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Six Sigma Design, Analysis and Evaluation of Unscheduled Bogie Faults in Freight Wagons for Optimum Performance and Enhanced Logistics Management

By

Tebogo Tlou Photo

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Supervisor: Prof Michael Ayomoh
Co-Supervisor: Mrs. Ilse Doyer

Abstract

In the South African economy, the rail industry is crucial in transporting large freight or consigning goods and humans at an affordable and safe cost. The rail industry's poor operational outlook and lack of competitiveness, caused by the frequent breakdowns of commuter trains, have become a significant challenge in recent years. This perceived level of unreliability, associated with the rail industry, has significantly impacted the downward trend of the competitiveness of trade and industry-related economic benchmarks. Improving the reliability of rolling stock in the rail industry has become a subject of great concern in many logistics and freighting organisations globally. Improving reliability implies better quality rolling stock will be available for running the trains. Improving rolling stock maintenance in the rail industry can be achieved through continuous supervision utilising effective business management techniques. Freight logistics companies need to be more proactive in the maintenance of their rolling stock. The complex competitive business challenges emanate from fluctuating market demands, globalisation, and economic uncertainty. The literature suggests that the adoption of DMAIC (Define-Measure-Analyse-Improve-Control) tools is a highly effective initiative that can help the rail industry compete with other sectors in the national economy by reducing operational costs, enhancing productivity, and improving overall quality. The rail industry, being a backbone industry, is the backbone of the South African economy and is significantly lacking in these areas. The purpose of this study was to enhance the overall performance of wagons through process optimisation in the sole rail logistics and freighting industry of the Republic of South Africa by exploring, understanding, and analysing the unscheduled bogie faults and identifying the factors that contribute to high number of faults using the Six Sigma DMAIC problem solving methodology. A case study was presented to validate the DMAIC framework. Twelve months of data, covering the 2023/2024 financial year for bogies faults, was collected and analysed. The study revealed that 2551 faults were recorded for twelve months. Using the Pareto chart, the findings showed that unscheduled bogie faults contributed 48% with a total of 618, followed by brakes with 460 faults and followed by hallow wear with 239 faults. Therefore, the findings disclosed a significant link between Six Sigma structural effectiveness and Six Sigma enablers. Furthermore, Six Sigma enablers play a pivotal role in enhancing organisational prosperity. This study recommends exploring Six Sigma flexibility, expanding the research scope, and investigating its application across diverse South African industries.

Keywords: Rail Industry, Six Sigma, DMAIC, Process optimization, Quality improvement.

Declaration

Name: Tebogo Tlou Photo

Student number: u21677957

Degree: Master of Engineering (Industrial Engineering)

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I, Tebogo Tlou Photo, hereby declare that this dissertation is my original work. All sources utilized or quoted have been duly acknowledged and referenced in full. I further confirm that the dissertation has been subjected to originality-checking software and complies with the required standards for originality. Additionally, I affirm that this work has not been previously submitted for examination or qualification purposes at the University of Pretoria or any other higher education institution.

16/12/2024

Signature Date

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Abbreviations and Descriptions

ANOVA	: Analysis of Variance.
Black Belt	: Certificate for an individual who conducts Six Sigma projects.
CEO	: Chief Executive Officer.
CR	: Wagon class type.
CRM	: Customer Relationship Management.
DMAIC	: Define, Measure, Analyse, Improve and Control.
DMADV	: Define, Measure, Analyse, Design, and Verity.
ERP	: Enterprise resource planning.
ECP	: Electronic Check Presentment.
FOCUS	: Focus, Operate, Create, Utilize and Sustain.
Green Belt	: An individual who can conduct Six Sigma projects on a small scale.
Lean	: Focuses on removing wastes and idleness.
MRC	: Multiple regression correlations.
Muda	: Wastefulness.
MSA	: Master service agreement.
OTP	: On-time departure.
PRASA	: Passenger Rail Agency of South Africa
RFID	: Radio frequency identification.
SHEQ	: Safety, Health, Environment and Quality.
Six sigma	: Reducing process variation of any product during its production.
SLA	: Service level agreement.
TE	: Transnet Engineering.
TFR	: Transnet Freight Rail.
TPS	: Toyota Production System.
Yellow Belt	: A certificate for an individual who can conduct Lean projects.

CHAPTER ONE

INTRODUCTION

1.0. Chapter Overview

This chapter introduces the study, beginning with an outline of its background to provide a clear research overview. It then presents the problem statement, research inquiries, aim, and objectives. Additionally, the chapter covers the scope, rationale, and motivation of the research, concluding with an outline of the dissertation structure.

1.1. Background to the Study

Transportation is crucial in facilitating the movement of goods and people within a nation, contributing significantly to achieve economic objectives (Havenga & Pienaar, 2011). There has been a desire to improve South African freight rail system (Havenga & Pienaar, 2011; van der Merwe et al., 2023). The literature indicates that the improvements brought on board currently sit at 13.5% (Havenga et al., 2016). The estimated cost of freight logistics in South Africa in 2009 was approximately 35% of the country's GDP (Havenga & Pienaar, 2011). The cost of freight logistics in South Africa is significantly higher than that of first-world countries, where the percentage costs are approximately 10% in the United States of America and 20% in India and China (Havenga, 2010).

The contributing factor to this negative outlook is the deterioration of the rail transportation system. In the early 1990s, South Africa experienced a historic investment buildup, leading to service related issues and swift regulation in the freighting and transportation sector (Goedhals-Gerber et al., 2018). This has resulted in a rapid increase in road transport service providers. The proliferation of heavy vehicle fleets in South Africa harms the usage and growth of the rail transportation system, potentially limiting investment opportunities as rail freighting technology continues to gain momentum. As a result of unreliability, just-in-time, and unavailability, many companies stopped using rail transportation.

The new generation of locomotives in the estimated 78-million-tonnes, South Africa’s coal exportation scheme and 54-million-tonnes iron ore export system on the rail line facilities, accounts for 13% of the national network (Havenga et al., 2016). However, these locomotives account for 64% of the country's exported tonnes and 67% of the tonne-km of the railways' ongoing consignment and freighting task (Goedhals-Gerber et al., 2018). The market share for significantly long-distance rail transportion of fast-moving consumer goods (FMCG) is 2% of targetable traffic, and there is a great opportunity for improvement. According to Goedhals-Gerber et al. (2018), in the supply chain foresight study, 89% of participants in the FMCG and retail industry suggested that below 10% of freight transportion is through rail, even though 70% of the participants indicated that it can be more than 10%. There are plans to introduce technology such as Roadrailers and Roadrunners in South Africa to penetrate the market share. Transnet is the biggest rail transportation company in South Africa and has endorsed agreements with two private companies to validate via testing, the Roadrailers technology in 2015. The agreement aimed to reduce rail financial losses to the ever-growing road transportation system, while also leveraging new and improved turnaround times (van der Merwe et al., 2023). Therefore, this study sought to identify key drivers affecting Six Sigma implementation, develop a DMAIC-based Six Sigma model to enhance rail freighting performance and validate its effectiveness through data-driven analysis.

1.2. Problem statement

The last few years have seen the government-owned rail freighting system losing market value and shares in South Africa due to maintenance backlogs, cable theft, and skills shortages (Pieterse et al., 2016; van der Merwe et al., 2023). Some of the rail transportation challenges are geographical. About thirty-four per cent of South Africa’s gross value-added goods and services are concentrated in the Gauteng province, and the distance is quite considerable from all the ports (Goedhals-Gerber et al., 2018). The last 20 years have seen the South African rail industry fail to meet the demands of its client base. On the result of this ineffectiveness, the business community has since moved from rail to road transportation due to below-expectation service emanating from diverse scenarios, including the challenges revolving around the maintenance of railways. From a physical and institutional point of view, the South African transportation system's landscape is unique. This is premised as the important role played by a combination of the privatised road freight services and Transnet, which serves as the government agency responsible for determining transport logistic choices.

As a result, road transport dominated the flow of freight in the country for a considerable amount of time. During the first logistics survey (Van Rensburg & Krygsman, 2020), road transport held 84% of the market share in terms of volume flow. The contributing factor to this transport logistics challenge is South Africa's poor port performance, which affects the country's competitiveness in exports. Most companies that execute deals on exports in South Africa have restricted access to the freight rail market and associated port services. This includes large and small exporters in the non-traditional sectors.

More trucks on the road imply drivers are working long hours without rest to transport millions of tonnes worth of goods across different provinces in the country. The 2023 Road Traffic Management Corporation's (RTMC) report records 2237 fatal truck crashes over five years, involving 3,546 trucks. KwaZulu Natal province recorded the highest number of accidents with 22.4%, while the Northern Cape province recorded the lowest with 2.5% (Young, et al., 2023).

According to Boting (2021), Transnet Freight Rail is a major provider of rail transportation services, and it is involved in ensuring the success of rail transportation in South Africa. One way of encouraging competition among different carriers and other modes of transport is by ensuring that the national transport policy is more effective. South African Gross Domestic Product (GDP) growth is under 6% annually, while the average population growth rate in the country is about 1.3% annually. However, there has been a 20% decline in rail corridor traffic over the past 15 years. As a result, people and businesses are choosing road transport options over rail transport. As a result, the road corridor traffic has doubled, accounting for 89% of the total freight volume, while the rail corridor accounts for only 11% (Van Rensburg, 2021).

Both the Passenger Rail Agency of South Africa (PRASA) and Transnet have invested a total of R160 billion in improving the performance level of the rail transportation system. PRASA allocated R125 billion for the rolling stock fleet renewal procurement program. According to the yearly reports, PRASA has spent R53 billion on property, plant, and equipment since 2008, as indicated in Figure 1. Not much has changed in the value of its property, plant, and equipment. Rather, the value of the company's core assets increased more slowly than the investment capital.

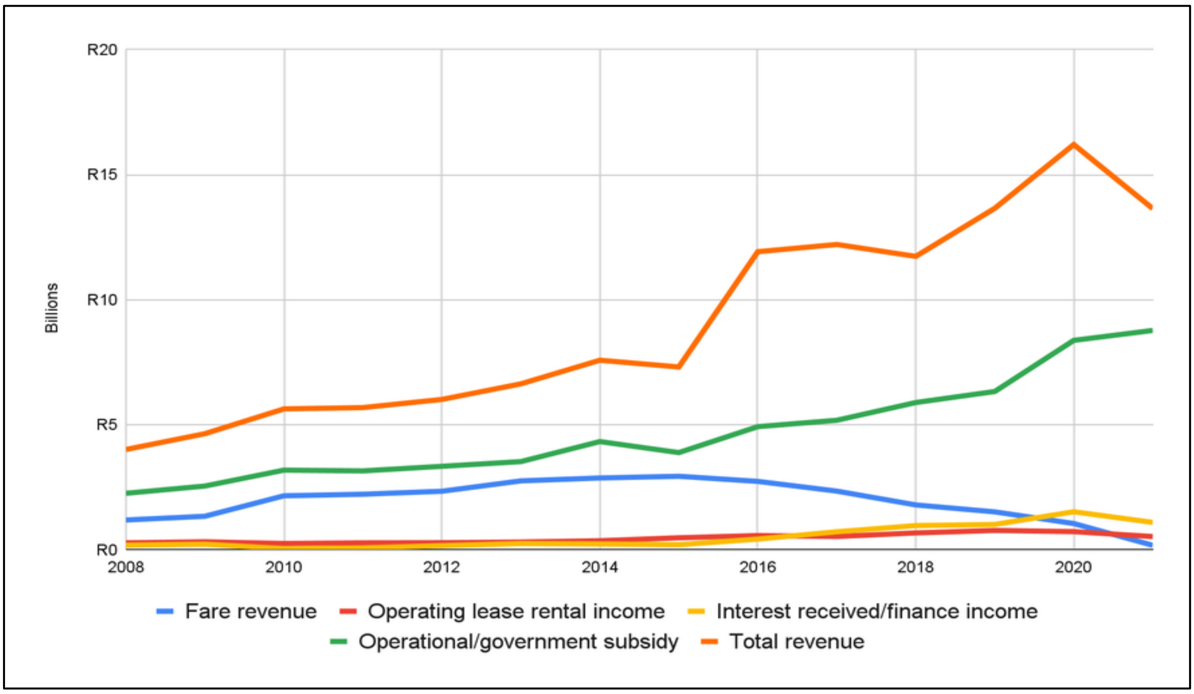


Figure 1 : PRASA annual reports

Transnet was allocated R35 Billion for the procurement of 1064 new Locomotive fleets. This amount is part of the R300 Billion upgrade for railways and ports to subdue the challenges of freight congestion. This will go a long way towards improving the rail transportation system. Hence, making it a preferred option in comparison with other modes of freight transportation in South Africa. Particularly the ever-growing road freighting option with a largely less economic outlook. Transnet claims that the 2012 Market Demand Strategy (MDS) assumed incorrectly that the South African economy would expand by 5% per year and did not specify how long this growth would be maintained (Transnet, 2023). To support the business case for the purchase of 1064 locomotives, estimates of Transnet's revenue and volume growth were made using this information. The strategy's substantial income and volume growth projections were not realized, since the South African economy has only grown by an average of

1.8% since 2012. The MDS predicted volumes of 351 mt for the 2018–19 fiscal year, as shown in Figure 2. The actual quantities during that time were 215.1 mt. During the 2018–19 fiscal year, real revenue was R65.5 billion, compared to the Strategy's R128 billion prediction.

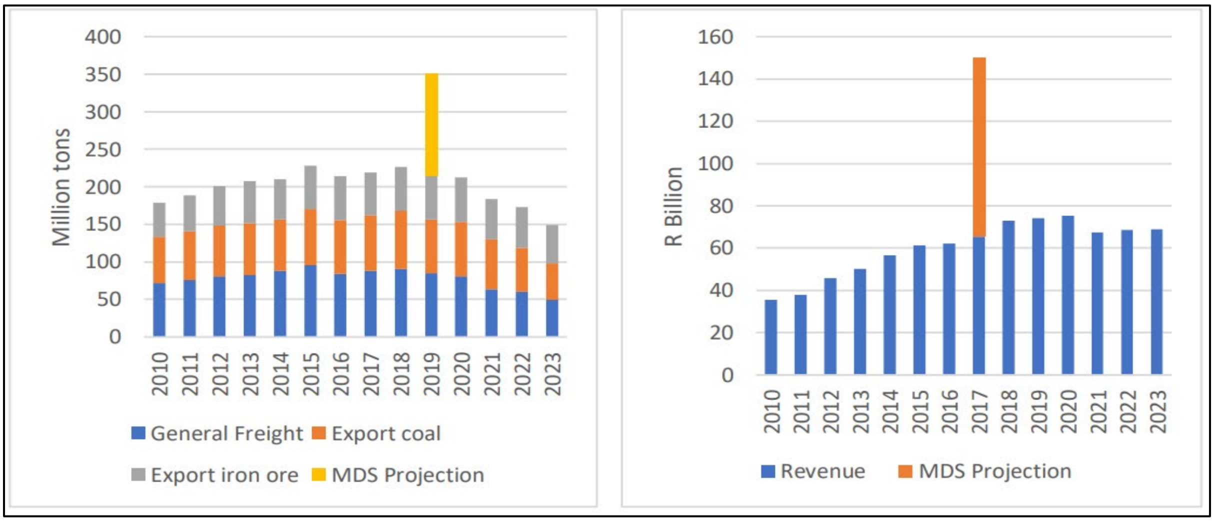


Figure 2 : Transnet Annual Reports 2010 – 2023

1.3. Research question.

This research sought to address the following questions:

a) What are the key drivers affecting the implementation of Six Sigma methodologies in the rail freighting industry of developing economies, and how can they be prioritized?

b) How can a Six Sigma-centric model, based on the DMAIC approach, be developed to enhance the performance of rail freighting operations?

c) How can the effectiveness of the developed Six Sigma models be validated through data deployment and performance analysis?

1.4. Research Aim and Objectives

1.4.1. Research Aim

This research study explored and applied Six Sigma methodologies, specifically the DMAIC framework, to improve process efficiency, reduce defects, and improve overall operational performance within rail freighting in developing economies, using the

South African scenario as a case study. This study sought to develop and validate data-driven models and actionable strategies that address challenges, ensuring quantifiable advances associated with key performance indicators such as quality, cost minimisation, and customer fulfilment.

1.4.2. Research Objectives

The objectives of this research were as follows:

a) Identification and prioritization of drivers affecting the implementation of Six Sigma methodologies in the rail freighting industry of developing economies.

b) Development of a Six Sigma-centric model premised on the DMAIC approach to performance enhancement of rail freighting operations.

c) Validation of the effectiveness of the developed Six Sigma models through data deployment and performance analysis.

1.5. Scope of the Research

This research focused on the implementation of Six Sigma methodologies, specifically the DMAIC (Define, Measure, Analyse, Improve, Control) framework, to enhance the operational efficiency of rail freighting in developing economies. It looks into important factors affecting the implementation of Six Sigma in this situation, including infrastructure constraints, process inefficiencies, and resource limitations. The study focused on the economic impact of the nation's current inadequate rail transportation system and the potential advantages of revitalising this sector. It also examined the possible contributions that the Department of Transport (DoT) and Transnet could make by improving freight services and transport systems and redirecting freight loads currently on the nation's roads to rail routes.

Large steel manufacturer Arcelor Mittal South Africa (AMSA) transports raw materials, including iron ore, line and coke, very often by rail from the Sishen and Kumba mines. These businesses have partnered with Transnet to use its services to transport raw materials needed to make steel. This study evaluated the overall effectiveness of South Africa's rail transportation system.

The scope of this study ensured a targeted and practical investigation, contributing to the advancement of Six Sigma practices in improving the operational efficiency of rail freighting in developing economies. Additionally, the study has looked at how South Africa might use rail transportation to increase its competitiveness in the sub-Saharan African (SSA) market and boost national development.

1.6. Rationale for the Research

The challenges of supply chain management and logistics, particularly in developing economies, necessitate efficient and reliable rail freighting operations. However, the rail freighting industry in these regions often faces numerous challenges, including outdated infrastructure, operational inefficiencies, and high operational costs, which hinder its ability to meet the growing demand. Adopting structured, data-driven methodologies such as Six Sigma, which has proven to improve process performance and reduce waste, was necessary to address these challenges. The motivation behind this research was to bridge the knowledge gap on the application of Six Sigma methodologies in developing economies' rail freighting industry, establish a data-driven framework for performance enhancement, enhance the reliability and sustainability of rail freight operations, and tackle region-specific challenges by creating and validating Six Sigma-centric models tailored to the specific requirements of developing economies. The findings could enhance the theoretical understanding of Six Sigma applications in logistics while offering practical solutions to industry practitioners aiming to improve efficiency and competitiveness in the rail freighting industry.

