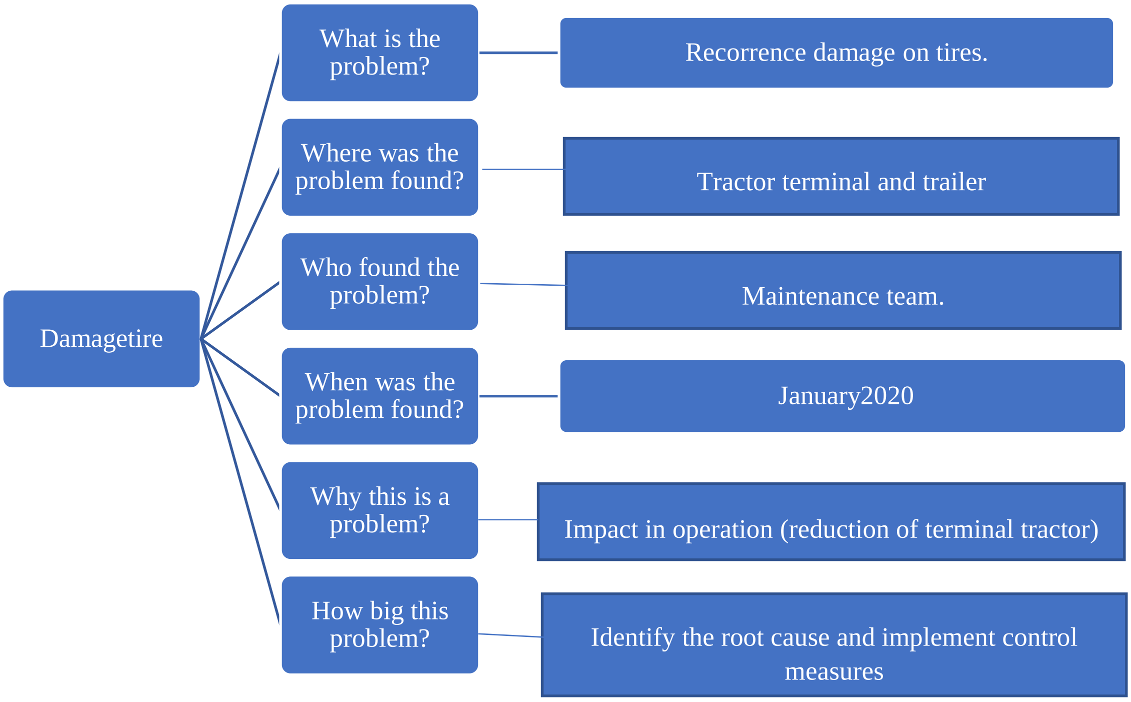


Figure 9: 5W1H method

Adapted from Autor

2.3.4. Pareto Diagram

Vilfredo PARETO (1848-1923) had observed that 80% of wealth was held by 20% of people, he had deduced a law: Pareto law known as the 80/20 law.

A Pareto diagram is a type of bar chart in which the various factors that contribute to an overall effect are arranged in order according to the magnitude of their effect. This ordering helps identify the "vital few" (the factors that warrant the most attention) from the "useful many" (factors that, while useful to know about, have a relatively smaller effect). Using a Pareto diagram in this research will helps to concentrate the efforts on the factors that have the greatest impact in tire problem.

2.3.5. Risk Management Process

Risk has been considered as the chance that someone or something that is assessed will be adversely affected by hazard (Woodruff, 2005), while "hazard" is any unsafe condition or potential source of an undesirable event with the potential for harm or harm (Reniers et al. al., 2005).

According to (ISO 31000 - 2009), Risk assessment is an overall process of risk identification, risk analysis and risk evaluation.

MPDC is committed to identifying all hazards and associated risks in its operations. The strategy to the success of the MPDC operational safety and environmental standards is the application of a risk management process to their entire operations.

MPDC has established and implemented a procedure to manage the risk that can result in injury or illness, material damage and environmental impacts, and it applies to all activities carried out in its operations, including all employees, contractors, vessel and cargo agents and visitors.
The main purpose of risk assessments is:

- Identify health and safety hazards and evaluate the risks presented within the workplace.
- Evaluate the effectiveness and suitability of existing control measures.
- Ensure additional controls (including procedural) are implemented wherever the remaining risk is anything other than low.

For the analysis of the case of study, will be conducted the risk assessment based on problems, as it is intended to analyze the reasons that result to the damage of tires of the terminal's tractors and trailers. The figure10 below illustrates the sequence of the risk assessment process flow:

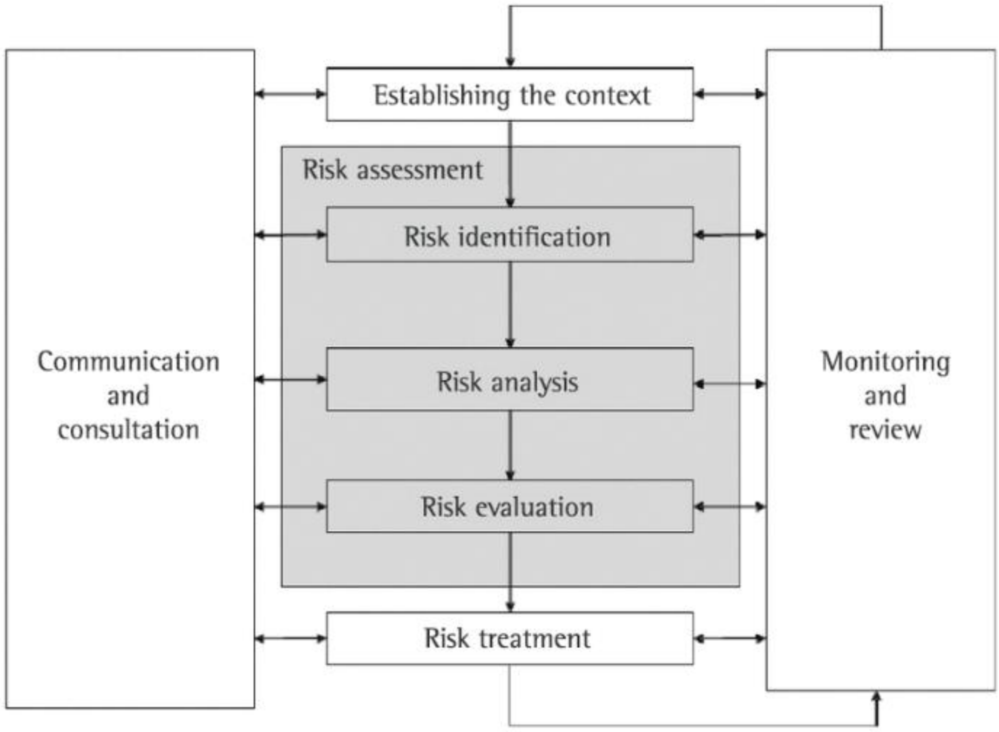


Figure 10: Risk assessment process flow

Source - ISO31000 (2009)

2.3.6. Failure Mode and Effect Analysis FMEA

Risk assessment is an important tool in risk management to reduce project risks and achieve sustainable development.

FMEA is an efficient tool for the identification of potential failure modes and their effects to increase the reliability and safety of complex systems. In other side, this technique is useful to gather data needed for decision making and risk control. Along the master's course, was understood that the purpose of this technique is:

a) To identify failure modes and their effects.
b) To specify the corrective actions to eliminate or reduce the probability of failure and ultimately.
c) Development of efficient maintenance system to reduce the occurrence of potential scenarios.

The FMEA is initially applied qualitatively, during the survey of failure modes, the determination of their effects and the components whose failures have a critical effect on the operation of the system. Subsequently, a quantitative analysis is carried out to establish the probability of failure or system reliability by calculating the Risk Priority Number (RPN), which is the result of multiplying the values assigned to the Severity, Occurrence, and Detection criteria (Loureiro, 2013).

$$NPR = SxOxD$$ *Formula (1)*

Where:

S - Severity

O - Occurrence

D – Detection.

According to Loureiro (2013), the concept of the tree parameter to define the Risk Priority Number are:

a) **Severity (S)** is considered as the result of the potential effect of failures of each component in a system and can be defined based on the use of the indices in annex 1.

b) The **Occurrence (O)** determines the frequency of the failure to occur, considering the prevention controls if existing in the company. For this criteria, prior knowledge and process statistical data are used, respectively.

Its index is established based on annex 2 of criteria for occurrence in attachments.

c) **Detection** determines the probability of detecting the failure mode by evaluating the ability of existing controls to identify the failure. Its index is established based in annex 3 of criteria for detection.

3. METHODOLOGY

Based on objectives of the present research and to the problem identified, qualitative and quantitative research of an applied nature was carried out. As for the technical procedures, a case study was applied, consisting of tires damage in terminal tractors and trailers.

The researchers Yin (2011) and Stake (2009) characterize the case study as a methodological approach, which allows the in-depth aspectual analysis of a phenomenon, situation, or problem, that is, the case.

3.1. Bibliographic research

It is carried out from the survey of theoretical references already analyzed, and published by written and electronic means, such as books, scientific articles, web pages. Any scientific work begins with bibliographical research, which allows the researcher to know what has already been studied on the subject (Fonseca, 2002).

For the present research the bibliographic reviewing consisted of the bibliographic reviewing of book, thesis and internet related to the study case theme and recycling and reuse of scrap tires.

3.2. Observation

According to Ludke and André (1986), observation is one of the basic tools for collecting data in qualitative research. In fact, it is a data collection technique, using the senses, to obtain information about certain aspects of reality. It obliges the researcher to have a more direct contact with reality, helping him to identify and obtain evidence regarding objectives of which individuals are not aware, but which guide their behavior (Lakatos & Marconi, 1990).