1.7. Motivation of the Research

Transnet, as a critical player in South Africa's logistics and freight transportation sector, faces significant challenges in maintaining operational efficiency, minimizing costs, and meeting customer expectations in a rapidly evolving market. Infrastructure limitations, resource constraints, and the growing demand for reliable and cost-effective services compound these challenges. Six Sigma, with its structured, data-driven approach to process improvement, offers a compelling opportunity to address these issues. Despite its proven success in other industries, the implementation of Six

Sigma methodologies within Transnet's operations remains underutilized. The need to explore how Six Sigma can optimize Transnet's processes, enhance service delivery, and contribute to its long-term sustainability motivates this research. By focusing on Transnet, this study aimed to provide personalised, practical solutions that align with the organisation’s goals while also addressing broader challenges within South Africa’s freight and logistics industry. In the end, this research sought to demonstrate how Six Sigma can drive operational excellence, support economic growth, and strengthen Transnet’s position as a leader in the logistics sector.

1.8. Structure of the Dissertation

Table 1 presents the dissertation's structure. This spans from Chapter 1 through the conclusion of the dissertation.

Table 1 : Detailed dissertation structure

#	Chapters	Description
1	**Chapter 1** Introduction	This chapter delineates the study's background, problem statement, research questions, aim, and objectives. It also covers the scope, rationale, and motivation for the research, concludes with an overview of the dissertation structure.
2	**Chapter 2** Literature Review	This chapter reviews existing knowledge about Six Sigma, emphasizing its definition, key frameworks, and implementation challenges. It examines the role of leadership, resource allocation, and global adaptation of Six Sigma across various sectors.
3	**Chapter 3** Research Methodology	This chapter outlines the research design and methodology used in the study. It details the processes of data collection, the application of the Six Sigma framework, and the methods of data analysis. The chapter also addresses issues of validity and reliability, ethical considerations, and the limitations of the study.
4	**Chapter 4** Results and Discussion	In this chapter, the collected data and results are presented and discussed in detail. The results are aligned with the research objectives, and their implications are analysed. The chapter concludes with a summary of findings and highlights their relevance for industry practitioners and Six Sigma researchers.
5	**Chapter 5** Conclusion and Recommendation	This chapter presents the research conclusions by summarizing the key findings and aligning them with the research questions. It highlights the challenges and limitations encountered during the study. Practical recommendations are provided, including suggestions for training, capacity building, and areas for future research.

1.9. Limitations of the study

The study does not present a global perspective of Six Sigma in the freight logistics industry. It is also not a broad opinion of the entire industry in South Africa. The implication of this research was conducted to limited freight logistic industry in Gauteng province rather than the broader sector. The findings of the study are important because they help to explore and expand the methodologies beyond the applications of the tools as has been in previous research in South Africa.

1.10. Chapter Summary

This chapter introduced the study by providing a comprehensive overview of its background and offering a clear research context. It presented the problem statement and research inquiries, aim, and objectives, establishing the foundation for the investigation. The chapter further highlighted the critical role of the rail freighting industry in the economic development of developing countries while addressing key challenges such as inefficiencies and resource limitations. It emphasized the potential of Six Sigma methodologies to tackle these issues by improving operational efficiency, reducing delays, and enhancing service quality. Additionally, the chapter outlined the scope, rationale, and motivation of the research, concluding with a detailed structure of the dissertation.

CHAPTER TWO

LITERATURE REVIEW

2.0. Chapter Overview

The previous chapter introduced the study by providing the research background, problem statement, objectives, scope, and rationale. This chapter reviews existing literature related to Six Sigma, focusing on its definition and origin as a data-driven methodology. It examines the DMAIC framework and its phases, the importance of management commitment, and challenges related to resource allocation. Additionally, the chapter explores the global adoption and adaptation of Six Sigma across different cultural and economic contexts. This review provides a theoretical foundation for addressing the research objectives of this study.

2.1. Origins and Definition of Six Sigma

Tomkins (1997) explained Six Sigma as principles that remove defects from all the processes, transactions, and products. Harry and Schroeder (2000) characterized Six Sigma as a strategic instrument that enhances market share, boosts profitability and guarantees customer satisfaction through statistical techniques that steer the advancement of significant quality improvements. On the other hand, Raisinghani et al. (2005) defined it as a methodology for the improvement of quality. History indicates that an American company named Motorola first introduced it around the 1980s. This company produced high-quality products (Motorola, 2009). Motorola’s challenges began in the 1970s when the Japanese started targeting all their businesses. The intense competition with the Japanese led to the dissatisfaction of Motorola's customers. The defective products they were producing were the root cause of this frustration. The Japanese were producing high-quality products due to the exceptional quality standards they had established. Many American companies could not keep up with the competition because they did not have such systems in place (Motorola, 2009). Due to serious financial pressure and other challenges, Motorola decided to take action to remedy the situation.

According to Montgomery and Woodall (2008), the Engineers at Motorola were tasked with the responsibility of minimizing the errors on the products, which was to be done in such a way that every product must be of good quality before shipping to the customer from the factory. A quality management program was established by combining the available quality management practices available at that time. That was how the methodology was created. The Methodology to minimize the product defects in Motorola was developed by an Engineer and scientist called Bill Smith. He presented the idea to Bob Gavin who was the CEO at Motorola at that time, and he agreed that the approach would help them solve the quality-related challenges they were facing on their products (Godfrey, 2002). When they started the journey, four Six Sigma phase approaches were followed (Measure, Analyse, Improve and Control) and introduced new operational strategies in their factories such as Installation of measurement systems, documentation of key processes, alignment of processes, improvement of processes as well as continuously monitoring them.

The Japanese were still way ahead of Motorola, even with their substantial quality improvements on the products. Consequently, the top management of Motorola initiated a 10-fold improvement drive in the quality department in 1970. The employees initially struggled, but by 1985, everyone was on board and working toward this goal. By the end of the five years, all of Motorola's businesses had achieved their improvement targets. Motorola leadership visited Japan to understand how they do things. Once they arrived, they realized the Japanese were far ahead because they had used similar technologies longer (Yang, 2012). The situation bolstered the determination of the Motorola executives, prompting them to set a new tenfold target, this time with a two-year deadline. Their goal was to achieve 3.4 defects per million opportunities by 1992.

Edward Deming and Walter Shewhart established continuous improvement programs in Japan and the United States of America in the 1950s to ensure quality production. Motorola came up with Six Sigma, and this practice says that 3.4 defects per million are tolerable (Motorola, 2009). In other words, an organisation achieving one million orders per year and having just one error opportunity per order with 3-sigma correctness (99.95%) will have 66,738 errors versus a 6-sigma (99.9997%)

organisation, which would encounter 3.4 errors (Vivekananthamoorthy & Sankar, 2011). As product designs become increasingly complex, so do the errors associated with them. Therefore, Six Sigma serves as an ideal quality tool to effectively manage these types of faults. Six Sigma strives to enhance the predictable quality of services and products by reducing normally distributed errors.

Table 2 presents a list of all the error rates of Sigma levels. σ is a Greek symbol for Sigma.

Table 2 : Six Sigma errors and error rates

Sigma Level	Defects per million opportunities (DPMO).	Defects percentage (%)
1σ	690,000	69%
2σ	308,000	30.8%
3σ	66,800	6.7%
4σ	6,210	0.62%
5σ	230	0.02%
6σ	3.4	0.00003%

Sigma or standard deviation is the measure of the fact or quality of being different from the intent that has an equivalent region on the other side of the average line. The most important aim of Sigma is to achieve 99.9997 % precision in the process.

2.2. Six Sigma methodology.

Six Sigma can achieve its goals through two types of methodologies: DMAIC and DMADV. The following are the two main methodologies used in different business environments:

2.2.1. DMAIC

DMAIC is an acronym that stands for Define, Measure, Analyse and Improve. This data-driven approach is used to optimize and improve existing business designs and processes. It is an effective method of controlling change management. We list the five phases of DMAIC as shown in Figure 3, each involving tools and tasks to help find the final solution.

Training and rewards for employees at all levels of the organisation are some of the most important aspects of Six Sigma. According to Padhy (2017), champions typically select projects to secure resources and set goals for improvement efforts. Employees receive master black belts, black belts, green belts, yellow belts, and white belts as a reflection of their training progress. Any organisation must establish a Six Sigma team structure before implementing the methodology and completing all five phases (Wooles & Allardice, 2008).

Figure 3 : DMAIC – The 5 Phases of Six Sigma

2.2.1.1. Define Phase

The Define phase of the DMAIC methodology aims to establish a cross-functional Six Sigma team to summarize the problems that happened, articulate the parameters and objectives of the enhancement initiative concerning customer specifications, and formulate a procedure that fulfils these specifications (Sunder, 2016). Critical to quality (CTQ) parameters are those that significantly impact the enterprise's quality goals. We use the Voice of the Customer (VOC) to identify the goals of CTQ. We generate VOC by conducting a brainstorming session with customers. The project charter, CTQ, flow down, and process mapping are crucial components in this phase of the project. A project charter is a document that explains the motive behind the project. It contains components such as the project business case, problem statement, and goal statement. Business cases articulate the project's purpose, initiating its objectives and goals.

The problem statement outlines the necessary actions and enhancements. After initiating the problem statement, the project team will decide on the target values using historical data. The goal statement outlines these values. Mapping the process is critical because it helps in understanding the operations and processes of the organisation. The supplier, input, process, output, and customer (SIPOC) chart is a process map that starts with the supply of raw materials and ends when the customer receives the product or service.

2.2.1.2. Measure Phase

The objective of the measure phase is to select the appropriate product characteristics, map the respective process, study the precision of the measurement system, record the data, and establish the baseline performance of the process. Additionally, this phase collects data in the form of critical quality (CTQ) (Wooles & Allardice, 2008). The baseline statistics, such as sample mean (μ), standard deviation (σ), and process capability indices Cp and Cpk for each CTQ, are calculated. The mean is the average in a data set. We calculate the sample mean by adding all observations in a sample and dividing by the number of observations in that sample (Wooles & Allardice, 2008). Standard deviation calculates the variability of the observations around the mean. It is equivalent to the positive square root of variance. The level, strength, or value of the observation fluctuates irregularly around the average. Measurement System Analysis (MSA) is another important element of this measure phase (Phruksaphanrat & Tipmanee, 2019). The degree to which variation in the measurement process adds to overall process variability is ascertained experimentally and mathematically.

2.2.1.3. Analyse Phase

During this phase, we perform important analysis using tools such as cause-and-effect diagrams, also known as fishbone diagrams and sort the numbers using the Pareto diagram (Singh et al., 2023). The fishbone diagram identifies many possible causes of an effect or problem. The fishbone diagram delineates numerous potential causes of an effect or issue. It can be utilized to facilitate a brainstorming session. It promptly organises concepts into beneficial classifications. It is highly beneficial for identifying the causes of defects, variations, or failures in a process. In other words, it assists in deconstructing, in successive layers, the fundamental causes that may contribute to an effect. This phase thoroughly examines each major cause. Investigating the subcauses and their impact on quality features accomplishes this. The cause-and-effect diagram assists in examining the reasons for variabilities. The Pareto diagram assists the project team members in separating the significant aspects of a problem from the trivial ones. The team focuses their improvement efforts by graphically separating the problem's aspects.

2.2.1.4. Improve Phase

Failure Mode and Effect Analysis (FMEA) identifies possible types of failures. We prioritize failures based on their severity, frequency of occurrence, and ease of detection (Wu, Liu, & Nie, 2021). The main aim of the FMEA is to foresee all possible types of failures that could occur. The table of FMEA gives a structure that categorizes the failure modes in a system. The table's first column lists subsystems and components in their respective rows. If the system is complicated, we may add more details to ensure its accuracy. The second column records distinct ways in which each item can lose function. Each of these failure modes has its row. A single item in the first column may have a few different failure modes. The third column lists the potential effects. Additional columns capture the causes of the failure modes and outline the current measures in place to prevent and control each failure mode.

FMEA can pave the way for hypothesis testing. You can use the risk priority number to identify high-risk areas for testing. It can also aid in formulating necessary questions about the relationship between variables (x's and y's) within the process. Additionally, by comparing occurrence and adjusted occurrence after changes have been implemented, the FMEA can provide data to support or reject hypotheses about the effectiveness of those changes. According to Chen and Chang (2020), hypothesis testing is one of the tools used to examine data to determine if the changes made in the process are better or not. We accomplish this by scrutinizing the null hypothesis and the alternative hypothesis. Hypothesis testing allows us to determine whether there is a statistically significant difference between data sets when considering different distributions.

When the data is discrete, one can detect a defect in proportion, and when it is continuous, one can detect a difference in average and variance. Steps in hypotheses involve determining the appropriate hypothesis test, stating the null hypothesis Ho and alternate hypothesis Ha, calculating the test statistics/P-value against the table value of the test statistic, and interpreting the results accepting or rejecting Ho. The P value is also known as probability, and it measures how likely it is that any observed difference between groups is due to chance. The values range between 0 and 1. It normally works with a 5% alpha risk. When the P value is below 0.05, we reject the null hypothesis and accept the alternative hypothesis.

2.2.1.5. Control phase

The control phase is responsible for implementing actual changes, which include behavioural and physical retraining of employees on new procedures, rewriting work instructions and procedures, introducing systems to calculate and monitor the new processes, and establishing an action plan (Vargo & Lusch, 2018). In this phase, the focus is on the implementation of plans for monitoring the system's performance and taking corrective action in situations where deviations from the idea are detected. The control phase is crucial for future process improvements. The improve phase provides all the necessary tools to sustain the project's improvements.

2.2.2. DMADV

DMADV stands for "define, measure, analyse, design, and verify." DMADV, a second methodology of Six Sigma, focuses on designing or redesigning processes, products, or services to meet customer expectations and achieve quality objectives (Vargo & Lusch, 2018). DMADV applies when a process or product requires a complete development or fundamental redesign, in contrast to DMAIC, which concentrates on improving existing processes. Steps of DMADV:

- Define: Clearly define the project goals, customer requirements, and key deliverables.

- Measure: Identify and measure critical metrics and factors that align with customer needs and project objectives.
- Analyse: Analyse the data to develop high-level design concepts and evaluate potential alternatives.
- Design: Create detailed designs for the process or product, incorporating the insights from analysis.
- Verify: Test and validate the design to ensure it meets customer expectations and performs as intended.

Six Sigma designed the DMADV methodology to create or redesign processes, products, or services to meet customer expectations and achieve quality objectives (Vargo & Lusch, 2018). By following its five steps, namely, Define, Measure, Analyse, Design, and Verify, DMADV ensures precision and customer-centric outcomes. DMADV offers the following key benefits (Vargo & Lusch, 2018):

- Ensures customer-centric design and development.
- Reduces defects and inefficiencies from the outset.
- Aligns processes and products with organisational goals and customer needs.
- DMADV is particularly useful in industries where precision and quality are paramount, ensuring that new processes or products achieve Six Sigma standards.

2.3. Difference between Six Sigma and other improvement initiatives.

The Six Sigma methodology began as a quality improvement technique. Over time, the Six Sigma methodology evolved into a comprehensive strategic approach for continuous improvement across various organisations. During its evolution, the Six Sigma methodology distinguished itself from other quality tools such as Total Quality Management (Mahdikhani, 2023). People regard Six Sigma as an extension of quality concepts such as statistical engineering (SE), ISO 9001, statistical process control, total quality management (TQM), and Deming statistical quality control. Table 3 below compares the attributes of Six Sigma and other Quality enhancement approaches.

Table 3 : Comparison between Six Sigma and other Quality Enhancement Approaches

No:	Attribute	Six Sigma	Deming cycle	Total Quality management	Statistical Engineering
1	Process-centric approach.	High emphasis.	Implicit.	Implicit.	High emphasis.
2	Customer focus.	Implicit.	Invisible.	Explicit.	Implicit.
3	Statistical approach.	Has a statistical base.	No confinement to the statistical approach.	Tools have a statistical base.	Usage of simple statistical tools.
4	Behavioral content.	Exist.	Does not emphasis the behavioral side of problem solving.	Emphasizes the behavioral approach to problem-solving.	Talk less about behavioral attributes.
5	Easiness.	Difficult in terms of goal implementation.	Simplest guide to solve problems.	Easier to implement.	No publicized estimates are available.
6	Cost.	High to medium investment.	Usually low-investment projects.	Usually, moderate.	Moderately difficult.
7	Duration.	High.	It depends on the project size.	Project sizes are moderate.	No figures are made available.
8	Executive role.	Top down.	Not emphasized.	Top down.	Bottom up.

According to Kumar et al. (2008), Six Sigma is a methodology that consists of certain elements. The components of Six Sigma are as follows:

- Financial results,
- Strong customer focus,
- Total quality management,
- Additional data analysis,
- Key personnel, and
- Project management.

Six Sigma is a five-phase process for improving processes known as DMAIC (Define, Measure, Analyse, Improve, and Control). Six Sigma phases are similar to the phases of Deming known as the Plan-Do-Check-Act (PDCA) cycle (Nguenang, 2010). The Deming cycle is important when implementing solutions for the Six Sigma project (Knop, 2022). What makes DMAIC more powerful is the fact it focuses on the Defects Per Million Opportunities target of 3.4 as well as combining other excellent problem-solving tools and techniques into the DMAIC structure. This is what distinguishes Six Sigma as a revolutionary approach to product and process quality improvement, employing statistical methods more effectively than TQM (Soundararajan, 2019).

According to Saxena and Srinivas Rao (2019), the Six Sigma methodology and some of the quality management concepts have similarities, as illustrated in Table 2. However, those programs differ in many ways, and Six Sigma focuses its attention on the following areas:

- Six Sigma underscore data-driven decision-making.
- Six Sigma provides an organisational infrastructure consisting of key trained personnel for an effective implementation of this approach.
- Six Sigma utilizes the idea of statistical thinking that persuades the utilization of powerful statistical tools and techniques for process variability reduction.
- Six Sigma focuses on financial return achievements.
- Six Sigma begins with top leadership and the proper curriculum of management roles is defined within the Six Sigma framework.
- Six Sigma gives an organisational infrastructure consisting of personnel trained for an effective implementation approach.

The distinction between Six Sigma and alternative quality methodologies initiatives is that the focal point of Six Sigma is to drive business results directly. The project’s execution carefully selects and equips individuals for that purpose. Six Sigma is a business philosophy that entails full commitment and involvement from top leadership, data analysis and validation using statistical tools and techniques, and a specific project goal. The individuals involved in the project remain fully committed from the project's inception to its completion, striving to reduce defeats, reduce costs, and generate benefits.

2.4. Benefits of Six Sigma

According to Linderman et al. (2003), Six Sigma is a properly structured and arranged method that can achieve various objectives, including the improvement of existing processes and services. It is essential to acknowledge that in Six Sigma, it is necessary to statistically prove that your potential Xs are indeed the root causes (Linderman et al., 2003). This is typically achieved through hypothesis testing. Antony (2008) noted that Six Sigma has gained momentum in recent years, and its implementation has yielded the following results:

- Cost reduction of operations
- Reduction of defeats
- Improved satisfaction of customers and shareholders.

Research on the application of Six Sigma revealed substantial benefits that emanated from the endorsement and application of this continuous improvement technique by many organisations in different sectors. More than 390 companies assessed the impact of Six Sigma adoption on their financial performance, highlighting its importance in improving return on investment and the positive impact of reducing indirect costs (Swink & Jacobs, 2012).

According to Alhamali (2019), the implementation of Six Sigma in hospitals has led to the attainment of comprehensive medical quality. Feng and Manuel (2008) noted in their investigation that introducing Six Sigma can lead to patient satisfaction, high-quality care, and a reduction in medical errors. The investigation concluded that different hospital departments can apply Six Sigma (Feng & Manuel, 2008). Project-oriented implementation of this can enhance process flow and reduce cycle time. According to Antony et al. (2007), this methodology enhances organisational processes, leading to increased profitability, market share, customer satisfaction, and productivity. The authors' top health sector priorities are radiology cost reduction and throughput improvement. Alhamali (2019) highlights the reduction in waiting times for surgery as one of the important benefits of Six Sigma. Table 4 highlight some of the benefits Six Sigma benefits according to Alhamali (2019).

Narula and Grover (2013) discovered that excellent financial health is one of the most important benefits of introducing Six Sigma in any organisation. There is a direct relationship between productivity and implementation of Six Sigma (Hekmatpanah et al., 2008). Estimating hospital operations is crucial for saving lives. Doctors can use Six Sigma to enhance service safety and patient satisfaction (Zafiropoulos, 2015).

Table 4 : Examples of benefits of Six Sigma (Alhamali, 2019)

No.	Six Sigma benefits
1	Reduced waiting time for surgeries
2	Reduced unnecessary movements
3	Reduced medical and non-medical errors in healthcare
4	Reduced length of stay in hospitals
5	Reduced fall rates of patients
6	Reduced costs
7	Minimized waste
8	Increased satisfaction of patients, physician, and staff
9	Increased rate of return on investment
10	Increased competitiveness
11	Improved quality of care
12	Improved process of hospital discharge
13	Improved patient satisfaction
14	Improved organisational productivity
15	Improved medical process
16	Improved financial health of organisation
17	Improved business performance
18	Ensuring continuous improvement
19	Enhanced efficiency of physicians
20	Enhanced data integrity

2.5. Organisational infrastructure for Six Sigma.

According to Nguenang (2010), an organisation must first establish certain features before initiating Six Sigma implementation. Those elements include teamwork, resource availability, communication skills, and long-term focus. Some researchers propose that Six Sigma provides organisations with infrastructure that makes it simple to implement and sustain the implementation of the methodologies. The shortage of tangible infrastructure to sustain the establishment of total quality management was one of the main contributing factors to its failure (Knapp, 2015).

For an organisation to reach the long-term targets of Six Sigma, there should be a commitment from each component of the value chain. Employees should actively participate in and play specific roles and responsibilities (Knapp, 2015). Six Sigma resources receive extensive training in problem-solving, statistics, and the selection and execution of Six Sigma projects (Nguenang, 2010). They are considered catalysts who establish cultures and norms within the organisations.

Employees ranked according to the belt system typically select and conduct Six Sigma projects from the Define to Control phase (Stankalla et al., 2019). Professionals who earn Six Sigma certification become key stakeholders in improving the quality of operations within their organisations. They strive to eliminate variation in manufacturing and business operations by implementing standard processes and establishing metrics that minimize the potential for defects. The certification levels individuals qualify to dictate their roles. Those levels indicate which role each belt should play in completing the projects and promoting management practices (Stankalla et al., 2019).

2.5.1. Six Sigma White Belt.

White belt certification is the first level of certification in the Lean Six Sigma methodology (Theisens, 2021). This introduces the principles and tools used in process improvement and quality management. White belt training assists employees in comprehending the basics of Six Sigma.

2.5.2. Six Sigma Yellow Belt.

An individual with Yellow Belt certification demonstrates knowledge of Six Sigma concepts beyond the foundational level covered in White Belt training (Theisens, 2021). Normally a Yellow belt training session is about one to two days. The training is structured in a way that can equip the resource to fully participate meaningfully as a Team member in a project. They assist managers at higher belt levels, and they lead limited-scope projects (Theisens, 2021).

2.5.3. Six Sigma Green Belt.

Lean Six Sigma Green Belt is an individual who applies problem-solving frameworks such as DMAIC (Define, Measure, Analyse, Improve, and Control) and receives the Green Belt certification (Hollingshed, 2022). This is a continuous improvement methodology that lays out a series of steps to understand the problems in a business process, inspect and analyse data, establish reasonable metrics to track improvements or changes in processes, implement solutions, and ensure that there is sustainability in the results. Green belt training is important for employees who play roles in health care, financial management, and project management, amongst others (Hollingshed, 2022). It provides them with tools such as Pareto charts, Failure Mode and Effect metrics (FMEA), cause and effect metrics, and control charts to comprehend the optimal performance of the process. A Green Belt certification prepares an individual to lead and conduct Lean Six Sigma independently, connecting the organisational goals with Lean Six Sigma concepts (Theisens, 2021). They eliminate waste and obtain useful insights from data.

2.5.4. Six Sigma Brown Belt.

This Belt is mostly awarded to an individual who has completed a black belt examination; however, a second Six Sigma project remains unfinished. The Brown Belt is not conventionally utilized in Six Sigma and lacks recognition from the majority of organizations and accrediting bodies. (Carver et al., 2024).

2.5.5. Six Sigma Black Belt.

A Black Belt certification in Six Sigma represents the advanced level of the training methodology, a data-driven project management system that utilizes data and statistics to assess the effectiveness, productivity, and success of various company processes (Theisens, 2010). This is advanced training, requiring a solid understanding of Lean Six Sigma. In other words, a green belt is a prerequisite for black belt training because you must master the skills to plan, guide high-cost projects, make organisational changes, and simplify compound projects. Black belt trainees are prepared to gain a meticulous comprehension of implementing organization-wide transformations, analyzing data, and executing Six Sigma principles, and coaching green belt trainees (Carver et al., 2024). Black belt certification requires an individual to demonstrate their experience conducting a project for their organization. Typically, they accomplish this by identifying a problem, gathering and analyzing data, creating a project charter, and utilizing all the essential Six Sigma tools in a practical setting. Black belt-trained individuals develop abilities to increase productivity in their businesses and enhance customer satisfaction.

2.5.6. Six Sigma Master Black Belt.

According to Escobar et al. (2021), for an individual to start with a Master black belt, they must first be an experienced Six Sigma Black belt that possesses problem-solving and leadership skills. The master black belt is like an internal responsible for the strategic direction of Six Sigma within the organisation and they also coach green belts and Black Belts.

2.5.7. Six Sigma Champion.

Champions of Six Sigma are usually senior managers. They are responsible for developing the idea to commit to sponsoring, leading the strategy and deploying it (Stankalla et al., 2019). Champions ensure that Six Sigma projects and other initializes minimize waste and eliminate defects align with the organisational needs for growth and objectives formulated by the executive leadership (Stankalla et al., 2019).

2.5.8. Six Sigma Executive.

A Six Sigma Executive is an individual at the executive level within the organization. They are responsible for developing and ensuring that the strategy is known throughout the organization. The executive is usually a member of the C-suite, such as the Chief Executive Officer, Chief Operating Officer, and Chief Financial Officer, among others (Stankalla et al., 2019). The executive is responsible for setting the overall strategy and direction for Six Sigma implementation, as well as overseeing the day-to-day operations of the program.

2.6. Key elements for Six Sigma implementation.

2.6.1. Management involvement and commitment

Chakravorty (2009) asserts that the introduction of methodologies such as Six Sigma in any organization requires the involvement of top management. Jack Welch, the Chief Executive Manager of General Electric (GE), significantly influenced the introduction of the Six Sigma methodology in GE. He also spearheaded the restructuring of the business organization, ensuring a change in the employees' attitude towards Six Sigma (Henderson & Evans, 2000). Commitment and continuous support by the top management of the organization are of paramount importance because employees look up to the leadership of the organization to lead by example (Alnadi & McLaughlin, 2021).

2.6.2. Change of culture.

When introducing a new strategy, it is crucial to consider the culture of the organization. The organization's culture and attitude will undergo some adjustment upon the introduction of a new strategy (Hess & Benjamin, 2015). The new strategy must motivate employees and assure them of its great benefits. Most importantly, they must accept responsibility for the quality of the work they do. In the case of GE, the introduction of continuous improvement methodologies by Jack Welch caused concern among the employees due to the statistical implications associated with the strategy (Hess & Benjamin, 2015). One of the challenges was the lack of knowledge about Six Sigma. Due to the continuous involvement of the top management, the mindset of employees changed, and the strategy was a success. The right attitude and culture of all employees from lower to top leadership depends on the success of Six Sigma in any organization.

2.6.3. Organisational infrastructure.

The introduction and development of Six Sigma requires proper organisational infrastructure for its effectiveness. While top executives of the organization play a crucial role in ensuring the success of Six Sigma, infrastructure also plays a critical role in this process (Hess & Benjamin, 2015). An organization typically trains its employees in Six Sigma to lead teams in identifying, executing, and managing Six Sigma projects to completion. Most importantly, they normally undergo extremely thorough statistical training. Most organizations, such as General Electric and Motorola, entrust their initiatives to their chief executive officers, who are considered champions. The Master Back Belts, Black Belts, Green Belts, and other team members trail behind the Champion. The team members are responsible for supporting specific projects within the organization (Laureani & Antony, 2018). In other organizations, there are project sponsors in addition to the belt system. They are responsible for guiding project team members in arranging resources and budgets for the project. Before implementing the methodology, the organization must prepare. Six Sigma necessitates significant resources, including the commitment of executive management, employee dedication, energy, and cost, among others.

2.6.4. Training

Six Sigma does not only reduce waste; it assists in maximizing process effectiveness in an organization. Formal training assists employees in learning how to utilize resources effectively. An organization needs to communicate with the employees as early as possible to improve their comfort level via training classes (Laureani & Antony, 2018). An organization uses a belt system that ranks specialists. The belt system helps everyone in the organization communicate in a common language. Aligning all employees facilitates the quick and effective completion of projects. Organizations typically outline the roles and responsibilities of individuals involved in Six Sigma projects in their organisational curriculum. For instance, Motorola requires a minimum of one year to achieve the status of a black belt. To become an accredited black belt, a candidate must fill out an application form that demonstrates their fulfilment of the

Six Sigma practice and training requirements (Theisens, 2010). The training in General Electric takes between 16 and 20 weeks. Black belt certification is crucial for promotion purposes. According to Yang (2004), GE Six Sigma is more structured compared to Motorola training. GE training is shorter than Motorola training, and GE can train and produce a substantial number of black belts. Be that as it may, Motorola black belt training is more adaptable, and it results in a greater breadth of expertise.

2.6.5. Project management skills.

Six team members need to possess project management skills because Six Sigma, in its nature, is a project-driven methodology (Antony et al., 2020). This assists project team members in meeting deadlines during the projects. According to Antony et al. (2020), some of the main contributing factors to Six Sigma project failure are a lack of roles and responsibilities, poor project management skills, and setting and keeping ground rules.

2.6.6. Project prioritization and selection, reviews, and tracking.

The success of Six Sigma projects relies on the criteria for project selection and prioritization in any organization. Projects that are not properly selected and defined can create many challenges that can result in projects not generating benefits. According to Antony and Banuelas (2002), project selection criteria can be categorized into three main areas as shown below:

a. Business Benefit criteria

- Financial influence.
- Effect on key capabilities.
- Effect on achieving external customer requirements.

b. Feasibility criteria

- Complications.
- Resource needs.
- Accessibility of skills.

c. Organization impact criteria

- Cross-functional interest.
- Leaning benefit.

2.6.7. Understanding the Six Sigma methodology, tools, and techniques.

The Six Sigma team members need to understand the theories and the methodology. There are three types of techniques and tools that employees can learn during the Six Sigma training (Laureani & Antony, 2018). These tools include team tools, process improvement tools, and leadership tools. Simple quality or statistical tools suffice to address issues within organizations. Regression analysis, statistical process control, and the analysis of variance design of experiments are some of the tools required for advanced improvements in business processes (Hess & Benjamin, 2015). Most importantly, there should be a proper and precise set of metrics used to calculate process performance against customer requirements. The metrics compromise throughput yield, defect rate, and cost of poor qualities. The project requires accurate data for analysis to make value-adding decisions (Laureani & Antony, 2018).

2.6.8. Linking Six Sigma to Business Strategy

The organization must link Six Sigma to other business strategies for it to be successful. Treating Six Sigma as a standalone will hinder its success (Cheng, 2013). According to Coronado and Antony (2002), setting customer demand is the first step in conducting a Six Sigma project. On the other hand, Coronado and Antony (2002) argue that a good understanding of how an organization operates and its relationships with other different activities of the business is important. Six Sigma can connect with the customer in two ways:

- Determining the fundamental processes, Describing the key basic outputs of these processes and defining the key customer that they serve.
- Identification and defining the customer's needs and requirements.

2.7. South African economy and role of the logistics industry.

The South African economy is significantly dependent on energy-intensive sectors, including mining and primary minerals beneficiation, which, in turn, depend on fossil fuels as their energy source of energy (Goedhals-Gerber et al., 2018). South Africa ranks 13th among the world's top 10 economies with the highest carbon emissions. With a Gross Domestic Product (GDP) of R 3,655 trillion and a carbon intensity of 0.972 metric tonnes of CO2 per R 18278.00 GDP in 2011, South Africa lags behind leading countries like Germany, which contributes about 0.290 metric tonnes of CO2 per R 18278.00 GDP, and China, which contributes 0.804 metric tonnes of CO2 per R 18278.00 GDP (Goedhals-Gerber, 2018). According to the National Treasury (2010), South Africa promised to reduce domestic greenhouse gas (GHG) emissions by 34% by 2020 and by 42% by 2025.

The cost of logistics in South Africa in terms of GDP percentage increased from 11% to 11.8% between 2010 and 2016; however, it went down in 2003 from 13.6% (Chakamera & Pisa, 2021). The reduction of logistics costs as a GDP percentage is the direct result of more efficiency in the last mile (Goedhals-Gerber, 2018). The drive toward efficient supply chain management was a result of the increase in diesel prices over the years. This resulted in a reduction in the number of tonne-kilometers spent on last-mile distribution (Stellenbosch University , 2015)

Since 2011, the cost of logistics has consistently increased in terms of primary and secondary GDP, rising from 47% in 2013. The cost of transport in South Africa contributes 62% of the logistic cost compared to the world average of 39% (Rodrigue et al., 2009). In addition to the 15% increase in the already high cost of transport, which is attributed to 30% emissions and 40% accidents, Goedhals-Gerber et al. (2018) estimate that transport externalities amount to R40 billion. 88% of South Africa’s total freight tonnage in 2013 was on the road (Havenga & Simpson., 2013). This poses a significant concern, as 86% of long-distance transportation occurs on roads. As much as road freight has more advantages compared to other modes of transport, it contributes to high traffic congestion, higher levels of carbon emissions, deterioration of road networks, and overloads (Goedhals-Gerber et al., 2018). According to Havenga and Simpson (2013), diesel cost was the main contributing factor to 40% of South Africa’s freight transport cost in 2013.

2.7.1. Road Freight

In February 2013, South Africa's National Traffic Information System registered nearly 12 million vehicles. Out of 100% of those vehicles, over 64% were passenger vehicles in the form of buses, motor cars, and minibuses. Trucks and light-duty vehicles contributed approximately 26 percent (eNaTis, 2017). The largest vehicle population is Gauteng province at 39%, followed by Western Cape at 16% and KwaZulu Natal at 14%. The population of heavy vehicle fleets has grown more than the GDP over the years. The decline in rail use is the reason there is an increase in South Africa's heavy vehicle fleet (eNaTis, 2017). Unreliability, unavailability, and the just-in-time needs of freight owners are the reasons many companies stop using rail transport (Mathabatha, 2015). Furthermore, Mathabatha (2015) suggested that many companies could potentially return to rail if they focus on capacity challenges and service delivery. According to Kilian (2017), there was a 10-year contract between Railway and Exxaro, and a partnership between Grindrod and Barloworld, ArcelorMittal, and rail to establish a new logistics centre (Pieterse et al., 2016; Odendaal, 2016). These examples highlight that addressing capacity constraints and improving service delivery could restore confidence in rail transport, offering a viable solution to the logistics challenges faced by freight owners.

2.7.2. Rail Freight

Long-distance transportation of consumer goods is the biggest opportunity for rail because it accounts for only 2% of targetable traffic (Goedhals-Gerber et al., 2018). Transnet introduced new generations of locomotives with regenerative capabilities on the iron ore and coal lines (Mathu, 2014). Most of the locomotives in South Africa are very sophisticated. The 78-million-ton coal export system (over a distance of 561 kilometers) regenerates 27% of the energy required for a round trip. Locomotives on the 54-million-tonne iron ore export system (over a distance of 882 kilometers) regenerate 38% of the energy required for a round trip (Munshi, 2014). When expressed as a percentage of tons transported, regeneration is 13% for the coal line and 34% for the iron ore line (Li et al., 2014). In terms of the network coverage, iron ore and coal expert railways constitute 13%. However, 64% of tons shipped and 67% of tonne-km of the railways' current freight task. The goal is to introduce new technology in the general freight business.

2.8. Six Sigma Case Study Applications in Selected South African Industries

Research on Six Sigma applications with diverse industrial focus has been conducted in a few South African industries. Those industries include hospitality (Ramphal, 2017), banking (Goldsmith, 2014), clothing (Ramdass & Pretorius, 2008; Tampubolon & Purba, 2021), automotive (da Silva et al., 2021), healthcare (Rathi, Vakharia et al., 2022), and construction (Fitchett & Rambuwani, 2022; Maradzano et al., 2019). According to (Mabotja & Mavutha, 2024), there is a slow adoption of Six Sigma in South Africa. (Mabotja & Mavutha, 2024) encourages large organizations with more experience in Six Sigma methodologies to assist those struggling with the adoption and implementation of these methodologies.