As advantages of this technique, we can refer to the fact that observation allows getting closer to the "subjects' perspective" and direct experience is better to verify occurrences (Ludke & Andre, 1986), or even allowing the evidence of data that would not be possible to obtain in the answers to questionnaires (Lakatos & Marconi, 1990).

For a better understanding of the tire life cycle in MPDC operations, it was necessary conducting observation by field visit since the process of tires reception, storage, assembly on terminal tractors and trailers, maintenance, and disposal after use. This process was also accompanied by the observation of the route which the terminal tractors travel during operations, with special attention for Ferro Chrome ore loading operations, which is the operation that has made the largest volumes in terms of cargo handled and to use terminal tractors and trailers as the main resource to loading the ore from the storage area to the shipping position on the vessel.

3.3. Documental analysis

To complement the information collected by observation, resorted to document analysis, where all relevant documentation related to the case study, specifically in the transport and logistics industry, including MPDC maintenance reports, incident investigation reports, in order to gather all information related to the issues of tires damage in terminal tractors and trailers.

3.4. Interview

To obtain information and collect data that would not be possible only through observation and document analysis, an interview was carried out.

Haguette (1997) defines an interview as "a process of social interaction between two people in which one of them, the interviewer, aims to obtain information from the other, the interviewee". Of the various forms of interviews, the most relevant are the structured, semi-structured and open interview.

A structured interview is elaborated through a fully structured questionnaire, that is, it is the one where the questions are previously formulated and where there is a concern in not escaping them (Lakatos, 1996).

The open interview technique is the most suitable for exploratory purposes, being widely used to refine questions and for a more precise formulation of related concepts. For its structure, the interviewer introduces the theme, and the interviewee is given the freedom to discuss the suggested theme. It is a way of being able to explore an issue more broadly. Questions are answered within an informal conversation. The open interview is used when the aim is to obtain as much information as possible on a given topic, according to the interviewee's point of view, and to obtain more and better details about the subject in question (Minayo, 1993).

In a semi-structured interview, open questions are combined with closed questions, where the interviewee could discuss the proposed topic.

For present case study was applied the open interview technique, in this process were interviewed technical specialists for assembling and maintenance of tire and the users (operators) of terminal tractors, where was possible to collect information's related some possible factors that lead to tire losses in MPDC operations. On annex 4 is presented the structure of interview questionnaire.

3.5. Data analysis

For data analysis were based on quantitative and qualitative tools. For quantitative analysis were used the following tools:

- Failure Modes and Effects Analysis (FMEA).
- Risk Assessment Analysis.

For qualitative analysis were used the following tools:

- Brainstorming.
- Ishikawa Diagram.
- Pareto Diagram.
- Action Plan 5W1H.

To better structure the FMEA, were used quality tools such as: Brainstorming, Ishikawa Diagram, Pareto Diagram and 5W1H action plan. Brainstorming is a technique conducted in group, to collect different ideas about the possible causes that result in tire losses. For this specific brainstorming where present the following team: HSE, Maintenance, Operations Waterside and Operations Landside. The Ishikawa Diagram tool was used to analyze causes and analysis. For the interpretation of the data and determination of the priority causes, the Pareto Diagram technique was used, where it was possible to visualize the causes that most influenced the tire failures. With the 5W1H, an action plan was drawn up for the problems identified as priority, establishing a pressure control plan, training operators in the calibration procedure, replacing protective barriers for weighbridges from rigid material to flexible material (used tires) and defensive driving training for operators.

The application of the FMEA tool proved to be efficient for analysis of failures that occur in tire maintenance, achieving benefits to better act on the control and elimination of risks, ensuring better results for the continuity and continuous improvement of the MPDC business.

4. RESULTS AND DISCUSSION

4.1. Risk assessment analysis for iron ore shipping operation

The choice of this operation or activity for risk assessment was because it presents several stages with situations with potential occurrence of events that can result in tire losses. During this process, each identified risk will be analyzed in terms of its probability of occurrence and severity or consequences, should it materialize.

The risk evaluation depends on two mains parameters: probability and severity.

PROBABILITY (P)

Refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively, or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time) (ISO3100: 2009).

As defined above, to determinate the probability is important also to analysis the frequency of the exposure (FOE) or how often are you exposed to this threat and evaluate the history (H) of similar events in your area, operation, or division. MPDC are following the probability criteria which have a potential maximum value of 5, as presented on table 2 below.

Table 2: Probability classification used at MPDC

Likelihood		Level	Description
Almost Certain		5	Is expected to occur in many circumstances (e.g., many times a week)
Likely		4	Will probably occur sometime (e.g., once week)
Possible		3	Might occur sometime (e.g., once a month)
Unlikely		2	Could occur sometime (e.g., once in 1 years)
Rare		1	May only occur in exceptional circumstances (e.g., once in 10 years)

SEVERITY (S)

The Severity measures the impact on the health and safety of employees, product users, public, environment as well as potential financial losses or impact on the bottom line of the company.

The safety impact value is a measurement of the potential injury or health consequences in the worst-case scenario. In table 3, on the next page, indicate the classification of severity that has a maximum value of 5.

Table 3: Severity classification used at MPDC

Severity	Category	Description	
		Safety/Health	Environment
Catastrophic	5	Multiple Fatalities Multiple fatalities because of occupational disease.	Environmental disaster. Irreversible ecological damage and/or extensive permanent impacts on the community.
Major	4	Single fatality, extensive injuries such as permanent disability/amputations and/or resuscitation. Fatality, or a number of irreversible occupational disease cases.	Major environmental incidents. Potentially reversible, long-term ecological damage and/or widespread and permanent impacts on the community.
Moderate	3	Medical Treatment, > 3 days lost time. Irreversible occupational disease.	Reportable environmental incident. Long-term ecological disturbance and/or significant impacts on the community.
Minor	2	First Aid Treatment, 1-2 days lost. Reversible health condition	Minor environmental incident; Short-term ecological disturbance and/or restricted impacts on the community.
Insignificant	1	Hazard Identified with no injury; Over-exposure.	Environmental near miss, damage; Expected ecological stress and/or nuisance to the community or the public.

RISK VALUE

Risk Value (RV) for each identified threat is calculated by multiplying the **Probability (P)** and **Severity (S).**

$$RV = P * S$$

Formula 2

The **Risk Value (RV) or risk matrix** has a maximum value of 25. See table 4, on the next page.

Table 4: Risk Matrix used at MPDC

Consequence → Likelihood ↓	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)	Medium (5)	Medium (10)	High (15)	High (20)	High (25)
Likely (4)	Low (4)	Medium (8)	Medium (12)	High (16)	High (20)
Possible (3)	Low (3)	Medium (6)	Medium (9)	Medium (12)	High (15)
Unlikely (2)	Low (2)	Low (4)	Medium (6)	Medium (8)	Medium (10)
Rare (1)	Low (1)	Low (2)	Low (3)	Low (4)	Medium (5)

After evaluation of the Risk Value, it must be classified according to the level of the Risk Value, as Low, Medium and High Risk, as classified on table 5, below.

Table 5: Risk classification used at MPDC

Risk Ranking	Recommended Action
High Risk (12 – 25)	High risk activities should cease immediately until further control measures to mitigate the risk are introduced.
Medium Risk (ALARP) (5 - 12)	Medium Risks should only be tolerated for the short-term and then only whilst further control measures to mitigate the risk are being planned and introduced, within a defined time. Note: Medium risks can be an organizations greatest risk, its Achilles heel, this because they can be tolerated in the short-term.
Low Risk (1 – 4)	Low Risks are largely acceptable, subject to reviews periodically, or after significant change etc.

For the risk assessment of the operation or activity described above, the following resources are required:

- Terminal tractors connected with respective trailers: to load cargo (iron ore) from stockpile to quay.
- Forklifts (28tons – 40tons and 15 tons): the forklift of 28 – 40tons is to offload the skip full of cargo from trailer to the ground on position for shipping, and the forklift of 15ton is to load the skip empty from the ground to trailer.
- Payloaders: to load the cargo from stockpile to skip on the trailer.
- Stevedores: to connect the chains in the skip.
- Ship crane: to load the skip from the trailer to the hatch.

- Weighbridge: to weigh terminal tractor full and empty of cargo.
- Skips: to full the cargo that will be shipped.

Table 6: Risk assessment matrix for iron ore shipping operation

Task	Hazard and risk description	Whom will affected	Existent Control	P	S	RV
Access of terminal tractor	Running over to workers resulting in serious injury or fatality.	Workers	Demarcated pedestrian walkway with physical protection; Established speed limit on slab (10km/h); Mandatory use of high visibility vest; Trained and competent operators.	1	4	4
	Collision between mobile equipment resulting in damages.	Equipment's	Established speed limit on slab (10km/h); Defined route for terminal tractor; Trained and competent operators.	4	3	12
Access of terminal tractor on weighbridge platform to weigh empty	Collision between mobile equipment against physical infrastructure resulting in damage to tires and rim or infrastructure.	Equipment's	Established speed limit on slab (5km/h); Trained and competent operators; Demarcated pavement for orientation in entrance and exit.	3	2	6
Loading of ore to the trailer of terminal tractor through payloader	Collision between mobile equipment's (terminal tractor and payloader) resulting in damages.	Equipment's	Trained and competent operators; Work instruction for loading in trailer.	4	2	8
	Noise due to loading of cargo in the trailer resulting in hearing aid disorder.	Workers	Trained and competent operators; Work instruction for loading in trailer.	1	2	2
Movement of terminal tractor from stockpile to weighbridge	Overload resulting in damage to tires	Equipment's	Trained and competent operators; Weighbridge system.	4	3	12
	Mobile equipment (terminal tractor) movement over the ore stones or collision with physical infrastructure (jersey block) resulting in damage to tires.	Equipment's	Trained and competent operators; Housekeeping along the road and slab. Inspection of tire on shift change.	4	3	12

Access of terminal tractor on weighbridge platform to weigh full	Collision between mobile equipment against physical infrastructure (jersey block) resulting in damage to equipment (tire, rim) or infrastructure.	Equipment's & Infrastructure	Established speed limit on slab (5km/h); Trained and competent operators; Demarcated pavement for orientation in entrance and exit.	4	2	8
Movement of terminal tractor from slab to quay.	Running over to workers resulting in serious injury or fatality.	Workers	Demarcated pedestrian walkway with physical protection; Established speed limit on slab (10km/h); Mandatory use of high visibility vest; Trained and competent operators.	2	4	8
	Collision between mobile equipment's resulting in damages.	Equipment's	Trained and competent operators; Work instruction for loading in trailer.	4	2	8
	Collision between mobile equipment against physical infrastructure (jersey block) resulting in damage to equipment (tire, rim) or infrastructure.	Equipment's & Infrastructure	Established speed limit on slab (10km/h); Trained and competent operators; Demarcated pavement for orientation in entrance and exit.	4	2	8
Removal of full skips through forklift (28ton to 40ton) and placing in shipping position.	Pressure between fork and trailer platform resulting on tire damage and trailer.	equipment's	Trained and competent operators; Work instruction for load the skip	3	3	9
	Fall of skip that can spill the cargo to floor, contaminating the soil.	Soil	Trained and competent operators; Work instruction for load the skip	3	2	6
Manual connection the chain on the skip.	Contact with chain during the connection that can result in Injury on hands.	Workers	Use of PPE (gloves, glasses)	4	3	12
	Respirator or skin disease due to contact or dust inhalation from the ore.	Workers	Use of PPE (mask) or cloths with long sleeves;	2	3	6
Lifting the full skip with cargo to the hatch.	Fatality or serious injury due to fall of suspended load (skip full of cargo)	Workers	Trained and competent crane operators; Allocation of signal man.	2	4	8

Removal of empty skip from the hatch.	Fatality or serious injury due to fall of suspended load (skip full of cargo)	Workers	Trained and competent crane operators; Allocation of signal man.	3	4	12
Placement of empty skip on trailer of the terminal tractor.	Fall of skip that can spill the cargo to floor, contaminating the soil.	Soil	Trained and competent operators; Work instruction for loading in trailer.	2	1	2
Exit of terminal tractor from the quay.	Running over to workers resulting in serious injury or fatality.	Workers	Demarcated pedestrian walkway with physical protection; Established speed limit on slab (10km/h); Mandatory use of high visibility vest; Trained and competent operators.	2	4	8
	Collision between mobile equipment's resulting in damages for one or both equipment's.	Equipment's	Trained and competent operators; Work instruction for loading in trailer.	4	2	8
	Mobile equipment (terminal tractor) movement over the ore stones or collision with physical infrastructure (jersey block) resulting in damage to tires.	Equipment's	Trained and competent operators; Housekeeping along the road and slab. Defined route. Inspection of tire on shift change.	4	3	12

Source: Author

The graphic presented as figure 11 on the next page, illustrates the result of plotting the probability and severity of the risk, evaluated on previous table (table 6):

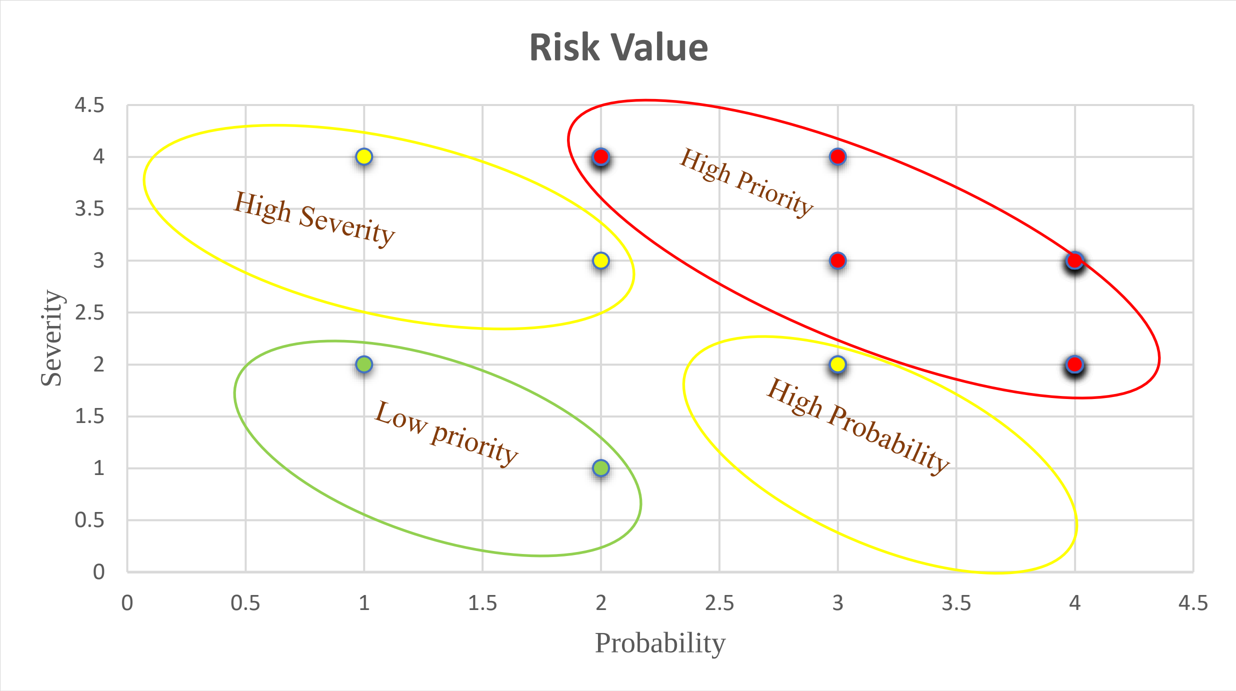


Figure 11: Risk Value

Source: Author

Analysis of the graphical results (figure 11)

High Priority Risks

These exposures generally have a high probability of occurrence and the effects or severity if occur could be catastrophic. The Risk Values (RV) are normally between 8 and 25.

The best method of treatment would be to attempt to avoid the exposure in the first place or to reduce the severity and likelihood of the event.

High Severity Risks

These incidents generally have a low probability of materializing however when they do occur the consequences could be catastrophic. The Risk Values (RV) are normally between 4 and 8 but the Severity (S) value is higher than 2.5.

Treatment of such exposures could include outsourcing, contractual arrangements, insurance or other methods of Risk Financing, effective emergency recovery plans, etc.

High Probability Risks

These failures have a high probability of materializing and could generally be expected to occur on a frequent basis. The Risk Values (RV) are normally between 4 and 8 but the Probability (P) value is higher than 2.5.

These failures are generally predictable and can be effectively managed by good practices as safety standards, procedures, training, awareness, and toolbox talk. The chosen corrective action should be weighed against the relatively low impact on business continuity.

Low Priority Risks

These exposures generally have a very low probability of occurrence and the effects on business continuity could be minimal. The Risk Values (RV) are normally between 0 and 4.

As shown in table 6, from the risk assessment matrix of the iron ore shipping operation, activity with potential for the damage of tires from terminal tractors, by the quantification of risk from the multiplication of probability and severity, this event fits in the high priority risk, as the risk level is in the range of 8 to 12, classifying as medium (table 5, page 40), in which strict control measures must be implemented.

4.2.Tire maintenance at MPDC Operations

Like any other machinery component, tire maintenance must be given the necessary attention.

MPDC subcontracted a company that maintains its tires, and some control indicators were established to highlight:

- Measurement of tire tread.
- Systematic pressure measurement.
- Inspection of objects in the tire.

a) Measurement of tire tread

The tire tread is one of the parameters that has been verified during the inspection or tire maintenance. To conduct this measurement, the technical use pachymeter instrument, as illustrated in figure 12 on the next page.

Figure 12: Tread measurement

Source: Author

b) Pressure measurement

Maintenance established the process to monitor the pressure on terminal tractor and trailer tire during the shift change. To conduct this measurement, the technical use manometer instrument, as illustrated in figure 13 below.

Figure 13: Pressure measurement

Source: Author

c) Inspection of objects in the tire

Based on visual check the technical and operators use to identify if there are not strange objects stucked on tires, as stone between 2 tires, metals, or signal of any impact. See figure 14 on the next page, illustrating the stone stucked between 2 tires.

Figure 14: Tire inspection

Source: Author

It was observed that although the company is carrying out actions that aim to guarantee the reliability of the tires, these are not enough to avoid failures that result in tire damages, as there are so many other uncontrolled factors that significantly affect the failures and damage of them, some of them:

- Non-systematic housekeeping of ore spillage along the road and slabs.
- Overload under trailer tire axle.
- Inadequate alignment.
- Inadequate balancing.
- Inadequate tread design, due to install on the terminal tractor and trailer different brands of tire.

4.3.Tire failure analysis in terminal tractor and trailer in MPDC Operations

In the last 2 years there have been many occurrences that resulted in the damage of tires. For the case study, will be analyzed 4 types of failure that result in tire loss:

a) Penetration
b) Impact Fracture or Incident Related
c) Side wall cut
d) Repair failure

The used tires after considered scrap, are stored in identified areas, until the opportunity of exit for an alternative to adequate treatment.

With the objective to identify the causes that are linked to the tire losses and prioritizing the actions for the most important step, the failure analysis method tool (FMEA) was used, to assist in the identification of the main causes and the development of measures to improve tire maintenance. To build the tire damage event FMEA, some steps were established to be followed:

1) Identification of failure modes that occur in tires and their effects.

2) Identification of the causes of each failure mode.

3) Determination of risk priority (RP) rates for each failure.

4) Determination of corrective or preventive actions.