Most organizations associate the success of Six Sigma with a highly efficient and disciplined Japanese work culture (Ono, 2018). As much as the culture contributed to the success of Toyota's growth, they ensured that they adjusted their global philosophy to modify principles and alter the operations and strategies of the business in the countries the organization is in (Shook et al., 2009). Their slogan, "think globally, act locally," effectively encapsulated their strategy. The acknowledgement of certain components in certain countries is important because they have an impact on the implementation of Six Sigma. After Hulamin introduced Six Sigma methodologies, it managed to save around R50 million (Rautenbach, 2022). This organization is in the aluminium industry and is responsible for transforming primary aluminium into two types of semi-fabricated products, namely, rolled products and extruded products. It is Africa's leading producer of semi-finished and fabricated aluminium products. The Six Sigma tools assisted the organization to grow sustainably and realize profitability (Dube, 2014).

The unique South African culture is a challenge when it involves implementing continuous improvement methodologies. Babu et al. (2020) assert that ethnic differences significantly hinder the successful implementation of Six Sigma in South Africa. Six Sigma requires teamwork and collaboration. At the project level, individuals are designated as master black belts, black belts, green belts, yellow belts, and white belts (Babu et al., 2020). These individuals execute projects and implement enhancements. The master black belt often trains and coaches Black and Green Belt enthusiasts. Their role is to develop important metrics and the direction of the strategy. They act more like organisational consultants. Black belts train and coach project team members; they also lead problem-solving projects (Dube, 2014). Green Belts make significant contributions by collecting and analyzing project data for the benefit of Black Belts. Team members of a project are considered yellow belts, and their role is to participate in the project and review process improvements that support it. The White Belt, the first belt in Six Sigma, is reserved for individuals who can actively participate in a local problem-solving team that supports projects (Babu et al., 2020).

It can be challenging to involve members of different ethnic groups in Six Sigma teamwork. White South Africans are more comfortable working alone, while Black South Africans prefer to work together. The spirit of Ubuntu, a prominent aspect of Black culture, inspired the Blacks to work together (Gade, 2010). We must encourage the spirit of Ubuntu when attempting to incorporate different perspectives in the implementation of Six Sigma. Element Six is a worldwide leader in the design, development, and manufacturing of synthetic diamonds and tungsten carbide supermaterials. The De Beers Group company employs over 1,900 people. Its primary manufacturing sites are located in the UK, Ireland, Germany, South Africa, and the US. It consists of seven manufacturing plants nationwide. This organization introduced the Six Sigma training program as a way of ensuring that everyone works toward the same key strategic objectives (Casey-Maslen, 2013). This company managed to win the Golden Award for Excellence in the corporate sector (manufacturing) from Productivity SA and the Department of Trade and Industry (DTI). The company equipped everyone with the Six Sigma Principles. More importantly, the training helped all employees understand the impact of their actions and embraced the methodologies (Casey-Maslen, 2013).

According to Statistics SA (2024), South Africa's official unemployment is 33.5%.8.4 million people are now unemployed in South Africa. More than 76% of these people have been without a job for more than a year, compared to less than 66% in 2024. Since the introduction of Six Sigma, managers have faced significant challenges due to the emphasis on employing only necessary employees within a company. The labour laws in South Africa (Statistics SA, 2024) make it challenging to terminate employees who are no longer necessary after implementing the Six Sigma methodology. It is always important to question the morality and ethics of employees when applying engineering ethics and professionalism.

The apartheid system in South Africa brought about an adversarial relationship between managers and employees, even though the current political situation discourages those adversities. According to Mtongana and Musundire (2020), there seems to be constant conflict between managers and employees. In South Africa, employees and their organization must approve every change introduced or proposed by the organisational leadership. This makes the introduction of Six Sigma methodologies challenging, as employees often express dissatisfaction with changes that could impact their daily tasks (Nakhai & Neves, 2009). The company should properly train and coach employees of all levels and their unions about the tools and benefits. South African manufacturers often use materials or parts that have been imported from different countries and commonly spend a few weeks on a ship to reach their destination (Nakhai & Neves, 2009). Hence it is why it is very challenging to implement Just-In-Time in South Africa.

One of the largest financial institutions in South Africa, Standard Bank, has published a Six Sigma implementation case study in its company (Idrissi et al., 2016). Research and analysis reveal that Bloor, a European independent IT research and analysis firm, presented a case study that demonstrates the bank's 438 million rand in savings over four years through Six Sigma projects (Idrissi et al., 2016). In 2005 Standard Bank implemented a process improvement program in the personal and business banking divisions responsible for the provision of financial services to individual customers and small and medium enterprises (Mezouari et al., 2013). In 2005, the managers of the company realized that there were individual operations for each product group. This department was responsible for the minimization of redundant functions and documents, wastes, reworks, and high error rates (Mezouari et al., 2013). It was difficult to perform a root cause analysis of the problem and establish solutions because there was no performance measurement system in place. The bank introduced Six Sigma at that time, leading to the completion of projects focused on waste reduction and process improvement (Mezouari et al., 2013). The bank established a scorecard to monitor the gains from the improvements.

In this study, the first objective focused on identifying and analyzing the factors that influence the adoption and effective use of Six Sigma methodologies. These factors were critical for understanding how organizations, particularly in the rail freighting industry of developing countries, can successfully implement Six Sigma to improve operational efficiency and service quality. The key factors influencing the adoption and effective use of Six Sigma methodologies, as identified in this study, are as follows (Hess & Benjamin, 2015):

- **Leadership Commitment:** Strong and consistent support from top management is essential for driving Six Sigma initiatives and embedding them into organisational culture.
- **Employee Training and Engagement:** A well-trained workforce with knowledge of Six Sigma tools and techniques ensures successful implementation and sustained improvement.
- **Technological Infrastructure:** Modern and robust technological systems enable the collection, analysis, and application of data for Six Sigma processes.
- **Financial Resources:** Adequate funding is required for training, technology acquisition, and process redesign necessary for Six Sigma adoption.
- **Regulatory and Policy Support:** Supportive government policies and industry regulations can facilitate the integration of Six Sigma methodologies.
- **Market Competition:** Competitive pressures encourage organizations to adopt Six Sigma to maintain efficiency and customer satisfaction.
- **Cultural Factors:** Organisational culture, including readiness for change and resistance levels, plays a significant role in the adoption of Six Sigma.

These factors collectively determine the success of Six Sigma implementation. Addressing these influences through strategic planning and tailored approaches might help overcome challenges, particularly in resource-constrained environments such as the rail freighting sector in developing economies. This analysis provides a foundation for prioritizing these factors and aligning them with organisational goals.

2.9. Chapter Summary

This chapter reviewed the pivotal elements affecting the implementation of Six Sigma methodologies in the rail freighting industry within the context of developing economies. It highlighted the unique challenges and opportunities of applying Six Sigma to improve operational efficiency, reduce delays, and enhance service quality in resource-constrained environments. The key drivers identified included leadership commitment, employee training, technological infrastructure, financial resources, regulatory support, market competition, and cultural readiness for change. The researcher emphasized analytical tools such as the Analytic Hierarchy Process (AHP) and Pareto analysis to prioritize these drivers and allocate resources effectively. The chapter identified significant challenges, including limited funding, outdated technologies, and resistance to change, despite the potential benefits of Six Sigma. The chapter also highlighted gaps in existing literature, particularly the lack of empirical studies specific to rail freighting in developing economies and the need for region-specific frameworks. In conclusion, the literature review established a foundation for understanding the factors and challenges associated with Six Sigma adoption in this context, emphasizing the need for tailored strategies to maximize its effectiveness in the rail freighting sector.

CHAPTER THREE

METHODOLOGY

3.0. Chapter Overview

In this chapter, the research methodology used in this research is outlined. The chapter provides a detailed description of the DMAIC approach, which includes the key phases of Six Sigma: Define, Measure, Analyse, Improve, and Control. The chapter further highlights the tools and techniques applied during each phase, such as process mapping, data analysis, capability studies, and control mechanisms. This systematic approach identifies critical factors contributing to operational inefficiencies, validates root causes, proposes solutions, and ensures sustainable improvements in wagon reliability and availability.

3.1. The DMAIC Approach Introduction

Conceptual framework

The conceptual framework for Six Sigma in this research integrates the research problem, objectives, and research approach to provide a structured understanding of the factors influencing successful implementation as shown in Figure 4. The framework address challenges specific to the rail freighting industry in developing economies, such as inefficiencies, resource constraints, and organisational resistance. Independent variables such as leadership commitment, employee training, financial resources, technological infrastructure, and cultural readiness are identified as critical drivers of Six Sigma implementation. These factors are analysed through the mediating processes of Six Sigma frameworks such as DMAIC and DMADV, which guide systematic improvements. Moderating variables, including market competition, organisational size, and economic conditions, contextualize the strength and direction of these relationships.

The research framework aligns these elements with the research objectives: identifying and prioritizing key drivers, evaluating their impact on process outcomes, and proposing tailored strategies for implementation. Using a mixed-methods approach, qualitative insights from interviews and surveys complement quantitative techniques like Analytic Hierarchy Process (AHP) and statistical analysis to validate the relationships between variables. This systematic approach ensures a comprehensive investigation into how Six Sigma can drive operational efficiency, cost reduction, and enhanced service quality in the unique context of developing economies.

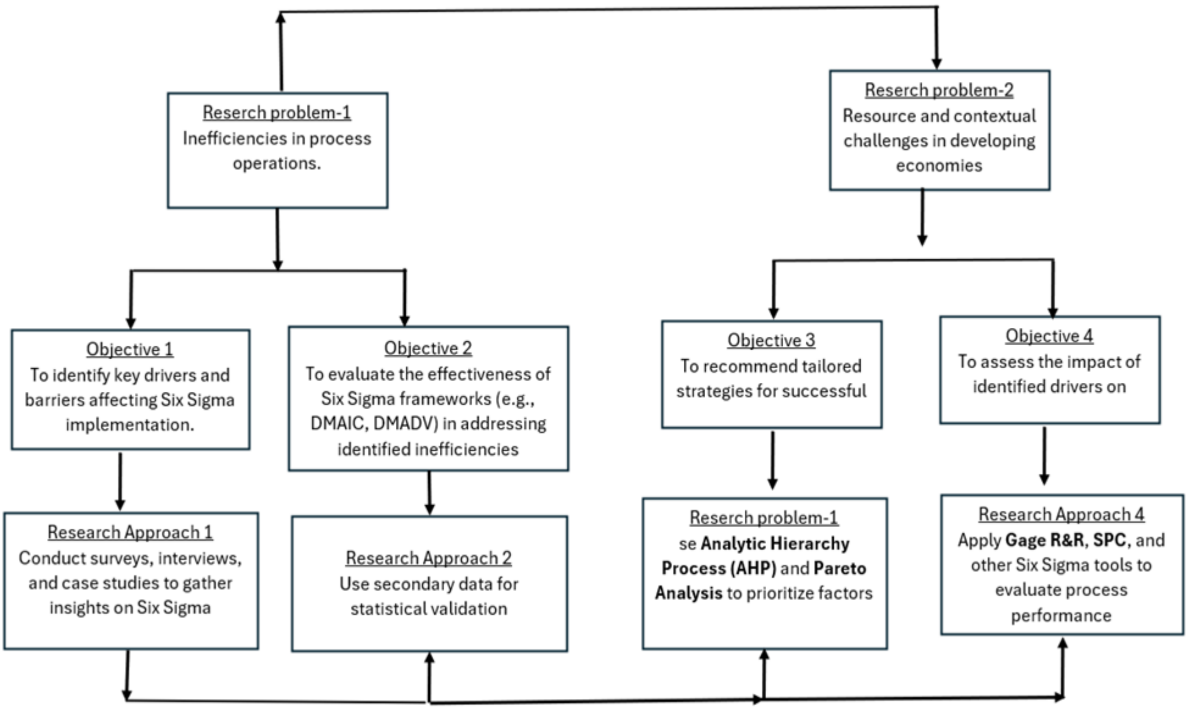


Figure 4 : Conceptual framework

Six Sigma is a data-driven problem-solving methodology that focuses on variation reduction (Zafiropoulos, 2015). The methodology's five phases adhere to the defined, measured, analysed, improved, and controlled phases for problem-solving. The study first identified the wagon fleet type. The chosen fleet type is of utmost importance to the customer, and the selection process involves identifying the fleet type that has the potential for improvement, even if it is associated with higher faults and lower reliability. We concluded the selection process, received all necessary standard documents, granted relevant permission, drafted a decision tree, and established a process flow to create a project baseline, targets, and goals. The charter, voice of the customer, project plan, and SIPOC are well defined; the team, workshop layout, and current process mapping are well defined.

The second step is all about data collection and measurement. We gathered the data through in-service inspections of the wagons. The SAP system records the data on the notification document and captures it, enabling the user to view historical data throughout the hardware's lifetime (Taherdoost, 2021). This follows the transfer of the data to Microsoft Excel and Minitab software for further analysis. We present the obtained results in the form of figures, tables, and graphs. We compared the outcomes with the historical data to confirm potential process improvement.

3.2. Theoretical Framework

The theoretical framework presents a detailed description of the modus operandi of the theories contained in the conceptual diagram.

3.2.1 Define phase

This phase makes sure the identified problem aligns with the organisational priorities. The maintenance engineer and engineering technician collected and presented the data (Taherdoost, 2021). A team comprising the production manager, industrial engineer, quality manager, and supervisor analysed the data. The main objective of the meeting was to discuss how to reduce unscheduled bogie-related faults on wagons. A bogie fault refers to a problem with the bogie, a subassembly of axles and wheels that supports a vehicle, particularly on trains or trucks. These faults can range from structural issues like cracks in the bogie frame to problems with suspension, bearings, or other components that affect the bogie's ability to function properly. The problem statement was that the monthly average unscheduled faults result in low reliability and lower availability of the wagons, which affects the running of trains. Therefore, the goal is to improve the reliability of the wagons. After the problem statement discussion meeting, we conducted interviews with the management team to identify a capable employee who could perform wagon inspections and produce the necessary data to analyse and determine the daily faults recorded.

The checklists, devices, and process flow were in place. Seven team members comprise the inspection process: a supervisor, a subject matter expert; two examiners; and four process workers. The inspection activity takes place in the yard while wagons are still in service. Figure 5 illustrates the process flow of the Maintenance Alarm terminal, outlining the steps involved in carrying out wagon maintenance.

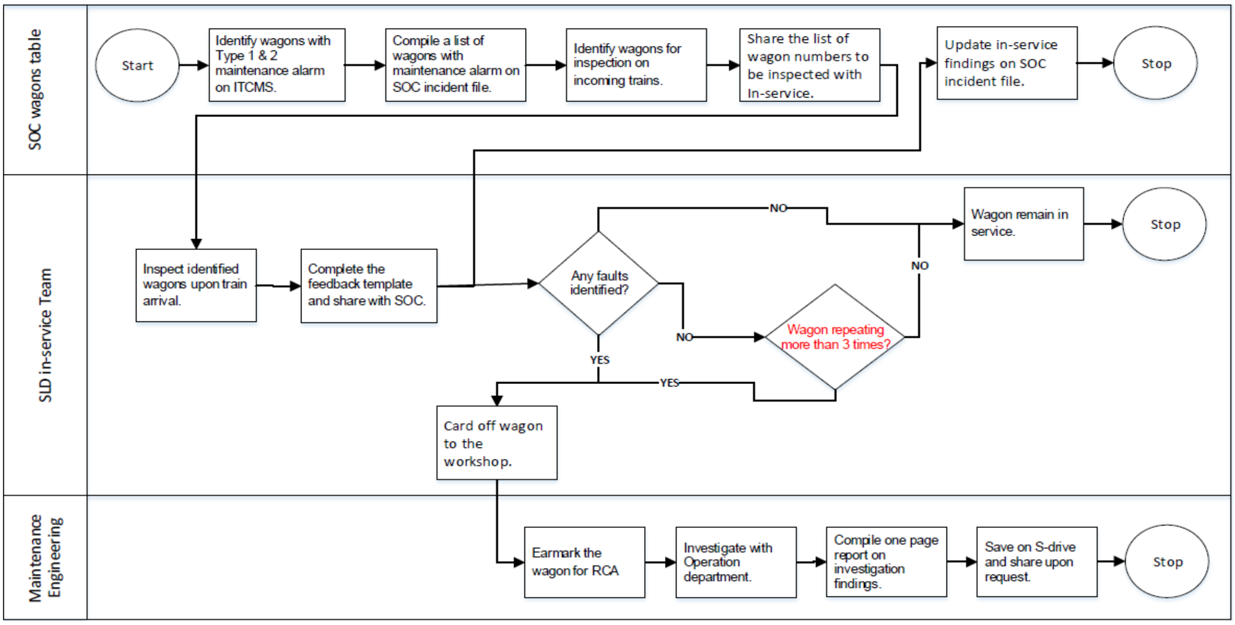


Figure 5 : Maintenance Alarm terminal process flow.

3.3. Measure phase

This step consists of measuring the number of faults recorded by incoming train wagons. Historical data is collected from the in–service term's server, which is collected every time a train arrives in the yard (Taherdoost, 2021).

3.3.1. Baseline

To determine the historical data of unscheduled faults of the bogie and the reliability associated with availability, the researcher gathered the train inspection data by the in-service from the SAP system for 12 months. The faults were recorded daily basis. Both reliability and availability were constructed to determine a baseline that could assist in the study as a standard or reference for future performance comparison. Baseline focuses on the details of bogie faults, wagon availability and reliability. The faults recorded, the quality of released wagons and how reliable the wagons are to

Transnet Freight Rail as the customer to run the train effectively and efficiently (Mtebele, 2023). Figure 6 illustrates an example of baseline data, which includes monthly averages, baseline, entitlement and project goal.