4.3.1. Identification of failure modes that occur in tires and their effects.

From the determination of the failure mode, it was possible to develop the first step of the FMEA:

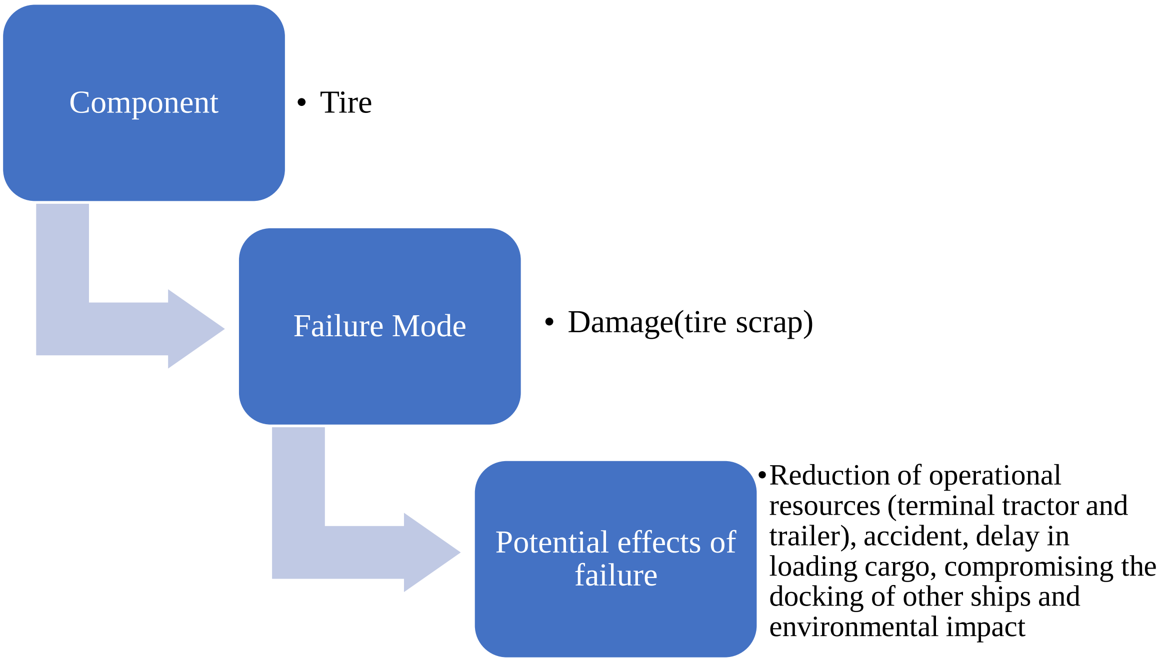


Figure 15: Failure mode and affect scheme

Source: Author

4.3.2. Identification of failure mode causes

With the determination of the failure mode, it was possible to continue the steps of the construction of the FMEA, that is, to identify the causes of the failure and then determine its indices of occurrence (O), severity (S) and detection (D).

To look for the causes of the failure mode that result in damage to the tires, a brainstorm meeting was conducted, with the participation of a multidisciplinary team composed of 5 participants represented by different areas, namely: HSE, Maintenance, Operations-Waterside, Operations-Landside and Auto Group.

The definition of attendees of these areas was due to the following reasons:

- **HSE:** area responsible to manages the occupational risk and occurrences that may result in accidents.
- **Maintenance:** area responsible for the correct operation of terminal tractors and trailer
- **Operations - Waterside:** final stage of the iron ore shipping using terminal tractors and trailer.
- **Operations - Landside:** where begins the process of loading the ores in the terminal tractor.
- **Auto Group:** responsible for managing the fleet of operational equipment and operators who drive the terminal tractors.

The data collection was based on the use of the brainstorming technique, where resulted in positive interaction from the attendees mentioned is heard.

In isolation from this meeting, an analysis was carried out by observation with the participation of technicians from the company contracted to manage tire maintenance at MPDC. The technique was developed with great productivity, where the members were active and collaborated with different and constructive opinions.

After the brainstorming application, another tool was used to help identify the causes, the Ishikawa Diagram, which is useful to relate the result of a process (effect) and the factors (causes). The causes were allocated using the 6M classification or six sigma: Materials, Machine, Measurement, Method, Manpower and Mother Nature (Environment), as presented on Figure 16, on the next page.

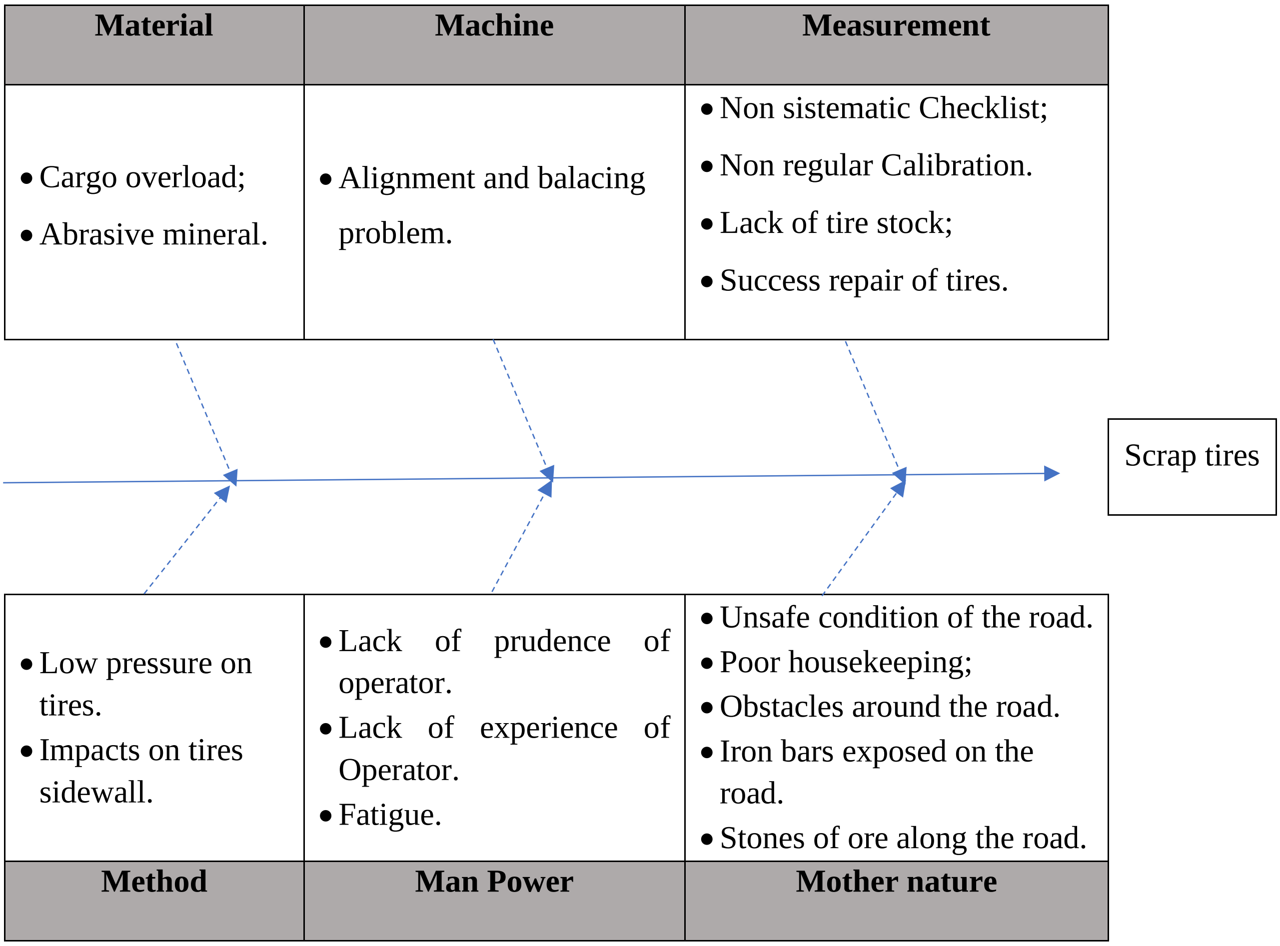


Figure 16: Ishikawa diagram

Source: Author

The application of the Ishikawa diagram allowed the completion of the second stage, by identifying the set of causes of the identified failure mode, as table 7 below.

Table 7: Causes of the failure modes.

Component	Failure Mode	Potential effect of the failure	Failure causes
Tire	Scrap tire	Reduction of operational resources (terminal tractor and trailer). Accident, delay in loading cargo, compromising the berthing of other vessels. Environmental impact	Collision against physical barrier in weighbridge.
			Movement under railway line.
			Movement in the road holes.
			Fatigue of operator.
			Lack of prudence of operator.

			Iron bars exposed on the road.
			Stones of ore along the road. and slab.
			Low pressure
			Overload
			Successive repair on the same tire.
			Lack of stock.

Source: Author

4.3.3. Determination of Risk Priority Number for each failure

Based on annex's 2, 3 and 4 (Severity, Occurrence and Detection respectively), was determined the Risk Priority Number (RPN) using the following formula.

$$RPN = S * O * D$$

Table 8: Evaluation of RPN

Component	Function	Failure Mode	Failure Causes	Failure Effects	Occurrence (O)	Severity (S)	Detection (D)	RPN
Tire	Generate steering forces and provide directional movement and stability.	Impact Fracture or incident related	Collision against weighbridge physical barriers.	Tire damage (damage of tires). Weighbridge out of service.	6	6	8	288
			Movement of terminal tractor over the railway.	Tire damage (damage of tires). Reduction on productivity.	4	5	6	120
			Movement of terminal tractor over the terminal tractor over the pits.		4	5	6	120
			Operator fatigue.	Accident with injury. Equipment damages. Tire damage (damage of tires). Cost of repair the tire and tractor terminal.	5	6	5	150
			Lack of prudence of operator.		5	6	5	150

		Penetration	Iron bars exposed along of pavement and concrete barrier.	Cost of tire maintenance.	6	6	5	180
			Stones of ore along the road and slab.	Tire damage (damage of tires). Lost time for tire replacement.	6	6	5	150
		Side wall cut	Low pressure in tire. Non regular tire calibration	Tire damage (damage of tires). Lost time for tire replacement.	6	6	6	216
			Overload over the terminal tractor and trailer loaded with skips full of ore. Stones of ore stacked between two tires.		6	6	3	108
		Repair Failure	Successive repair on the same tire.	Tire damage (damage of tires). Tire explosion.	7	6	5	210
			Lack of stock.		6	6	6	216

Source: Author

From the RPN evaluation table 8, was extracted the causes and RPN value, for better identification of critical causes, as illustrated on table 9 below.

Table 9: Value of RPN

Component	Failure causes		RPN
Tire Loss	C1	Collision between terminal tractor against weighbridge physical barriers.	288
	C2	Movement of terminal tractor over the railway.	120
	C3	Movement of terminal tractor over the pits on the road.	120
	C4	Operator fatigue.	150
	C5	Lack of prudence of operator.	150
	C6	Iron bars exposed along of pavement and concrete barrier.	180
	C7	Stones of ore along the road and slab.	150
	C8	Tire with low pressure.	216
	C9	Overload over the terminal tractor and trailer loaded with skips full of ore.	108
	C10	Successive repair on the same tire.	210
	C11	Lack of stock.	216

Source: Author

To identify and analyze the most critical causes that contribute to the failure mode of tire loss, was applied the Pareto Diagram tool, where was calculated the cumulative RPN and then the percentage of RPN, as presented on table 10 below:

Table 10: NRP Cumulative and Percentage

Item	NPR	NPR Cumulate	% Cumulate
C1	288	288	15%
C8	216	504	26%
C11	216	720	38%
C10	210	930	49%
C6	180	1110	58%
C4	150	1260	66%
C5	150	1410	74%
C7	150	1560	82%
C2	120	1680	88%
C3	120	1800	94%
C9	108	1908	100%
	1908		

Source: Author

The graphic below (Pareto Diagram) was plotted based on table 10:

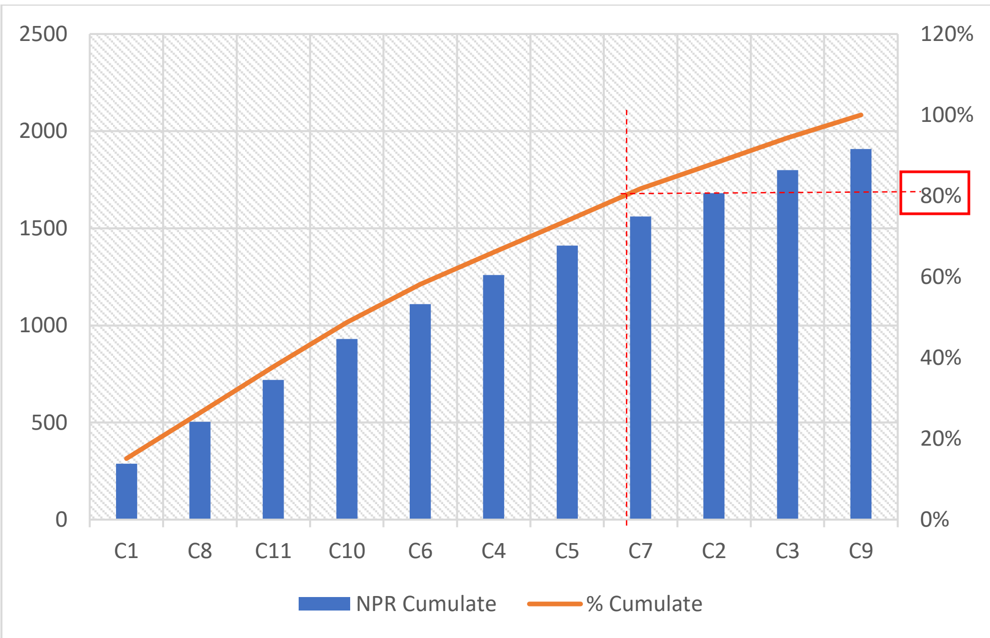


Figure 17: Pareto Diagram

Source: Author

The objective of applying the Pareto Diagram (illustrated on figure 17, on previous page) is to identify which 20% of the causes represent 80% of the total value of RPN, and with it develop the action plan.

By analyzing the results of the Pareto Diagram, it was possible to identify that C1, C8, C11, C10, C6, C4, and C5 (with description on table 9) are the causes that represent 80% of the problems, that is, they are the ones that most influence in tire losses. The causes mentioned above are defined as priorities, therefore, it is necessary to define corrective actions on them. With the determination of the priority causes, it is possible to develop the final stage of the construction of the FMEA, which consist in recommendation of corrective actions to eliminate or minimize the failure mode.

4.3.4. Determination of corrective actions applying 5W1H

After applying the Brainstorming Quality tools, Ishikawa Diagram and Pareto Diagram, which contributed to the development of the FMEA, it is essential to suggest corrective measures to minimize and, if possible, eliminate the identified failure mode. Defining the actions to eliminate or minimize the failure mode is the final step in the construction of the FMEA, and the 5W1H tool was used for development of action plan, as shown in table 11, below:

Table 11: Action Plan 5W1H

Causa	WHAT	WHO	WHERE	WHY	HOW	WHEN
C1	Replace the hard barrier with flexible one (used tire)	Engineering Manager	Weighbridge platform access	Reduce the impact in the machine due to collision.	Conducting Engineering work	Oct 2022
C11	Establishment of maximum and minimum stock	Store Supervisor	Store control system	Ensure immediate replacement of tire when justify.	Monitoring the stock system	Sep 2022
C10	Reduce success repair of tires	Maintenance Planning Superintendent	Maintenance Department	Reduce the level of risk for operators and equipment's	Define the "no go" item on tire checklist.	Sep 2022
C8	Establish a pressure control plan	Maintenance Planning Superintendent	Maintenance Department	Ensure that tires are calibrated with proper pressure.	Conduct records and monitoring in adequate spreadsheet.	Jun. 2022
	Training the Operators on	Maintenance Planning Superintendent	MPDC Training Center	Ensure the operators have knowledge	Periodic training once in 2 years.	Jul. 2022

	tire calibration standard			about adequate pressure in tires.		
C6	Establish the inspection plan for road and physical barriers.	Engineering Manager	Engineering Department	Ensure preventive maintenance	Conduct records in adequate spreadsheet.	Jun. 2022
	Repair the damaged road	Engineering Manager	Engineering Department	Ensure preventive maintenance	Conducting Engineering work	Aug. 2022
C4	Develop fatigue management program.	HSE Manager	Operations	Ensure operators awareness to follow the fatigue management practices.	Discussing on toolbox talk sessions.	Jul. 2022
C5	Conduct defensive driving training	Grupo Auto Superintendent	MPDC Training Center	Improve the defensive driving practices.	Demonstrate on training the practical scenery of defensive driving.	Jun. 2022
C7	Develop a systematic housekeeping plan.	Landside Operations Manager	Operations	Keep the terminal tractor traffic area clean.	Conducting follow up on implementation of the cleaning plan	Jun. 2022

Source: Author

For the low or not adequate pressure cause (C8), is suggested two control measures. First development of a pressure control plan, where will be possible to conduct a follow up of adequate pressure according to type of tires, as well as establish the frequency of checks, conditions of measuring equipment and follow the life cycle of tires. The second measures are focused to operators training, to acquire knowledge of standard procedures to perform the task of checking the pressure, based on manufacturer specifications.

Regarding the causes of collision with physical barriers (C1), in addition to replacing rigid barriers with flexible barriers, defensive driving training for terminal tractor operators is suggested, so that they can adopt preventive procedures in cargo transport (ores) to avoid accidents and premature damage of tires.

4.4. Alternatives for the reuse of scrap tires

According to Mozambican decree No. 83/2014, tire waste is classified as hazard waste.

Discussions about the possible environmental impacts of tires are often dominated by the risks and impacts associated with above-ground tire deposits. These deposits provide a strong visual impact, and, in addition, they potentiate the occurrence of fires and the creation of places for the proliferation of mosquitoes and parasites. However, the environmental impact of tires goes beyond these, appearing at all stages of the life of the products.

It is of real importance to consider all impacts, to ensure that waste management does not result in just transferring impacts to different stages in the life cycle, or to different types of receiving environment, but rather addressing all impacts, in a global form. The final disposal of scrap tires causes serious damage to the environment, whether in the improper form of disposal, storage, water deposit that can be a focus for diseases such as malaria, or disposal through open burning that contaminates the soil and the air. For this reason, it is extremely important to know more deeply the viable ways, both ecologically and economically, of using scrap tires, to reduce their improper disposal.

The most effective tire life cycle is illustrated as in diagram below:

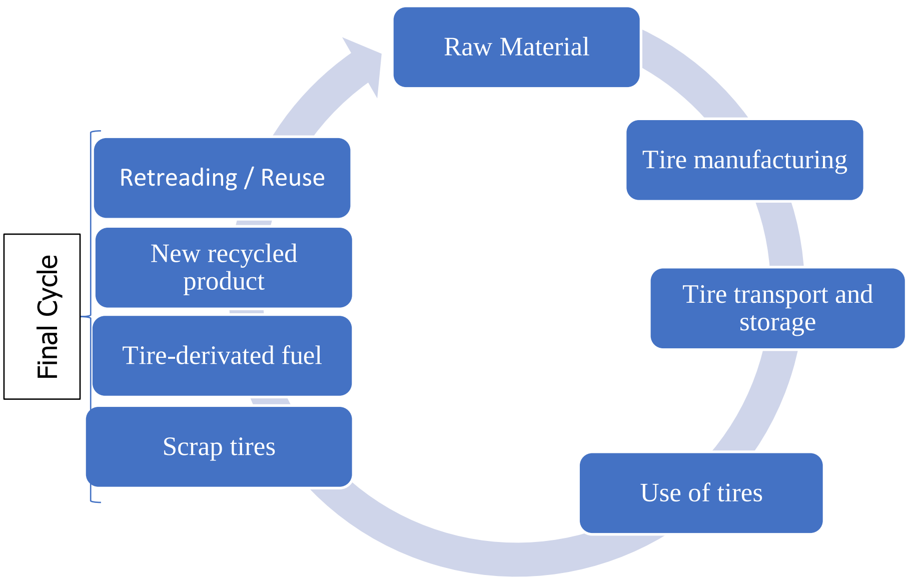


Figure 18: Tire life cycle

Source: Author

For MPDC, the life cycle of tires ends on scrap (see figure 18), and other final treatment alternatives are not being adopted after use.