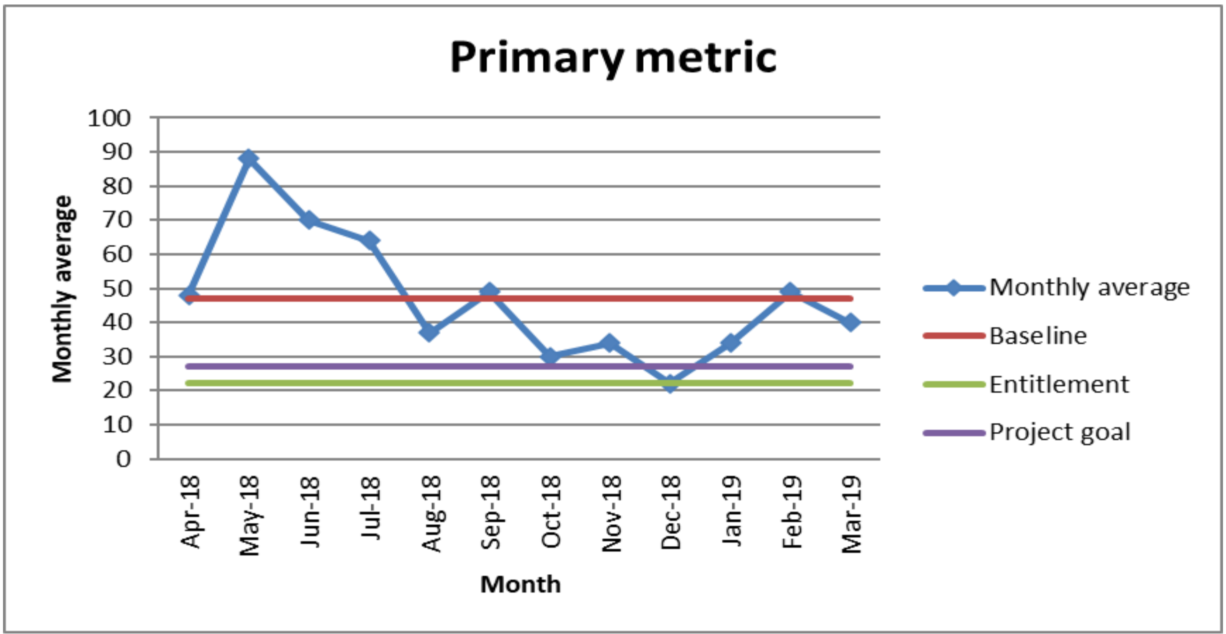


Figure 6 : Baseline data

3.3.2. Measurement system analysis (MSA).

Measurement system analysis is a method to determine the number of variations that exist within a measurement process. Variations in the measurement process can directly contribute to our overall process variability. This is the type of analysis that is used to verify the measurement system for utilization by evaluating the stability, accuracy, and precision of the system. Figure 7 is a measurement system analysis graph. Those graphs are used to evaluate the quality and reliability of a measurement system in Six Sigma projects. They help identify and quantify variability caused by the measurement system, assess accuracy and precision, and ensure its suitability for capturing reliable data. These graphs pinpoint sources of error, such as operator or equipment inconsistencies, and verify whether the system meets process requirements. By visualizing key factors like repeatability, reproducibility, and bias, MSA graphs ensure data integrity, enabling accurate analysis and effective decision-making.

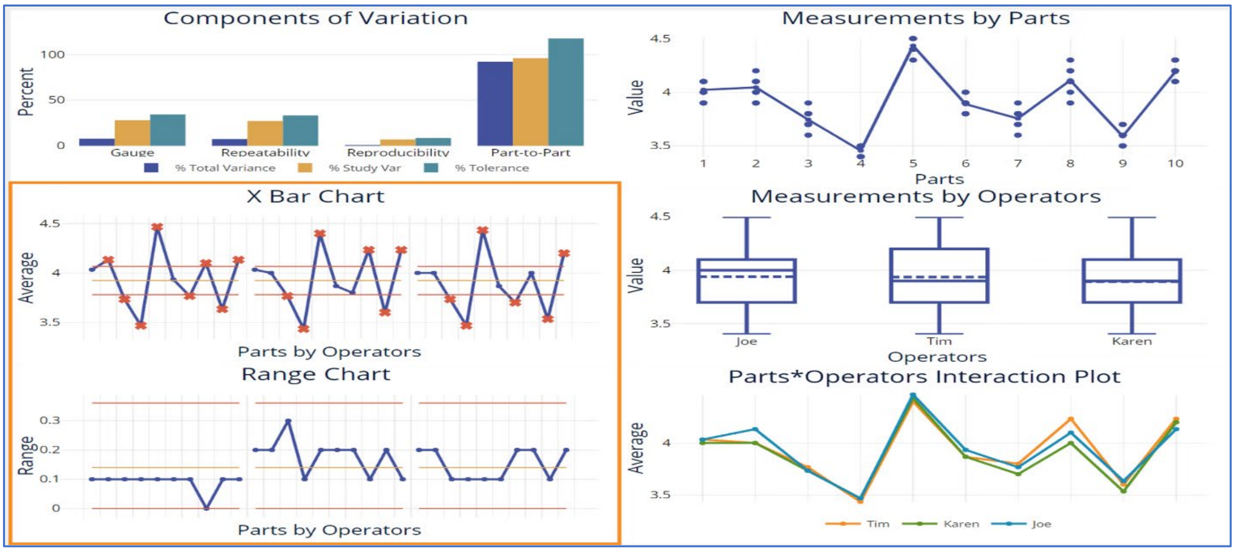


Figure 7 : Measurement system analysis

3.3.3. Baseline capability analysis.

In this section, calculations were done to assess whether the system is statistically able to meet a minimum set of requirements. Baseline capability analysis assesses the performance of a process by comparing its current output to specified limits or customer requirements. Baseline capability analysis in Figure 8 provides a snapshot of how well a process meets these specifications before improvements are made. Key metrics such as Cp, Cpk, Pp, and Ppk evaluate the process's potential and actual capability, including its consistency and alignment with targets. This analysis identifies areas for improvement, serves as a reference point for measuring progress, and ensures that process variations are well-understood before implementing Six Sigma initiatives.

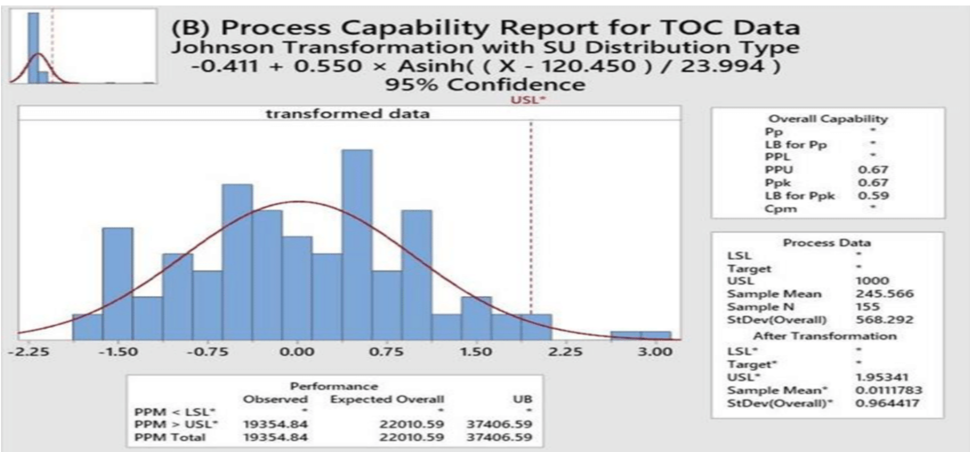


Figure 8 : Baseline capability analysis

3.3.4. DPMO Baseline.

DPMO stands for Defects Per Million Opportunities. It is a ratio of the number of defects in a sample to the number of defect opportunities multiplied by 1 million. A business that manufactures a product may use the DPMO measurement to determine the chances of defects occurring during production. Knowing its DPMO can help a business allocate its available resources properly and potentially prevent or reduce the number of defects. The DPMO was calculated by dividing the total number of bogie faults recorded with the sample size units, multiplied by the number of fault opportunities per wagon in a train and multiplied by 1,000,000. Figure 5 demonstrates the Sigma performance levels from one to six, percentage of defects per million opportunities and number of defects per million opportunities.

Table 5 : Sigma performance levels.

SIGMA LEVEL	% OF DEFECTS / MILLION	No OF DEFECTS / MILLION
1	69%	691,462
2	31%	308,537
3	7%	66,807
4	0.6%	6,210
5	0.0233%	233
6	0.00034%	3.4

3.3.5. Fishbone diagram.

A fishbone diagram is a brainstorming tool that was used to identify many possible causes for an effect and sort them into a useful category (Singh et al., 2023). Figure 9 demonstrates how a fishbone diagram is completed.

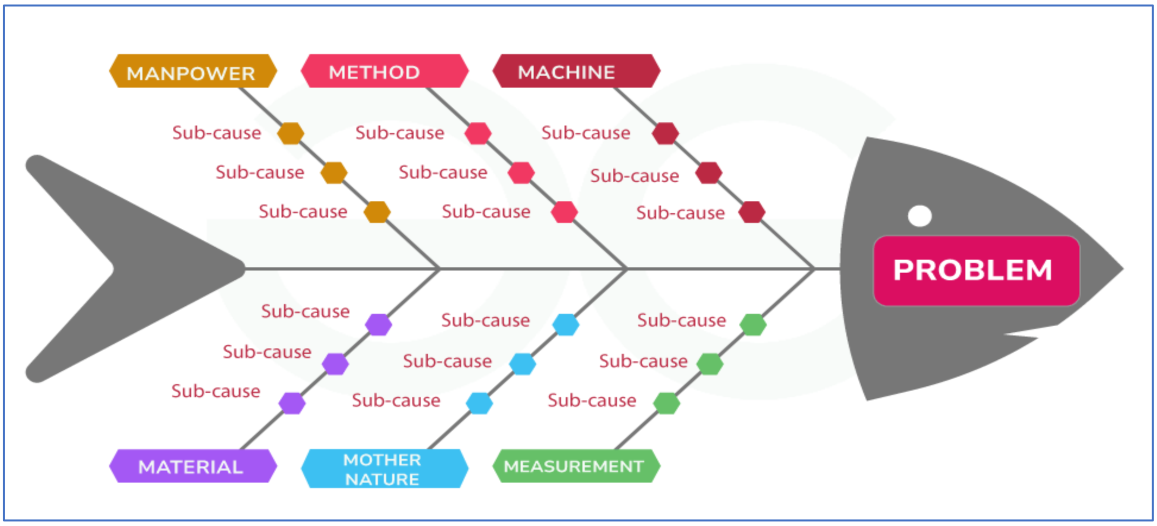


Figure 9 : Fishbone diagram

The following steps were followed when the Fishbone diagram was conducted:

- The team agreed on the problem statement
- Agree on the major categories of causes.
- List every potential reason why the issue could exist. Ask "Why does this happen?" Upon the presentation of each idea, the facilitator records the causal factor as a branch from the corresponding category.
- Again ask "Why does this happen?" concerning each cause. Enumerate sub-causes that diverge from the primary cause branches.
- Persistently inquires "Why?" to uncover deeper causal layers and systematically categorizes them under related causes.

3.3.6. Cause and Effect matrix.

A Cause-and-Effect Matrix is a Six Sigma instrument utilized to identify the critical process input variables based on customer priorities (Alkiayat, 2021). It is also known as the X-Y diagram, correction matrix and prioritization matrix. The main purpose is to mathematically calculate the relationship between customer output (Ys) and Key process input variables (Xs) as shown in Table 6. This diagram consists of the following steps (Alkiayat, 2021):

Step 1: First, customer requirements were identified in Table 7. This was done by conducting surveys to collect their priorities. Placed those priorities at the top of the X-Y diagram.

Step 2: Assign a priority factor for each of the customer outputs. A scale of 1-10, with 1 being the low priority and 10 being the highest priority for the customer.

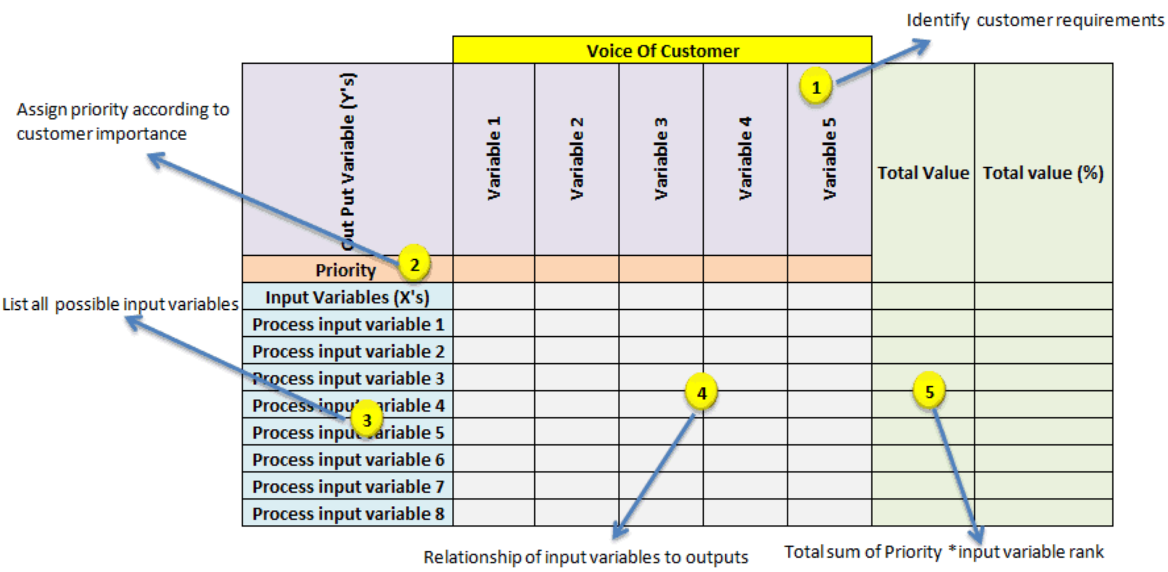
Step 3: Listed all possible key input variables or the improvement factors of the process in each row; those are the Xs in the X-Y diagram

Step 4: Assessed the relationship between key input variables and the customer outputs, and then ranked each input variable accordingly. A geometric progression scale (0,1,3 and 9), with 0 being no impact, 1 – low impact, 3 – medium impact, and 9 – strong impact or high correlation on output was used.

Step 5: Cross-multiply the customer output priority numbers with correlation rankings and each row at the extreme right column.

Step 6: Finally, determine the rank based on the highest sum total and highlight the critical few variables. This assists to identify the areas for improvement.

Table 6 : Cause and effect matrix



3.3.7. Pareto chart

Vilfredo Pareto (1848–1923), an Italian economist, observed significant inconsistencies in wealth distribution. A select few held the majority of the wealth. Juran discovered that the same "vital few and the trivial many" phenomena affected numerous Statistical Process Control (SPC) domains (Alkiayat, 2021). To describe this occurrence, Vilfredo Pareto is credited with creating the names "Pareto chart" and "Pareto analysis" (Alkiayat, 2021). According to Koripadu and Subbaiah (2014), Pareto analysis describes the tendency for the majority of issues to come from a small number of potential causes. Therefore, pinpointing and addressing the primary problem areas can significantly enhance efficiency and effectiveness. The Pareto chart is a visual representation that uses a bar graph with bars organized in decreasing magnitude to highlight the Pareto principle. The Pareto chart was used with the cause-and-effect matrix and failure mode and effect analysis (FMEA) to help prioritize issues by focusing on the most significant causes or failure modes.

3.3.8. Failure Mode and Effect Analysis

At the design stage of an existing process, the Failure Mode and Effect Analysis (FMEA) risk assessment tool is employed to proactively identify potential failure points and assess the severity of their potential impacts (Huang et al., 2020). The tool plays a crucial role in prioritizing process parts for changes aimed at eliminating and reducing the probability of failures. We selected the process to be evaluated with FMEA, which involves identifying the faults in the bogie. We assembled a team, comprising individuals involved in every step of the process. The team listed all the steps in the process. The team has filled the table with information. The columns of the FMEA include the failure mode, which lists any potential issues that may arise during that phase of the process. The FMEA includes failure causes, which enumerate all potential causes for each identified failure mode, and failure effects, which catalogue all possible adverse consequences for each identified failure mode. What is the likelihood of the failure mode occurring on a scale of 1-10, with 10 being the most likely. On a scale of 1 to 10, with 10 indicating the greatest probability of remaining undetected, what is the probability that the failure will go unnoticed if it occurs?, On a scale of 1 to 10, with 10 indicating the highest probability, what is the likelihood that the failure mode, if it occurs, will result in significant harm? Risk Profile Number The team multiplies the three identified scores (i.e., likelihood of occurrence, likelihood of detection, and severity) for each failure mode. The minimum attainable score will be 1, while the maximum will be 1,000. To compute the RPN for the entire process, aggregate all individual RPNs for each failure mode. Table 7 is an example of a completed Failure Mode and Effect Analysis.

Table 7 : Failure mode and effect analysis

Process Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Results				
												Actions Taken	Sev	Occ	Det	RPN
explanation of a function, step or item being analysed	Describe what has gone wrong 1	What is the impact on the key output variables or internal requirements?	7		What causes the key input to go wrong?	3	What are the existing controls that either prevent the failure from occuring or detect it should	3	63	What are the actions for reducing the occurence of the cause or improving the detection?	Who is responsible for the recommended action? What is the target date for the recommended action?	What were the actions implemented? Now recalculate the RPN to see if the action has reduced the risk.				
	Describe what has gone wrong 2		5		cause 2	3		3	45							0

3.4. Analyse step

The Analyse phase in Six Sigma concentrates on determining the fundamental causes of process problems or defects. This entails analysing data gathered during the Measure phase to identify patterns, relationships, and inefficiencies. This phase identifies the factors influencing process performance through the utilisation of tools such as cause-and-effect diagrams, hypothesis testing, and regression analysis. The objective is to attain a comprehensive understanding of the root causes, facilitating the formulation of targeted solutions in the ensuing Improve phase.

3.4.1. Statistical analysis

This procedure is systematic, and it determines whether the results of a study support a particular theory which applies to a population. This procedure was performed by first stating the hypothesis as a null hypothesis and alternate hypothesis (Ho) and (Ha or H1). Data was collected in a designed way to test the hypothesis. An appropriate statistical test was performed and decided whether to reject or fail to reject the null hypothesis. Findings are presented in the results and discussion section.

3.4.2. Confirmed root causes.

Confirmed root causes are potential X that were confirmed statistically using hypothesis testing. This was done using Minitab software.

3.5. Improve step

3.5.1. Potential solution identification.

From the confirmed root causes, the potential solutions are generated by the project team members.

3.5.2. Easy impact matrix.

This matrix is important in finding the most impactful ideas that require the least amount of effort. The matrix assisted the team in reducing the potential solutions to those that provided the biggest improvements. The list of potential solutions was ranked by the team based on the impact of the idea on reducing waste, and the ease of implementation. The impact was based on the data collected as well as the expert opinions of the employees working and managing the processes. The assessment of the implementation was based on the cost of the ideas along with any behaviour change required to implement the idea. Figure 10 illustrates a diagram of the Easy and Impact Matrix.

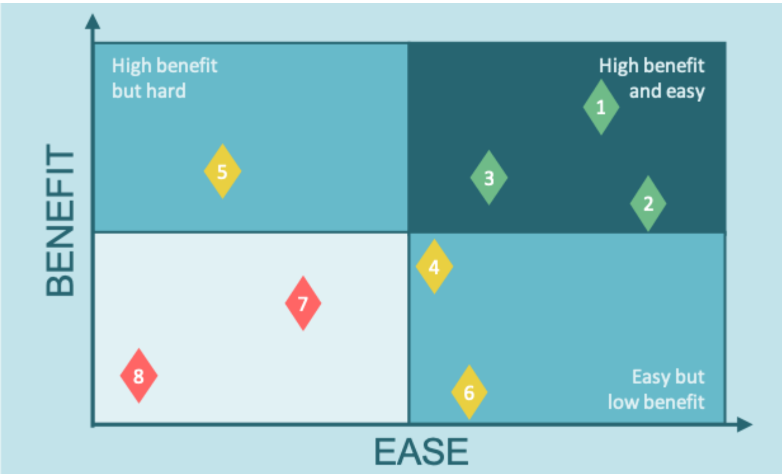


Figure 10 : Easy and Impact Matrix

3.6. Control step

The Control Phase is the final step in the DMAIC framework, focused on sustaining the improvements made during the project. Key activities include implementing control mechanisms, monitoring process performance, and ensuring that changes are standardized and maintained. Tools such as control charts, process documentation, and training plans are used to prevent regression and ensure stability. The Control Phase ensures that the process consistently meets performance standards, achieving long-term success and reinforcing the benefits of the Six Sigma project.

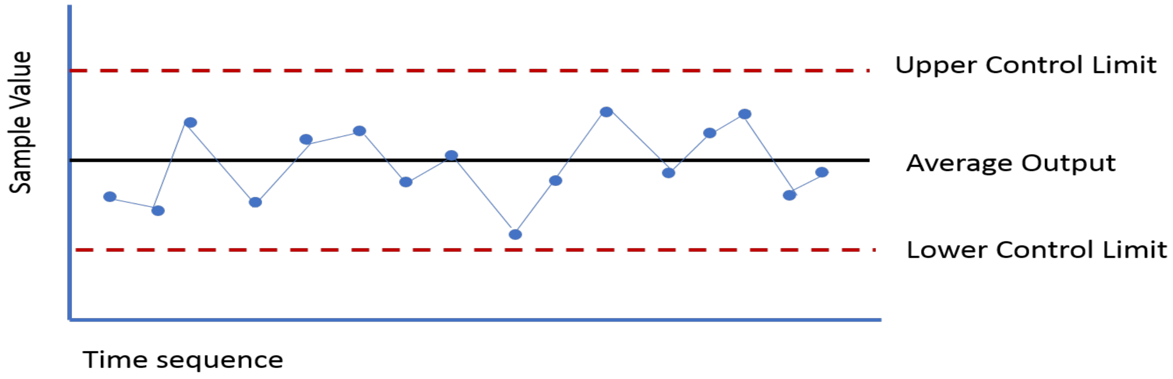


Figure 11 : Control chart

3.6.1. Control charts

This is a statistical process monitoring tools that assist in optimizing the processes by identifying the variations. The control chart of before and after was created to evaluate the performance.

3.6.2. Process capability after improvements.

Process capability assesses the output of a controlled process against specification limits through the utilization of capability indices. The comparison was conducted by calculating the ratio of the spread between the process specifications to the spread of the process values, measured in six standard deviations of the process.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0. Chapter Overview

This chapter provides a detailed analysis of the results of the data collected using Minitab software. This part illustrates how data was collected and analysed to generate solutions, and improve unscheduled bogie-related faults.
This case study was undertaken in a freight logistics industry based in South Africa. The organization comprises six different operating divisions that are responsible for freight rail, engineering, ports, pipelines, and property. The freight rail division accounts for just above 50% of the entire workforce of the organization. The company uses new technology for the maintenance of the fleet of wagons and locomotives. The process of wagon maintenance usually involves a sequence of activities.

4.1. Define phase

This is the first step of the DMAIC methodology, and its purpose is to discuss data in terms of monthly averages, Baseline, Entitlement as well as project goal as indicated in table 10, problem definition tree, Voice of the customer (VOC) and SIPOC (supply-Input-Process-Output-Customer).

Table 8 is a team structure in the freight logistic company that comprises Mechanical Engineer, Industrial Engineer, Quality manager, financial representative, Engineering technician, Supervisor, Examiners, and technical workers.

Table 8 : Six Sigma team structure in freight logistic company.

Champion	Principal
Master Black belt	Executive manager
Black Belt	Senior manager
Green Belt	Specialists
Team member	Employees

Table 9 presents the top 3 highest faults data collected from the organisational repository and analysed. The analysis was done using Mintab software on the fleet of wagons recorded for 12 months. Each component on the wagon records these faults. Bogie faults represent the highest number among the three most prioritised sources of fault occurences hence, accounting for 50% of 612 faults.

Table 9 : Top 3 highest faults

Month	Bogie	Brakes	Hallow wear	Total
1	50	45	15	**110**
2	91	43	22	**156**
3	76	40	18	**134**
4	67	44	7	**118**
5	40	43	4	**87**
6	58	33	2	**93**
7	35	37	0	**72**
8	36	41	61	**138**
9	24	30	7	**61**
10	39	20	41	**100**
11	50	30	34	**114**
12	46	37	28	**111**
Total	**612**	**443**	**239**	**1294**

Table 10 explains the data collected over a 12 months period, including monthly average faults, a baseline that represents the monthly average, and entitlements that represent both the monthly target and the goal. The engineering department calculates the target based on the maintenance of the components. The engineering department calculates the goal using the 80% breakthrough improvement principle. The breakthrough principle is an approach that calculates the potential breakthrough level of improvement that a project could achieve (Ahn et al., 2021). This is critical because it assists in preventing you from setting unrealistic goals for a project. If you don't use this principle, you run the risk of either setting your goal too high or too low. What defines a breakthrough improvement is to consistently consider an 80% improvement as the initial target for improvement in your objective statement. We analysed the data from the in-service team and focused on the top three faults. We selected bogies-related faults as the primary element to measure (see Table 9) for the project due to their higher frequency compared to other sources of fault. Furthermore, from a sustainability point of view, the combination of the “brakes” and “hallow wear” related faults far exceed the “bogie” faults sources hence, these will still result in a non-available freighting system despite addressing the bogie faults.

Table 10 : CR wagons faults monthly average, Baseline, entitlement, Project goal

Months	Monthly Average	Baseline	Entitlement	Project goal
1	48	47	22	27
2	88	47	22	27
3	70	47	22	27
4	64	47	22	27
5	37	47	22	27
6	49	47	22	27
7	30	47	22	27
8	34	47	22	27
9	22	47	22	27
10	34	47	22	27
11	49	47	22	27
12	40	47	22	27

The problem definition tree as presented in Figure 12, has aided with finding solutions by delineating the anatomy of cause and effect surrounding an issue in a manner akin to a mind map, yet in greater structure (Yazdi, et al., 2023). The line unstricken elements represent the elements that we are focusing on. The line-stricken elements refer to those elements that are not within the focus area.

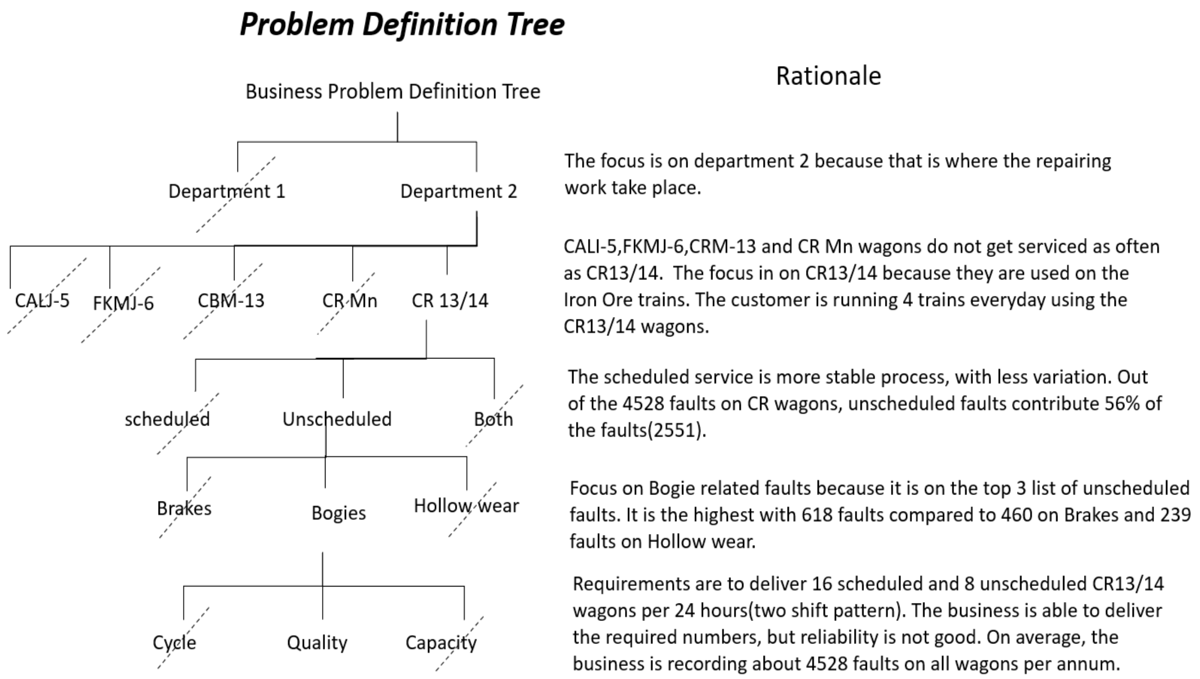


Figure 12 : Problem definition tree.

Table 11 demonstrates customer needs, wants, expectations, and preferences as well as critical to quality. It's the process of collecting and analyzing customer feedback to improve the Customer experience and overall business performance.

Table 11 : Voice of customer and critical to quality.

Voice of customer	**Customer requirement**	**Critical to quality (CTQ)**
Need wagons on time	As agreed per Service level agreement	97.5% availability
Cost to be in line with the budget	Do not exceed the budget	<21 hrs/ service
Good quality	Reliability of wagons	<40 bogie related faults/month

We first prepared the SIPOC chart for the current study, table 12, lists the contributors involved in wagon maintenance. Subsequently, the suppliers provide a list of their products. Thirdly, outline the key steps and tools used to transform inputs into the output(s) identified in the next step. Fourthly, it is a listing of the components, assemblies, services, and other outcomes for a given process, and lastly, it specifies different groups of people who receive the output.

Table 12 : Supplier-Input-Process-Output-Customer (SIPOC) diagram

Supplier	Input	Process	Output	Customer
Biggest Division	Wagons	Start Physical Work Complete Quality Stop	Repaired Bogie	Biggest division
Logistics department	Material			
Engineering Department	Labor			

4.2. Measure phase

Measurement system analysis (MSA) as shown in Figure 13 was carried out using Minitab software and the data P-value was 0.05 which indicates that the normal. The precision tolerance ratio(P/T) is used to estimate how precise the data is to the defined tolerances or specification limits set by the user. This method was used to analyse the variation coming from the gage due to its limitations in measurements and therefore requires only one part to be measured by one operator, multiple times.

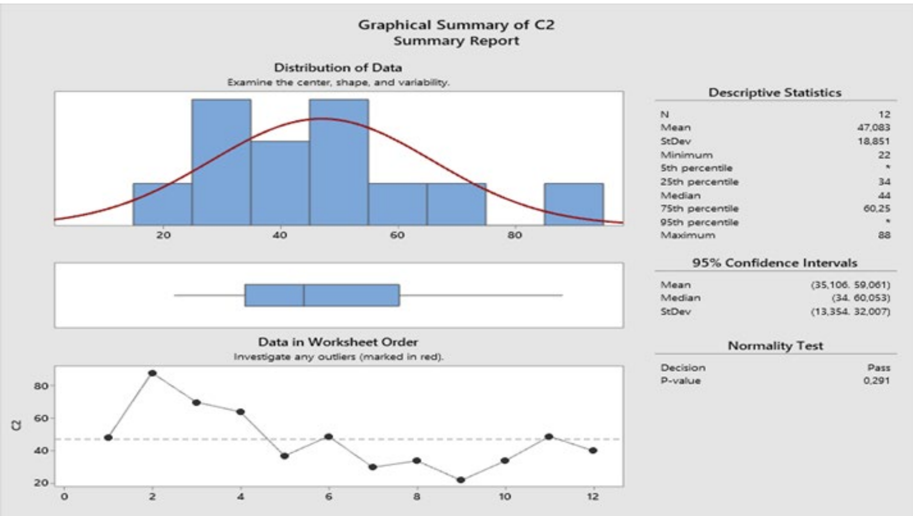


Figure 13 : Graphical summary

Figure 14 demonstrates the run chart for unscheduled bogie-faults. No obvious patterns were observed in mixtures, clustering, trends, or oscillation. No need for further investigation. Oscillations indicate a pattern where the data is oscillating. Mixtures indicate data that is mixed from multiple populations. Clusters indicate a shift in the mean where the data stays to one side of the overall median. P-values for the patterns are as follows; Clustery = 0,272, Mixture = 0,728, Trends = 0,598 Oscillation = 0,402. There is no need for investigations because the P-values of the patterns are more than 0,05.

In terms of Location of the Mean = 47.083**,** Median =44**,** Spread: Min =22; Max = 88**;** Range =66 Standard deviation = 18, 85 Variance = 355,32 Shape = right skewed and P value = 0,291. The data is normal because the P value is greater than 0,05.

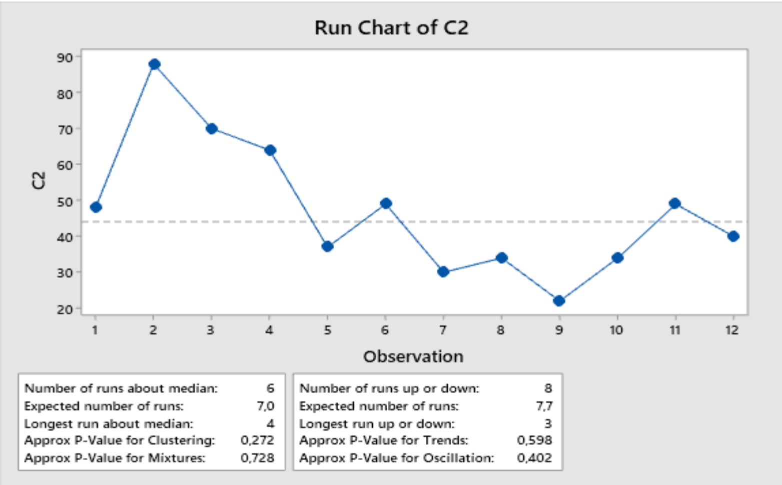


Figure 14 : Run chart for unscheduled bogie-related faults.

To determine the current baseline capability analysis, we examine the number of wagons used annually for train operations and the average number of faults recorded in the process. This will determine whether the process is capable of achieving the objectives set by the organization. According to the existing process of running 40812 wagons per year with an average fault of 3401 per month, the process is capable of running the minimum number of wagons because the chance of experiencing wagons with no defects is 98.6%. See Figure 15 for the above discussion.

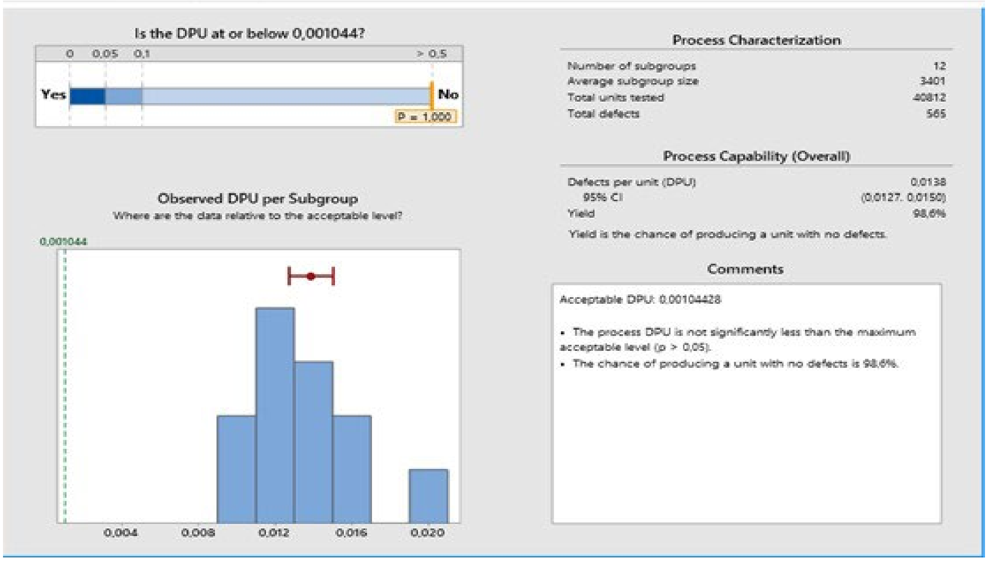


Figure 15 : Process capability analysis

Location: Mean = 7.55**,** Median = 7.4 **Spread:** Min = 4.8; Max = 13.6 Range = 8.8 Standard deviation = 1.49 Variance = 2.22 **Shape** = right skewed

In this research, the supervisor was used as an expert and two teams for inspection of the measurement system (MSA). Each team consist of 4 operators, 2 examiners and 2 maintenance assistants. In total, 30 samples were used with the expert, conducting the assessments. Firstly, the expert did the assessments on the 30 wagons to set the standard as indicated in Table 13.

Table 13 : Measurement system analysis data.