After the use of tires, the other stages of the optimal life cycle are not adopted due to the limitation of the industry for use as a fuel derivative, non-compliance with legislation after recycling a new product and retreading or reuse (challenges to treat waste material). Figure 19 below, show the damaged tires stored as scrap.

Figure 19: Scrap tire at MPDC

Source: Author

Now, Mozambique does not have any functional tire production industry, a fact that cancels out environmental problems related to the production process. Every tire used in MPDC's fleet of machines comes from other countries.

Due to excessive consumption of tires in MPDC operations, these are almost not in stock, factor which increase the probability for operationalization of the terminal tractors with tires in unsafe condition, contributing in this way to occurrence of events resulting in tire damage.

4.4.1. Recycling of scrap tires

Today, due to the great problem that has become with the final disposal of scrap tires, some alternatives have been created so that this waste can be used as raw material for a new product, or it could be used in others functions different of transport. Therefore, several technologies have being developed to support these new options for the use of scrap automotive tires.

However, it is important to point out that the tire that has reached the end of its useful life can still be classified as reformable or non-reformable, a factor that is linked to the issue of recapture, retreading, or remolding tires, and only those classified as non-reformable become a product for final disposal – the scrap tire. In the following topic, the operation of tire retreading processes will be discussed before, is presented issues related to the recycling of scrap tires.

4.4.2. Used tires and retreading process.

The tire retreading process helps to prolong the useful life of this product, and as this item is one of the most expensive for vehicle owners, there has been great demand for this service option before the final tire change.

The practice of tire retreading contributes greatly to minimizing the impacts associated with the final disposal phase of the automotive tire; In addition, "the retreaded tire makes it possible to minimize vehicle fleet maintenance costs due to the lower cost of this tire compared to new ones", as well as savings in raw materials obtained through oil and electricity used in the manufacture of new tires. (Kamimura, 2002).

However, it is important to note that not all tires can go through the retreading process. For this to occur, the tire structure must be intact so that it fulfills its original function when it is reused, in addition, the safety issue must not be compromised. (Kamimura, 2002).

The existing industrial processes for retreading tires are:

- Recapture.
- Retreading.
- Remolding.

a) Recapture

It is the rebuilding of a tire by replacing its tread. This technique is recommended to be applied to trucks on the rear wheels, as it only wears out from the longitudinal friction of the tire pushing the truck, which by nature is the tire that wears out the most.

Figure 20: Tire recapture

Source: [Como é feita a recapagem de um pneu? - Blog Canal da Peça (canaldapeca.com.br)]

b) Retreading

It is the rebuilding of the tire by replacing the tread and shoulders. It consists of removing the worn tread from the tire casing so that, through a new vulcanization process, a new tread is placed.

Figure 21: Tire retreading

Source: O ECONÓMICO, 20 de Março de 2020

The tire to be retreaded must present requirements such as: absence of cuts and deformations and that the tread is not totally worn out, which still has the tracks responsible for the tire's adherence to the ground. In addition, it can be retreaded a maximum of five times, after which the tire's performance is impaired. (Kamimura, 2002).

c) Remolding

It is another process of reusing tires classified as retreaded, with the tire being rebuilt by replacing the tread, shoulders, and the entire surface of its flanks.

It is another process of reuse of tires classified as retreadable, the tire being rebuilt by replacing the tread, shoulders, and the entire surface of its flanks. (Kamimura, 2002, p. 54).

Remolding is a process that is like retreading, the difference is due to the removal of the tread and the side parts of the tires, therefore, every tire receives a new layer of rubber and undergoes a new vulcanization process. “Tires remolded, because they use used carcasses as raw material, are not new tires, but new products made from used tires”. The figure 22, on next page illustrate the remolding process.

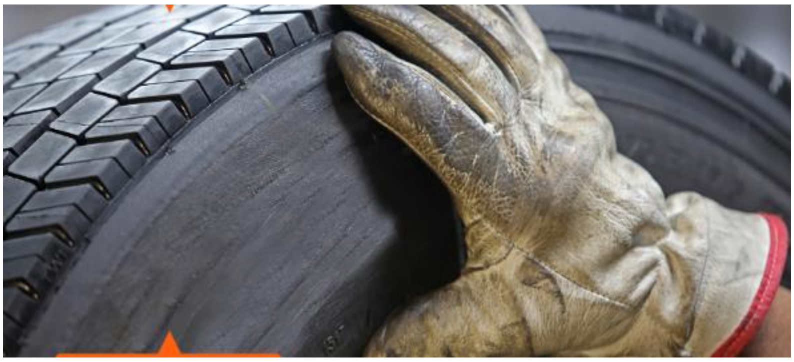


Figure 22: Tire remolding process

Source: Tire Retread | Different Tire Retreading Methods | SimpleTire

Due to the lack of a root tire industry in Mozambique, the country is completely dependent on imports of this extremely important asset in the transport and logistics industry. Mozambique was once a producer of high-quality tires for local consumption and export to Europe and some African countries. Some tires, after being used, can be reused for the same purpose, through the retreading process. The retreading process would be one of the alternatives for reducing the problem with tire waste, which has been a major challenge for MPDC. This process of reuse of used tires involves high-cost equipment, with high energy consumption and long production cycles.

Through this process, the tire's service life increases by around 40% and the tire has a market value of up to 70% cheaper than a new tire. (oeconomico.com)

To ensure safe condition in utilization of retreading tires is important to take in consideration the condition of carcass to insert a new rubber, it must comply established requirement.

4.4.3. Waste tire recycling alternatives

When confronted with the number of scrap tires generated in the world annually, the need for and importance of seeking new alternatives for the use of this material in other reuse and recycling processes was perceived.

In Mozambique, due to the growth in the number of light and heavy vehicles, as well as the growth of extractive industries such as multinationals producing mineral coal, gas, graphite, cement, the generation of scrap tires has been increasing.

Scrap tires are classified as hazardous waste, according to Mozambican decree No. 83/2014. The decree was prepared and approved due to the need to establish norms and procedures to guarantee the correct management of hazardous waste resulting from the implementation of human activities and industrial processes whose impact is reflected on public health and the environment, under the provisions of article 33, of Law No. 20/97, of 1 October, Environmental Law.

It is estimated that annually in the world the disposal of old tires reaches 800 million units. “In the countries of the European Community, 180 million tires are scrapped annually, and another 150 million in the United States of America alone”, it is estimated that 3 billion tires are accumulated in desert areas, with an ever-imminent threat of devastating fires (Andrietta, 2002).

Figure 23: Part of the scrap tire deposits (MPDC)

Source: Author

The reinsertion of tire rubber as a raw material for new products, whether whole (cement kilns) or crushed (granulated for asphalt mixtures) among other uses, depends on manufacturers' investments in manufacturing techniques, materials research, study on ways of reinserting this waste into the production chain. “For the development and advancement of these tire reuse and recycling technologies, a joint effort is needed – companies, government and society. (Sandroni, Pacheco, 2005).

The motivation for companies to carry out the waste tire recycling process does not depend only on choosing the ideal technology for the process, but also on factors related to - volume of tires, proximity to the market, type of consumers, necessary investment, in addition to tax and financial incentives (Sandroni, Pacheco, 2005).
Below are some processes that involve new technologies that have been presented as new recycling alternatives aimed at minimizing the problem of waste tires.

a) Devulcanization or regeneration of tire rubber

"The tire recovery and regeneration process require the separation of vulcanized rubber from other components (such as metals and fabrics, for example)". Wire and steel mesh are recovered as qualified scrap iron, nylon fabric is recovered and used as reinforcement in cardboard packaging (Bonente, 2005).

The devulcanization or regeneration of rubber modifies the waste, making it more plastic and ready to receive a new vulcanization process. Even so, they do not retain the same properties as raw rubber, which is why they are mixed with rubber in the manufacture of new artifacts – carpets, industrial floors, sports courts, traffic lights, furniture castors, domestic squeegees, strips for the upholstery industry, air chambers, etc.

b) Tire rubber and asphalt paving

The technology of incorporating waste tire rubber into asphalt for pavement construction is another alternative for tire recycling.

"The main factor that motivates the incorporation of polymers in the asphalt is the attempt to increase the service life of the pavement", reducing the susceptibility of the asphalt to thermal variations, the risks of deformations and fatigue failures. "They should also improve the elastic characteristics of the pavement, contribute to a better adhesion between the asphalt cement and the aggregate, increase the aging resistance of the asphalt". (Salini, 2000)

From the existing theories about asphalt with rubber incorporation, it would be an additional alternative in the recycling of waste tires, however due to the cost, the lack of conclusive research regarding the durability and benefits of incorporating this mixture into the traditional asphalt, this alternative could lead to some time to become a viable process.

c) The tire as an energy source (co-processing)

The practice of using the tire waste as a source of energy has been used since 1975, it has its origins in Dickerhoff Cement, in Frankfurt - Germany, it is known as TDF - Tire Derived Fuel.

The waste tire co-processing method is classified as one of the best, in point of view of complete use of waste tire, burning all its components.