NO:	Wagon No:	Expert check	Inspector 1	Inspector 2	Inspector 1	Inspector 2
1	259582	Approved	Approved	Approved	Approved	Approved
2	259574	Approved	Approved	Approved	Approved	Approved
3	506784	Approved	Approved	Approved	Approved	Approved
4	506776	Approved	Approved	Approved	Approved	Approved
5	260270	Approved	Approved	Approved	Approved	Approved
6	260262	Approved	Approved	Approved	Approved	Approved
7	233036	Approved	Approved	Approved	Approved	Approved

8	233028	Approved	Approved	Approved	Approved	Approved
9	183322	Approved	Approved	Approved	Approved	Approved
10	182970	Approved	Approved	Approved	Approved	Approved
11	248173	Disapproved	Disapproved	Approved	Disapproved	Approved
12	248165	Approved	Approved	Approved	Approved	Approved
13	2419098	Approved	Approved	Approved	Approved	Approved
14	241071	Approved	Approved	Approved	Approved	Approved
15	235187	Approved	Approved	Approved	Approved	Approved
16	235179	Approved	Approved	Disapproved	Approved	Disapproved
17	250178	Approved	Approved	Approved	Approved	Approved
18	250151	Approved	Disapproved	Approved	Disapproved	Approved
19	508477	Approved	Approved	Approved	Approved	Approved
20	508469	Approved	Approved	Approved	Approved	Approved
21	212047	Approved	Approved	Approved	Approved	Approved
22	212055	Approved	Approved	Approved	Approved	Approved
23	220570	Approved	Approved	Approved	Approved	Approved
24	220562	Approved	Approved	Approved	Approved	Approved
25	253762	Approved	Approved	Approved	Approved	Approved
26	253754	Approved	Approved	Approved	Approved	Approved
27	206098	Approved	Approved	Approved	Approved	Approved
28	206071	Approved	Approved	Approved	Approved	Approved
29	260505	Approved	Approved	Approved	Approved	Approved
30	260491	Disapproved	Disapproved	Approved	Approved	Approved

To validate the measurement system's accuracy and precision, Attribute agreement analysis was conducted. In this case, measurements on 30 wagons were repeatedly conducted twice by each team of examiners and maintenance assistants. After collecting data, Poisson analysis was performed with the help of Minitab statistical software. The results of Attribute agreement analysis are presented below and according to the results, there is no need for further investigation.

.

Attribute Agreement Analysis for Assessments

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	30	27	90,00	(73,47. 97,89)
2	30	0	0,00	(0,00. 9,50)

 # Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	Fail	0,345455	0,182574	1,89213	0,0292
	Pass	0,345455	0,182574	1,89213	0,0292
	Pass	*	*	*	*
	Overall	0,345455	0,182574	1,89213	0,0292
2	Fail	-0,034483	0,182574	-0,18887	0,5749
	Pass	-0,935484	0,182574	-5,12386	1,0000
	Pass	-0,935484	0,182574	-5,12386	1,0000
	Overall	-0,880878	0,166804	-5,28090	1,0000

** When no or all responses across trials equal the value, kappa cannot be computed.*

Figure 16 : All Appraiser's assessments agree with known standards (95%).

Figure 16 indicates that All Appraisers' assessments agree 95% with known standards. The evaluations or judgments made by all individuals (appraisers) assessing a specific process, product, or outcome are consistent with established benchmarks or reference standards 95% of the time. In other words, the appraisers' measurements or evaluations are accurate and align closely with the predefined correct or accepted values 95% of the time, indicating high reliability and validity of their assessments relative to the known standards.

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	30	25	83,33	(65,28. 94,36)
2	30	0	0,00	(0,00. 9,50)

 # Matched: Appraiser's assessment across trials agrees with the known standard.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	Fail	0,186688	0,129099	1,44608	0,0741
	Pass	0,186688	0,129099	1,44608	0,0741
	Pass	*	*	*	*
	Overall	0,186688	0,129099	1,44608	0,0741
2	Fail	-0,052632	0,129099	-0,40768	0,6582
	Pass	-0,463816	0,129099	-3,59270	0,9998
	Pass	*	*	*	*
	Overall	-0,441880	0,121556	-3,63519	0,9999

** When all sample standards and responses of a trial(s) equal the value or none of them equals the value, kappa cannot be computed.*

Figure 17 : Appraiser's assessment across trials agrees with the known standards

In Figure 17, each appraiser's assessment across trials agrees with the known standard. That means for every appraiser, their evaluations are consistent with the established benchmark or correct value in every trial or repeated assessment. This indicates that the appraiser demonstrates accuracy and reliability in their assessments, as their results consistently align with the predefined standard over multiple attempts. It reflects the appraiser's ability to produce results that are both valid (aligned with the standard) and consistent (repeatable over trials).

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
30	0	0,00	(0,00. 9,50)

 # Matched: All appraisers' assessments agree with the known standard.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
Fail	0,067028	0,0912871	0,73426	0,2314
Pass	-0,138564	0,0912871	-1,51789	0,9355
Pass	*	*	*	*
Overall	-0,127596	0,0886603	-1,43916	0,9249

** When all sample standards and responses of a trial(s) equal the value or none of them equals the value, kappa cannot be computed.*

Figure 18 : Appraiser's agree with the known Standard

Figure 18 above indicates that the appraiser's evaluations, measurements, or assessments align with a predetermined, accepted standard or accurate reference value. This agreement signifies that the appraiser's work is precise, conforming to the established or normative outcome. It demonstrates the appraiser's capacity to accurately assess by the established criteria or expectations, thereby ensuring the validity of their evaluations.

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
30	0	0,00	(0,00. 9,50)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
Fail	0,039191	0,0745356	0,52580	0,2995
Pass	-0,243386	0,0745356	-3,26537	0,9995
Pass	-0,318681	0,0745356	-4,27556	1,0000
Overall	-0,239541	0,0625945	-3,82688	0,9999

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
30	0	0,00	(0,00. 9,50)

Matched: All appraisers' assessments agree with the known standard.

Figure 19 : All Appraiser's agree with each other's

Figure 19 presents appraisers that agree with each other. That means evaluations conducted by all appraisers are uniform and exhibit minimal to no variation. This indicates inter-rater reliability, the extent to which various evaluators yield comparable outcomes when examining an identical item or process under uniform conditions. This signifies that the appraisers are consistently employing identical standards, criteria, or methodologies, resulting in uniform outcomes in their evaluations. Nonetheless, this does not imply that their assessments correspond with the accurate or established standard; it merely verifies consistency among the evaluators.

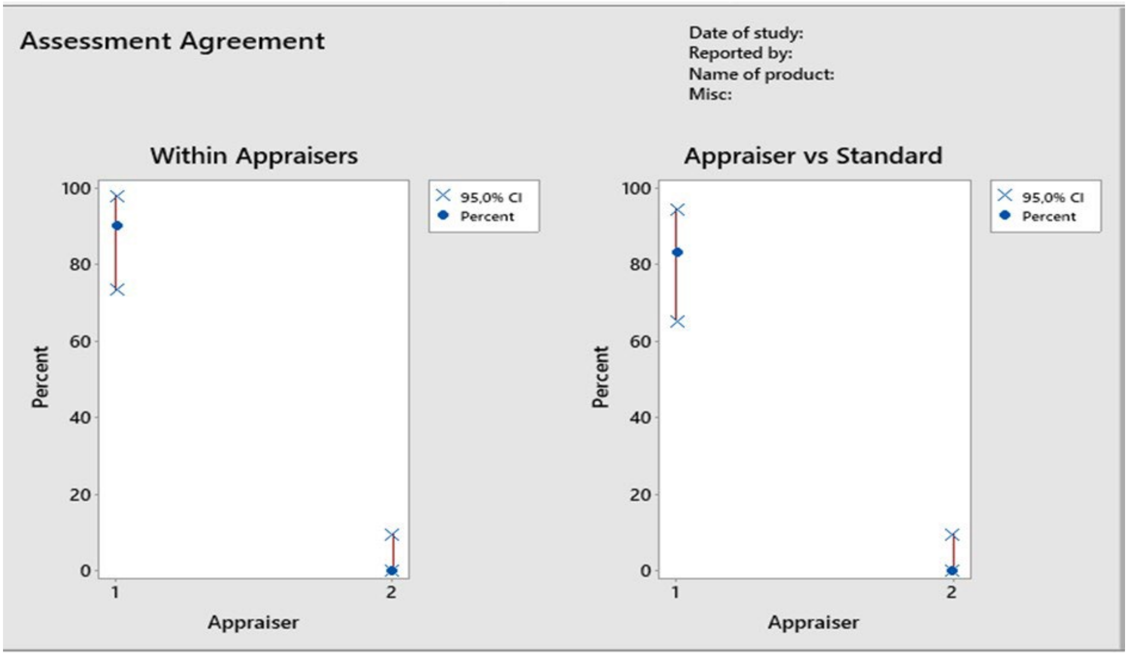


Figure 20 : Assessment agreement

The Assessment agreement in Figure 20, entails evaluating the consistency and precision of appraisers' evaluations through two primary methods: concordance among appraisers and alignment with the standard. The consensus among appraisers centers on the dependability of their evaluations, guaranteeing that various appraisers yield uniform assessments of the identical item or process. This demonstrates their mutual comprehension and implementation of assessment criteria. The agreement with the standard evaluates the alignment of appraisers' assessments with a predetermined benchmark or accurate value, reflecting precision. Collectively, these elements guarantee that evaluations are both reliable (consistent among evaluators) and valid (accurate according to the standard), which is essential for preserving confidence in the assessment process.

4.2.1. Business workshop layout

Performing maintenance and repair cannot always be executed directly at the location of the problematic asset. Maintenance depots are the central place where all the maintenance activities are managed and carried out and accommodate all the assets needed for all the activities. The term maintenance depot or workshop is generic, with design and contents differing due to the specific industry they relate to and their regulatory or geographical location. Maintenance depots include Inventory storage, vehicle access, receipt and Dispatch area, disposal area, IT systems and software, and offices for supporting employees. Figure 21 illustrates a maintenance workshop for the maintenance of wagons. Purple arrows (roads 10 and 13) indicate the arrival of wagons that are scheduled to be serviced on the jacks. Those are A and B services. Services A and B include activities such as the removal of split pins, lifting of the wagon, replacement of small components, lowering of the wagon, Assembling the wagon to bogie and final testing. Service C and D are performed on roads 11 and 12 (green arrow). Those services involve the replacement of bigger components that cannot be performed on the jacks such as services A and B. Hence they are performed on trestles. The testing workshop is the last station where final testing is performed before a wagon can be released.

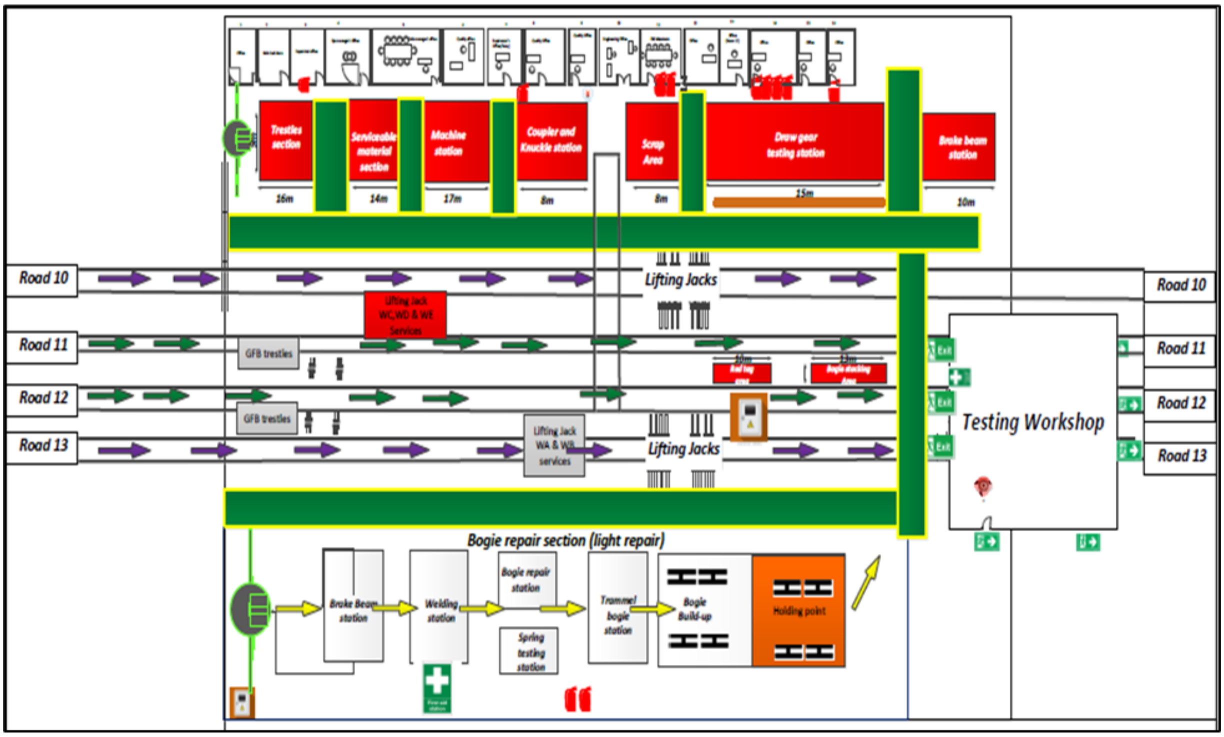


Figure 21 : Business workshop layout.

4.2.2. Process flow

Process flow is one of the most effective tools for process streamlining and organisational efficiency improvement. The main aim of this tool is to illustrate step-by-step, sequences and decisions of a workflow. It is very helpful in terms of simplifying complicated procedures into easy-to-understand diagrams (Hirtreiter et al., 2024).

There are different types of flowcharts namely, Process flowcharts, Swimlane flowcharts and Data Flow Diagram (Wilson & Rigakos, 2016).

There are various symbols and elements used for designing and creating a process flow diagram.

- Oval - Represents the start or end of a process.
- Rectangle - Depicts a step or action in the process.
- Arrow - connector that shows the relationship between the representative shape.
- Diamond – Indicate a decision.
- Parallelogram – Represent input or output.

The maintenance process in Figure 22 starts when a train arrives in the yard. The process is performed by two teams, namely, an in-service team which is responsible when the wagons are still used by the customer on the trains and an Out-service team which is responsible for wagons that are removed from service to be maintained in the workshop. The in-service will perform inspections and remove all wagons that require service in the workshop. The out-service team will then move the wagons into the workshop for repair. When the service process is completed, the out-service team will communicate with the customer to collect the wagons.

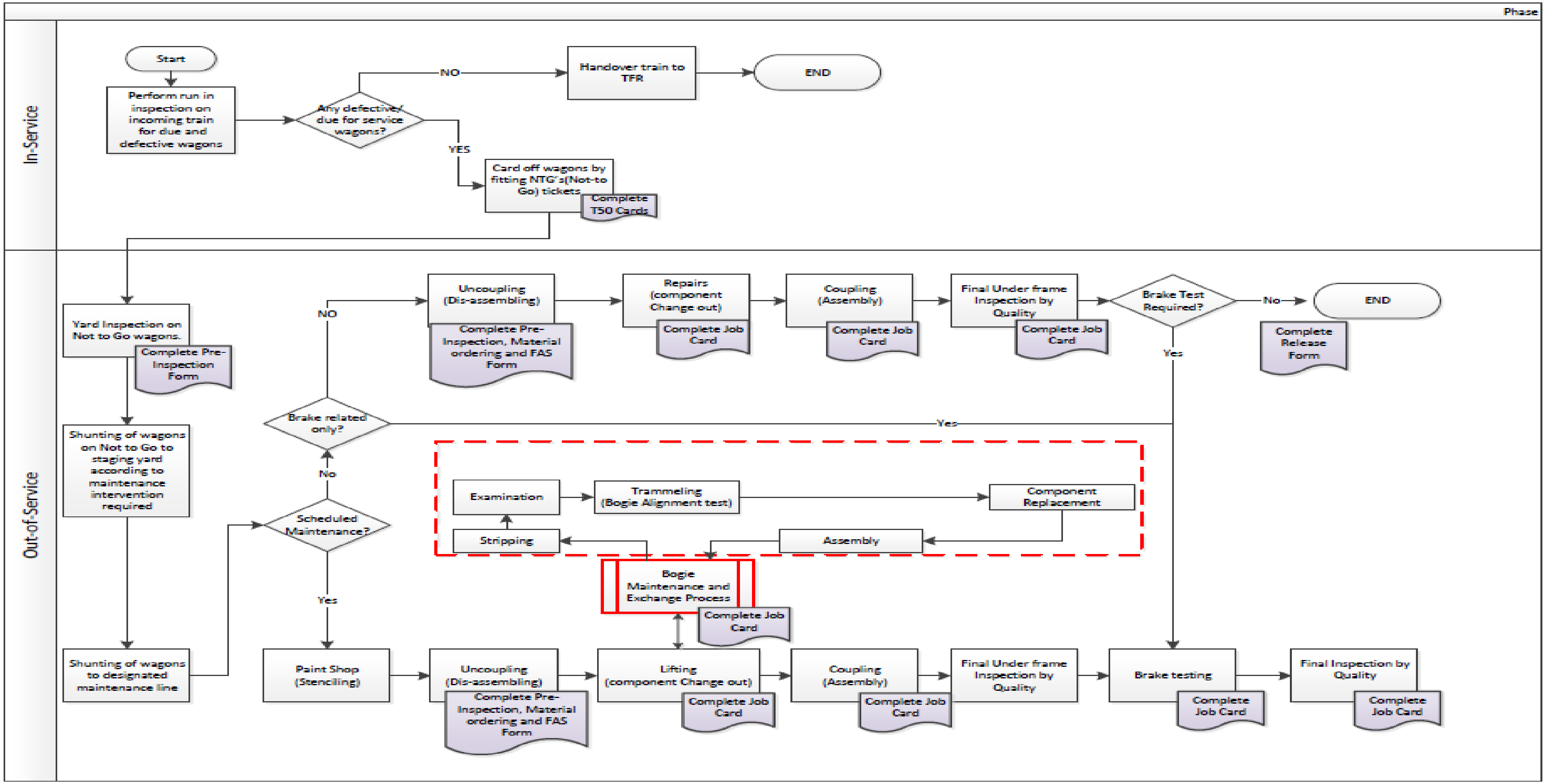


Figure 22 : Wagons Maintenance process flow.

4.2.3. Types of wastes

We frequently refer to waste as "the 8 wastes of lean operations," categorizing it into eight groups. Finding and eliminating waste can save expenses, lead times, and accidents for your business while improving satisfaction among staff and clients (Azadian, Masciangelo, Mendly-Zambo, Taman, & Raphael, 2023)

We identified wastes in Table 14 to optimize resources and increase profitability. It also assisted us in pinpointing specific areas within the work process where we could enhance our efficiency. It enabled us to see if an activity was necessary or pure waste.