Unlike other forms of recycling, co-processing reduces the energy cost that in other recycling techniques would be required for physical transformation of tire waste, by cutting or shredding or other forms before final treatment. One of the viable alternatives for co-processing is the clinker production kilns in the cement industries.

"The best method to burn tires without the problem of black smoke and pollutants is the coprocessor, that is, the burning of industrial waste in cement kilns", since the burning of industrial waste at 1700ºC chemically transforms hazardous substances, and in cement kilns, these residues are used to generate energy, and the resulting ash is incorporated into the cement and encapsulated in acceptable concentrations. (Kamimura, 2002).

4.4.4. Reuse of the waste tire in its entirety: other recycling alternatives

Many of the processes for recycling rubber from scrap tires require the separation of tire components or the grinding itself before use. However, there are other examples of reuse of waste tires in their entirety contributing to the question of the final destine of this waste.

The use of scrap tires has been used in different projects or utilities around the world, in Mozambique and MPDC.

From the point of view of several alternatives for the reuse of scrap tires, MPDC that due to the numerous tires it uses in its fleet of terminal tractor machines and their trailers, which is the main type of equipment in this research, in partnership with environmental specialists, institutions or interested individuals, has been putting into practice the following forms of waste tire treatment:

- Internally, scrap tires are used as barriers and limiters in the accesses of weighbridges of loaded or empty terminal tractors. To implement this alternative for treating scrap tires, the groove is opened in the pavement with a width slightly greater than the width of the tire, and this is introduced and then the cement mass is prepared to seat the tire. This alternative, in addition to reducing the number of scrap tires stored, also reduces the impacts of the tires or structure of terminal tractors and their trailers in the event of a crash type accident.

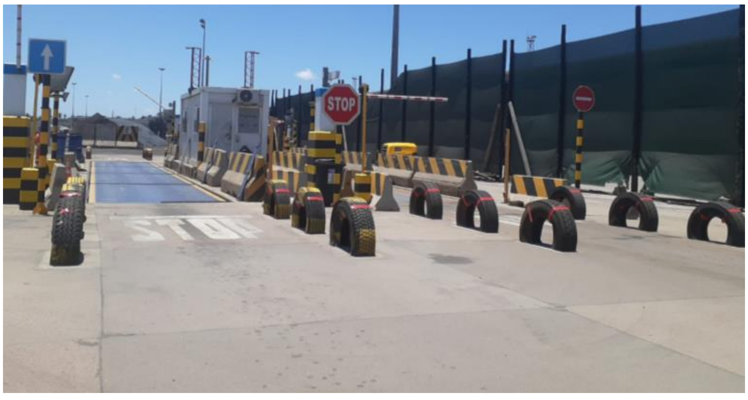


Figure 24: Tire used as flexible barrier in MPDC weighbridge

Source: Author

- On the other side, MPDC also has a partnership with an association of environmental specialists who are collectors of waste tires and use them to protect against coastal erosion. tires generate stability for the sea floor and the beach, in addition to enabling the stabilization of existing dunes. See below figure 25, the application of scrap tire for protect against coastal erosion.

Figure 25: Tire used to protect against coastal erosion.

Source: Autor

MPDC has received expressions of interest from different private institutions, associations and even individuals to benefit from the collection of scrap tires produced by MPDC, from terminal tractors and their trailers. Due to the limitation of compliance with local legal obligations for solid waste management (Decree n.º 94/2014 of 31 December), requests for partnerships with these institutions, associations and individuals, are not accepted, in order to not compromise MPDC's reputation regard to the correct treatment of waste tires.

Due to the lack of local industrial alternatives for the reuse of scrap tires, it raises major challenges for MPDC, namely: excessive accumulation of scrap tires within MPDC facilities, which constitute sources of mosquito proliferation and a threat of serious proportions in the event of fire.

For Mozambique and the world in general, the research in question identified alternatives for reusing waste tires in their entirety. Were identified the following alternatives:

Tire Craftwork: This is the case of an association of artisans who use scrap tires in the production of sandal soles based on rigid rubber and nylon wire and thread that are separated from the tires to produce cages, mousetraps and shoe sewing lines. This association get in contact with MPDC and expressed interest to be one of the collectors of scrap tire, was not accept because did not present a suitable plan to be done with remain waste tire, that can create negative impacts with the vicinity and compromise MPDC reputation. See figures 26 and 27, showing application of scrap tire on craftwork.

Figure 26: Rubber sandals

Source: MPDC

Figure 27: Cage made of tire wire

Source: MPDC

Drainage works: the tires joined in modules of approximately 15 tires form a pipe in place of the drains; in the USA "this practice has been adopted and has presented acceptable performance" (Kamimura, 2002).

Limitation in Sports Territory: tires can form walls of territory limitation for high-speed motor sports, also on horse racing tracks. See figure 28, in next page.

Figure 28: Tire as limitation in sport area

Source: Amándio Bouges, 2018, Jornal o País

Playground: the whole tires can be used as shock absorbers of toys, or even as toys, swings, obstacles. For this alternative is necessary the conduct a good selection of tires to be used, avowing tire that has wire exposed to avoid injury to playground users. See below figure 29.

Figure 29: Tire as playground

Source: 2,091 Tyre Playground Images, Stock Photos & Vectors | Shutterstock

Vases and furniture made with tires: whole tires are used as material in the manufacture of vases and furniture.

Among the alternatives described above, it is important to emphasize that these work as a palliative in the final destination of waste tires, as they do not use the existing stock of scrap tires on a large scale, the processes with the application of more complex technologies are those that incorporate the largest number of useless tires.

5. CONCLUSION AND RECOMMENDATIONS

5.1.Conclusion

The case study reached the expectations of the proposed objective, where the causes of tire losses in MPDC Operations can be analyzed. By collecting data regarding the situation of the tire management process and the use of quality tools, it was possible to identify the main problems associated with tire losses and propose improvements through an action plan.

The development of the work was based on FMEA methodology to determine the RPN (Risk Priority Number) and subsequent graphic illustration by the Pareto Diagram, it was possible to identify the “few vital” factors (the factors that warrant the most attention), and which constitute the main causes for the damage of tires in terminal tractors and trailers which correspond to 80% of the problems, and “very useful” factors (while useful to know, have a relatively minor effect). It was identified that the priority causes for the damage of tires in the case study were related to failures C1, C8, C11, C10, C6, C4 and C5, according to table 9 and figure 17. To mitigate the causes that contribute significantly to tire losses, using the 5W1H tool, corrective and preventive action plan was developed, where was proposed the replacement of protective barriers in weighbridges from rigid material (jersey block) to flexible material (used tires), establishment of air pressure control plan, definition on stock system the minimum and maximum tire, definition of tire repair limits, training of operators in the calibration procedure, and defensive driving.

With the significant damage of tires from terminal tractors and trailers classified as hazardous waste, a serious environmental problem arises for their management and destination. The generation of significant amounts of tire waste is a challenge for the world and Mozambique due to the development of the extractive industry and logistics. Therefore, for Mozambique the limitation of alternatives for reusing and recycling tires is related to the lack of rubber waste regeneration and tire processing industries, as well as the complexity in the process for export waste tires. For different alternatives existing for scrap tires reusing in Mozambique, are listed: use of inner tires to protect against coastal erosion and delimitation of areas, crafts (manufacture of sandals, cages, furniture, and toys in playgrounds) and retreading (the latter limited).

Due to the significant damage of tires in MPDC operations, the company has recently addressed this problem associated with the fact that there are limitations in Mozambique for the treatment of waste tires.

The result of the present work will be of great contribution to the MPDC where it was the object of study. For companies in the same or similar field of activity as the case study, the work can serve as a means of support and guide so that they can better evaluate their tire management processes and, if necessary, apply the preventive actions presented.

For the academic context, the study can be taken as a source of consultation for the development of works related to the topic.

For future work, it is recommended to carry out a study of failure costs, quantifying the damage in monetary terms to verify how failures that result in tire losses influence the company's revenue.

5.2.Recommendation

According to the causes identified that result the tire damage on terminals tractor and trailer in MPDC, indicate that a proper maintenance is key to ensure a long tire life, where the is recommended to look of the following item:

- Develop a systematic process to monitoring air pressure in tires.
- Rotate and align tires regularly.
- Get routine inspections on tires.
- Avoid bumping curbs or grazing them when parking.
- Avoid excessive acceleration, hard braking and aggressive cornering while driving.
- Ensure that tires stay within weight limit.
- Make sure of the manufacturing date of the tire – unused does not mean new, or that its not past its warranty period.
- Improvements on the truck route, condition of pavement, undulations, signalization on railway.
- Do not mix tires with different designs and brands should not be mixed on the same axle.
- Remove all obstacles along the operations areas, conduct regular housekeeping and maintain the road in good conditions.

In another side to prevent the high risk of tire, MPDC must ensure that in all areas where scrap tire are stored be distant of all others combustible material and ignition energy source and to avoid mosquito-borne diseases must be away of workplace areas.

To alternatives for the reuse scrap tires, the recommendation is to focus for industrialization (tire manufactures), training and awareness about the environment sustainability and establishment of clear requirement on local environment legislation.

BIBLIOGRAPHIC REFERENCES

ALMEIDA, A.A.R. (2016) *Análise e Aperfeiçoamento do Processo de Manutenção em uma Empresa de Óleo e Gás: Um estudo de caso*. 188 p. Monografia – Engenharia de Produção, Universidade Federal Fluminense, Niterói.

ARAUJO, R. P. (2006). *Sistemas de Gestão em Segurança e Saúde no Trabalho: Uma Ferramenta Organizacional*. Joinville, UDESC.

BARRETO, J. & LOPES, L. (2005). *Análise de falhas no processo logístico devido a falta de um controle de qualidade.* Revista Produção On Line – Universidade Federal de Santa Catarina. Florianópolis. Vol 5. Numero 2.

BEHR, A., MORO, E.L.S. & ESTABEL, L.B. (2008). *Gestão da biblioteca escolar: metodologias, enfoques e aplicação de ferramentas de gestão e serviços de biblioteca.* Revista da Ciência da Informação. Brasília/DF, v.37, n.2, p. 32-42

BONENTE, L. A., et al. (2005). *Transformação de Pneus Inservíveis em dormente ferroviário: proposta de pesquisa tecnológica.* Laboratório de Estudos e Simulação de Sistemas Metro-Ferroviários COPPE-UFRJ.

Brecka, J. (1994). *Study finds that gains with ISO 9000 registration increase over time, Quality Progress, 27(5), 18-20.*

BRIDGESTONE. *Como aumentar a vida útil do pneu. Disponível em:* <https://www.bridgestone.com.br/pt/sobre-nos/noticias/aumentar-vida-util>. Acesso em: 08 out. 2018.

BSI (2006). *PAS 99:2006. Specification of common management system requirements as a framework for integration, British Standards Institution, London UK.*

Constantinescu, C (2012). *Ecological Dimension of Tire Management. Environmental Impact of Tire* Use vol 2, 187–195.

CONTRAM – *Conselho Nacional de Trânsito (1980). Resolução n.º 558, de 15 de abril de 1980.* Fabricação e reforma de pneumático com indicadores de profundidade. Brasília, DF.

Dario, M. (2012) *Práticas, indicadores e custos na gestão de pneus: estudo em uma empresa de transportes.* Dissertação (Mestrado) - Mestrado Profissional em Administração, Faculdade de Gestão e Negócios, Universidade Metodista de Piracicaba, Piracicaba.

Dario, M., Silva, E. M. da, Sacomano Neto, M., & Pires, S. R. I. (2014). *Indicadores de desempenho, práticas e custos da manutenção na gestão de pneus de uma empresa de* *transportes*. Revista Produção Online, 14(4), 1235-1269. https://doi.or/10.14488/1676-1901.v14i4.1450

Estender, A. C., Niklis, R. B. R, & Barbosa, L. (2015). *Manutenção de pneus de frota como meio de redução de custos.* Revista Eletrônica de Administração (Online) ISSN: 1679-9127, v. 14, n.2, ed. 27. *http://periodicos.unifacef.com.br/index.php/rea*

Fonseca, J. J. S. *Metodologia da pesquisa científica. Fortaleza*: UEC, 2002. Apostila

Godlewska, J. (2017). *Recovery and Recycling of Waste Tires in Poland. Procedia Eng., 182, 229–234. ciencedirect.com/science/article/pii/S1877705817313097?via%3Dihub*

GOODYEAR. *Guia de cuidados e manutenção de pneus. Disponível em: <https://www.goodyear.com.br/pneu-cuidados-guia>. Acesso em: 08 out. 2018.*

Haguette, T. M. F. *Metodologias qualitativas na sociologia* Petrópolis : Vozes, 1997.

ISO 31000. (2009). *Risk management.*

Journal of Advanced Civil and Environmental Engineering Vol.1, No.2, 2018, pp 100-108 ISSN: 2599-3356;

Kamimura, E. (2002). *Potencial de utilização dos resíduos de borracha de pneus pela indústria da construção civil.*

Kmenta, S., Fitch, P. & Ishii, K. (1999). *"Advanced Failure Modes And Effects Analysis Of Complex Processes," in Proceeding of the 1999 ASME Design Engineering Technical Conferences*, Las Vegas, Nevada, pp. 1–9.

Lakatos, E. M. , Marconi, M. A. *Técnicas de Pesquisa.* São Paulo: Atlas, 1991. 205p.

Lima, V. R. (2018). *Gestão de pneus no transporte rodoviário: perspectiva dos profissionais do setor.*

LOUREIRO, R.G.(2013). *Aplicação das ferramentas a prova de falha" Poka-Yoke" como ações resultantes de FMEA de processo em unidades produtivas do setor automobilístico*. Monografia (Engenharia de Produção) - Fundação Eurípides Soares da Rocha, Marília.

Ludke, M., André, M. E. D. A. *Pesquisa em educação: abordagens qualitativas*. São Paulo: EPU, 1986.

Lundin, J & Jönsson, R. (2004). *Master of Science in Risk Management and Safety Engineering at Lund University. Sweden. Lund.*

Marshall J. et al, (2006) *Gestão de Qualidade*. 8 ed Rio de Janeiro

MARTINS, P. & LAUGENI, F. (2015). *Administração da produção*. 3 ed. São Paulo: Saraiva.

Minayo, M. C. S. *O desafio do conhecimento: pesquisa qualitativa em saúde*. 14ª edição. São Paulo: Hucitec Editora,

Pecorari, P.M. (2020). *Tire Management in a Truck Fleet and its Environmental Impact.* International Journal of Innovative Science and Research Technology

Peeters, J.F.W., Basten, R.J.I., & Tinga,T. (2018). *Improving failure analysis efficiency by combining FTA and FMEA in a recursive manner. Reliability Engineering and System Safety* (172) 36–44.

Pinto, A. K. & Xavier, J. A. N. (2001). *Manutenção: função estratégica*. 2. ed. Rio de Janeiro: Qualitymark.

Pudjotomo S. P, D., & Tifani, T. (2011) *"Cause Analysis Of Downloading Of Competitive Milk Dairy Products On Milk Import Milk On Milk Processing Industry (MPI) With Fault Tree Analysis (FTA) And Barrier Analysis Method,"* J@ti Undip J. Tek. Ind., vol. 4, no. 2, pp. 71–80.

Putra, M. N. M., Tama I. P., and Darmawan, Z., (2015) *"Defect Cause Analysis on Hull Construction (HC) of KM. Pagerungan with Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA)* (Case study in PT. PAL Indonesia)," J. Eng. Manag. Ind. Syst., vol. 3, no. 2, pp. 291–300.

Reniers, G., Dullaert, W., Ale, B., & Soudan, K. (2005). *Developing an external domino accident prevention framework*: Hazwim. Journal of DamagePrevention in the Process Industries, 18(3), 127-138.

Salini, R. B. (2000). *Utilização de borracha reciclada de pneus em misturas asfálticas*

S.S. Alizadeh et al., (2015). Scientific Journal of Review

STAKE, R. *The Case study method in social inquiry.* Educational Researcher, v.7, n. 2, p. 5- 9, 1978.

The Maintenance Council (1994). *Radial tire conditions analysis guide.*

Tire - Wikipedia.

Wang. T. (2017). *Analysis on Tyre Wear*. Degree project in vehicle engineering, second cycle, 30 credits

Woodruff, J.M. (2005). *Consequence and likelihood in risk estimation: A matter of balance in UK health and safety risk assessment practice.* Safety Science, 43, 345–353.

Wu, G., Zhai, M. and Wang, M. (2019) Radiation Technology for Advanced Materials

YIN, R. *Case study research: design and methods.* Newbury Park, CA: Sage, 1984.

Yu S, Liu J, Yang Q, Pan M (2011). *A comparison of FMEA, AFMEA and FTA. In: Reliability, maintainability and safety (ICRMS)*, 9th international conference.

ANNEXES

ANNEXE 1: Criteria to evaluate the Incident Consequent Severity in the FMEA method

Description	Scale
Complete failure (stop) of the system	10
Severe damage to the system	9
Damage to the system is too high	8
Damage to the system is high	7
Damage to the system is medium	6
Damage to the system is low	5
Damage to the system is very low	4
Minor damage to the system	3
Very minor damage to the system	2
No damage	1

Source: S.S. Alizadeh et al. / Scientific Journal of Review (2015)

ANNEXE 2: Criteria to evaluate the Incident Occurrence Probability in the FMEA method

Description	Scale
Incident or failure occurrence is very likely (once or more per day)	10
Incident or failure occurrence is likely (every 3 to 4 days)	9
Incident or failure occurrence possibility is very high (once a week)	8
Incident or failure occurrence possibility is high (once per month)	7
Incident or failure occurrence possibility is medium (every three months)	6
Incident or failure occurrence possibility is low (every six months to a year)	5
Incident or failure occurrence possibility is very low (once per year)	4
Incident or failure occurrence possibility is rare (once every 1 to 3 years)	3
Incident or failure occurrence possibility is very rare (once every 3 to 5 years)	2
Incident or failure occurrence is unlikely	1

Source: S.S. Alizadeh et al. / Scientific Journal of Review (2015)

ANNEXE 3: Criteria estimate the failure or Incident Detection Probability in the FMEA method

Description	Detection probability	Scale
No device control devices	No detection	10
Existing fault detection by control devices is unlikely	Negligible	9
Existing fault detection by control devices is very low	Very low	8
Existing fault detection by control devices is low	Low	7
Existing fault detection by control devices is modest	Modest	6
Existing fault detection by control devices is average	Average	5
Existing fault detection by control devices is more likely than average	More likely than average	4
Existing fault detection by control devices is high	High	3
Existing fault detection by control devices is very high	Very high	2
Existing fault detection by control devices is extremely high	Extremely high	1

Source: S.S. Alizadeh et al. / Scientific Journal of Review (2015)

ANNEXE 4: Interview questionnaire

Order	Question	Response
01	What is the recommended safe pressure for tires on terminal tractors and trailers?	
02	What time during operations do you conduct inspection on tires?	
03	Which frequency is recommended to conduct inspection on tires of the fleet?	
04	Are you follow the frequency recommended?	
05	The fitting of tires of different brands has any impact on the life of the same?	
06	Why some tires even new, has been damaged?	
07	What is the safe and critical measures of the tire tread wear?	
08	If the tire is identified with critical tread wear, which action is taken?	
09	After consider scrap tire which treatment is given for these tires?	
10	Why two tires in same axle got in friction contact on sidewall?	
11	Why do the fleet have terminal tractor or trailer with different brand of tires?	
12	How do you remove stones stacked between two tires?	

Source: Author