Table 14 : Eight Types of wastes

No	Type of waste	Observation(s)
1	Transportation	Forklift travelling a long distance(+/- 1km return trip) to fetch components for production
		workers walking long distance(+/-1km) return trip to warehouse to fetch material
2	Inventory	Bad quality of wheels
3	Motion	There are lot of unnecessary movement of the charger due to the defect of faulty couplers and also lack of experience of the operators.
		workers bending too much because the bogie is low
4	Waiting	Stopping operation to shunt in/add extra wagons
		Employees waiting for material from warehouse
		Production waiting for wheels from wheels business
5	Overprocessing	Too much paint used on springs
6	Overproduction	NONE
7	Defects/Rework	Bogie with faults- not properly inspected before transported to final assembly
8	Skills	Some operators working faster then other

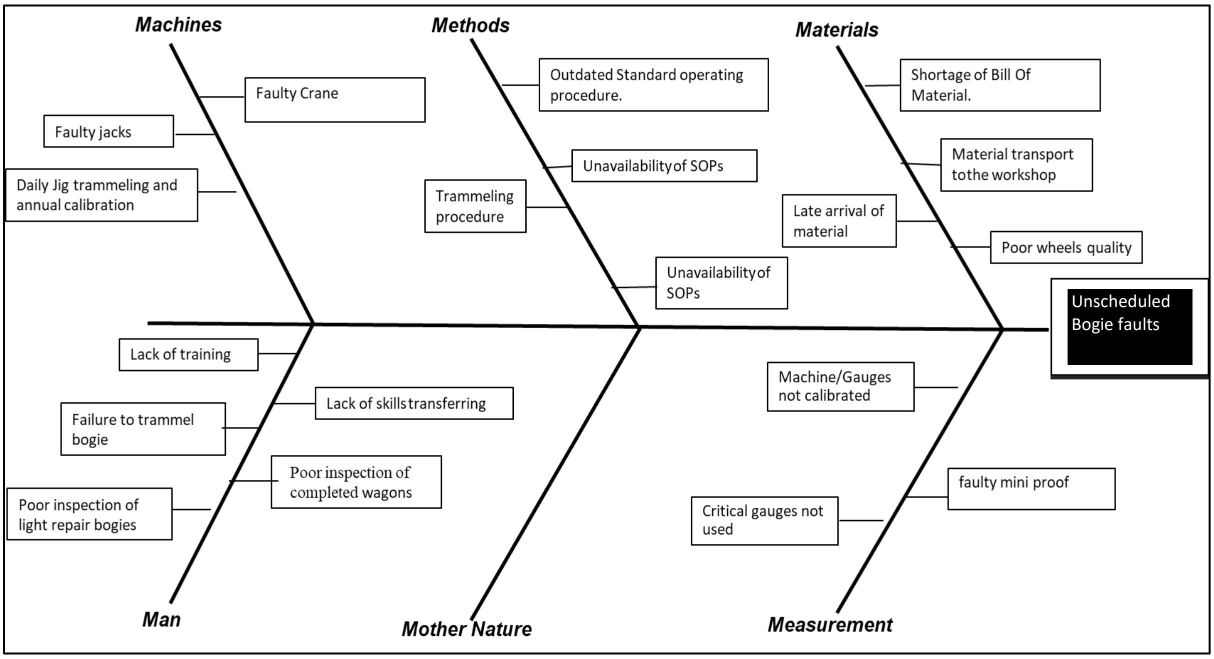


Figure 23 : Fishbone diagram for unscheduled bogie-related faults

Figure 23 presents A fishbone diagram, or cause-and-effect/Ishikawa diagram, which assisted in identifying and categorizing potential causes of a problem. It resembles a fish skeleton, with the issue (effect) at the "head" and primary cause categories as "bones" extending from the spine. Each category is subdivided into sub-causes, enabling teams to systematically analyse the root causes of an issue visually. This instrument is frequently utilized in problem-solving to identify areas for enhancement.

We classified the collected inputs also known as Xs using the cause-and-effect matrix. This work was done in a group of specialists from different areas. In the matrix, all XY combinations were rated. In Table 15, the matrix is present. We rate the key requirements (customer requirements) on a scale of 1 to 10 and identify the process inputs (Xs). Scores of 0, 1, 3, or 9 were assigned to each combination of X and key requirement.

Table 15 : Cause and Effect matrix

#	Input Variables (X's)	Output variables (Ys) 97.5% Availability	<21hours/ service	<40 bogie related faults/month	Rank	% Rank
		3	3	9		
1	Lack of training	9	3	9	117	7.94
2	Lack of skills transferring	3	3	1	27	1.83
3	Failure to trammel bogie	3	9	9	117	7.94
4	Poor inspection of light repair bogies	3	3	9	99	6.72
5	Poor inspection of completed wagons	1	3	9	93	6.31
6	Faulty Crane	9	9	3	81	5.49
7	Faulty jacks	9	9	3	81	5.49
8	Daily Jig trammeling and annual calibration	3	3	9	99	6.72
9	Shortage of BOM	1	3	3	39	2.64
10	Material transport to the workshop	3	1	1	21	1.42
11	Late arrival of material	9	3	0	36	2.44
12	Poor wheels quality	0	1	9	84	5.70
13	Outdated SOP	1	3	9	93	6.31
14	Unavailability of SOPs	9	3	9	117	7.94
15	Inaccurate Checklist	1	3	3	39	2.64
16	Trammeling procedure	3	3	9	99	6.72
17	Gauges not calibrated	1	3	9	93	6.31
18	faulty mini proof	1	1	3	33	2.24
19	Critical gauges not used	1	3	9	93	6.31
20	Workshop design	0	1	1	12	0.81

4.2.4. Pareto Chart

The Pareto Chart was used when prioritizing Xs. It helped in choosing the most significant problems and telling where to focus on improvements. The 20% of defects were Failure to trammel, Unavailability of SOPs, Daily Jig trammelling, poor inspections, trammelling procedure, Critical gauges not calibrated, and Gauges not used (Taghizadegan, 2010).

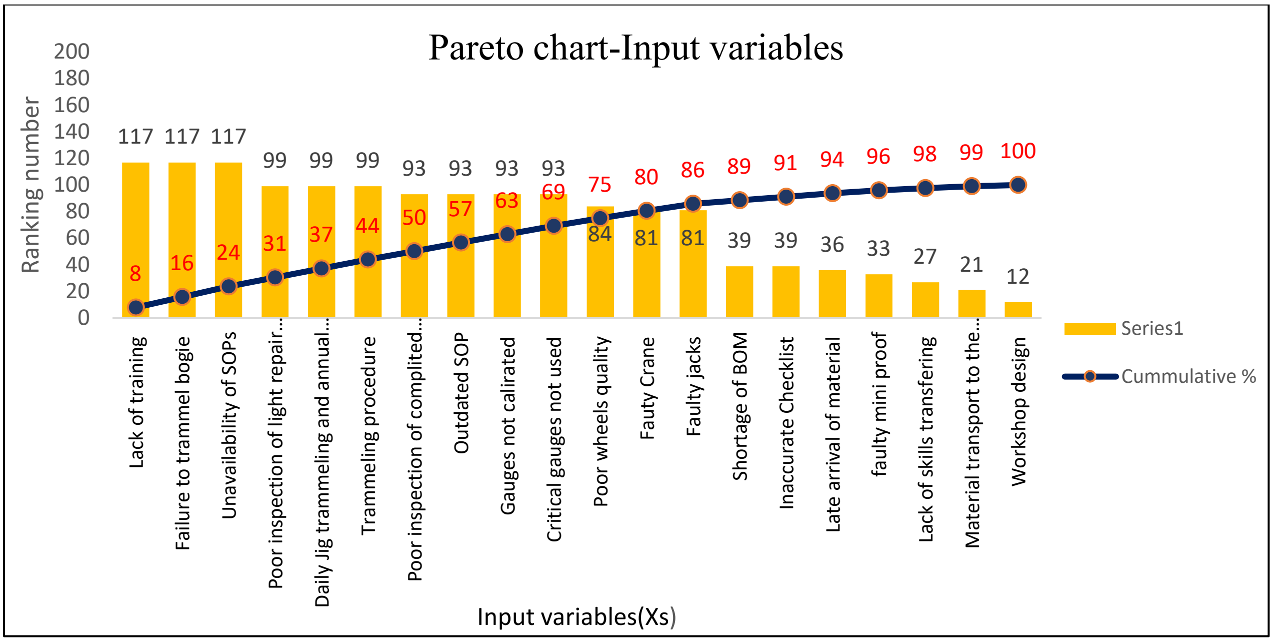


Figure 24 : Pareto Chart for input variables.

FMEA is a risk assessment tool that evaluates the severity, occurrence, and detection of risks to prioritize which ones are the most urgent (Wu et al., 2021). Each category has a scoring matrix with a 1-10 scale. A severity of 1 denotes low risk to the customer, and a score of 10 denotes high risk. The occurrence of 1 denotes a low probability of the risk happening, and a 10 denotes a very high probability of the risk happening. A detection of 1 denotes a process that will likely catch a failure, and a 10 means the process will likely not catch a failure. We completed the scoring of each category for each risk, then multiplied the three scores (Severity x Occurrence x Detection) to determine the Risk Priority Number (RPN). We sorted the RPNs in Table 16, from largest to the smallest as shown in Figure 25 and took actions on the top risks to reduce the overall risk.

Table 16 : Failure Mode Effect Analysis

Step 1	Step 2	Step 3	Ste p 4	Step 5	Step 6	Step 7	Step 8	Step 9
Process step	**Potential Failure Mode**	**Potential Effects of Failure**	**Sev**	**Potential Causes of Failures**	**Occ**	**Current Process Controls**	**Det**	**RPN**
Lack of training	work will not be done according to prescribed standard	Poor quality work	9	Lack of training personnel (SOE)	3	Monthly Business Skills matrix	9	243
Failure to trammel bogie	unable to identify faulty bogies	Self-steering effect of bogie	9	Not following SOP	9	Bogie/ Trammel check sheet	3	243
Unavailability of SOPs	Poor quality work	Wagons undersupply	3	first party audit not done frequently	9	Monthly first party Audit	9	243
Poor inspection of light repair bogies	Poor quality work	Falling of critical components	3	Train delays	3	Final Quality check sheet	9	81
Daily Jig trammeling	The measurements on the bogie won't be accurate	substandard bogie fitted on a wagon	9	Ignorance	3	Trammeling jig daily calibration sheet	9	243
Trammeling procedure	obtaining incorrect measurements	substandard bogie fitted on a wagon	9	No dedicated personnel for the activity	9	Supervision	1	81
Poor inspection of completed wagons	Releasing substandard wagons	Train delays	3	Too much workload	1	Final Quality check sheet	3	9
Outdated SOP	Incorrect work will be performed on a wagon	Poor quality work	9	first party audit not done frequently	3	Monthly first party Audit	9	243
Gauges not calibrated	Poor wagons released for service	Customer complains	3	Gauges not send for calibration	9	Monthly first party Audit	9	243
Critical gauges not used	No guarantee that critical components are up to standard	reliability of wagons will be affected	9	Gauges not send for calibration in time	9	Quality gauge check sheet	1	81
Poor quality wheels	Pre-mature wheels failure	self-steering effect of bogie	9	Failure to properly inspect wheels (business)	1	Wheel inspection sheet	1	9
Faulty Crane	Wagons won't be fully lifted	WE and WD services won't be maintained properly	9	Operator not certified to operate crane	3	Business skills matrix	9	243
Faulty jacks	wagons won't be fully lifted	Proper inspection will not be achieved	9	Lifting Jacks maintenance plan not adhered to.	3	Monthly machine inspections plan	9	243
Shortage of BOM	Over/under processing on a wagon	Customers complain	1	Bill of material establish.	1	Material cost on each job	9	9

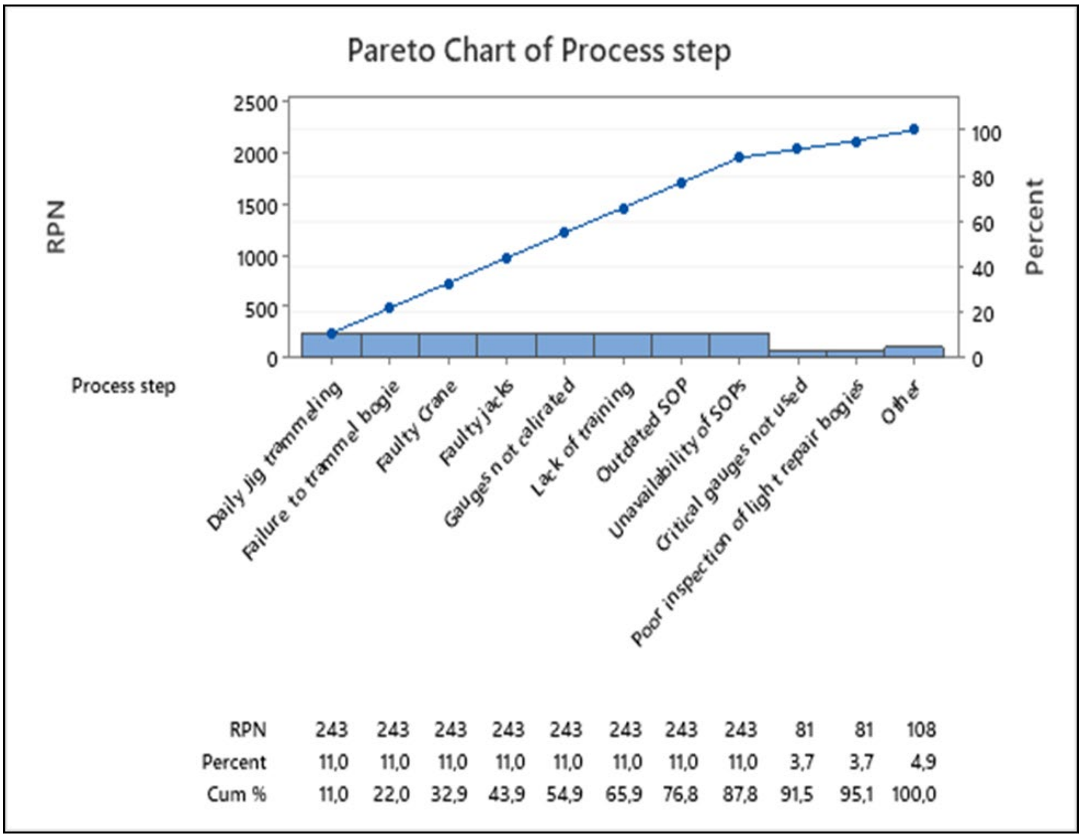


Figure 25 : Pareto for Failure Mode and Effect Analysis.

Figure 25 was used to determine the order for dealing with failure modes according to their relative importance (Sharma & Srivastava, 2018). The Pareto chart separates the significant aspects of a problem from the trivial ones. The principle asserts that approximately 80% of effects arise from 20% of causes (Irfanto, 2022). In other words, a small percentage of causes have an outsized effect. Table 16 presents Hypothesis testing that was used to examine whether changes made in the process are better or not.

4.3. Analyse phase

In this phase, probable causes of the problems were identified, and the actual root cause was identified using the fishbone diagram technique. The critical root cause that has the highest impact on critical quality (CTQ) was also discovered. The verification of root causes was completed using a hypothesis testing technique.

The practical Problem in column 3 presents a problem or pain area persisting on the production or shop floor. They were converted into statistical problems. A statistical problem is a problem that is addressed with facts and data analysis methods. This is the solution with confidence or risk levels versus an 'I think" solution. The solution is not how people feel or get influenced. The solutions are totally data-driven because they are Six Sigma approaches. Column 4 presents the types of tests performed. Some common types of hypothesis tests normally utilized in Six Sigma in projects are chi-square tests, ANOVA and t-tests to establish if observed differences or relationships in data are statistically significant. Column 5 presents the values of the probability known as the P-value. It is a statistical measure which indicates the probability of making an α error. The conclusion in the last column presents the conclusion drawn from the hypothesis testing. The conclusion is made up of two parts: 1) Reject or fail to reject the null hypothesis, and 2) there is or is not enough evidence to support the alternative claim. Option 1) Reject the null hypothesis (H0). This means that you have enough statistical evidence to support the alternative claim (H) (Anderson et al., 2000).

Table 17 indicates a list of potential inputs that may impact a desired result and their sources. This list is collected for the purpose of performing hypothesis testing.

Table 17 : List of potential Xs.

Number	Potential X	Source
1	Gauges not calibrated	FMEA
2	Outdated SOP	XY Matrix
3	Unavailability of SOPs	FMEA
4	Non-inspected CR Bogies	XY Matrix
5	daily Jig Calibration	FMEA
6	Final wagons examination	FMEA
7	Lack of Training	XY Matrix
8	Faulty Crane	XY Matrix

Table 18 : Data collection plan

Define Measures			Sampling				
Measure	**Type of measure (Y, X)**	**Type (Continuous, Attribute, Count)**	**What**	**How**	**Where**	**When**	**How Many**
Gauges not calibrated	X	Attribute	Monthly statistics	Skills matrix	Iso matrix	13/12/19	1
Outdated SOP	X	Attribute	Audit reports	Available Vs Unavailable	Quality system	20/01/20	1
Unavailability of SOPs	X	Attribute	Audit reports	Audit reports	Quality system	13/12/19	1
Non-inspected CR Bogies	X	Attribute	Audit reports	Audit reports	Quality system	14/12/19	1
daily Jig Calibration	X	Continuous	Calibration of document	check sheet	Bogie bay	15/12/19	3
Final wagons examination	X	Attribute	Completed wagon	Job card	Production line	20/12/20	5
Lack of Training	X	Continuous	outstanding training stats	Computer	Skills matrix	13/12/19	1
Faulty Crane	X	Continuous	Crane faults	computer	SAP	15/12/19	3

Table 18 is a data collection plan that outlines the steps and sequence required to gather data for a particular project. The Six Sigma data collection plan is a statistical method that aims to achieve breakthrough improvements by reducing variation or defects. This is important because the people involved in data collection may differ from those who created the plan.

There are three types of hypothesis tests: right-tailed, left-tailed, and two-tailed. When the null and alternative hypotheses are stated, it is observed that the null hypothesis is a neutral statement against which the alternative hypothesis is tested. Table 19 is a summary of statistical analysis for the hypothesis performed.

Table 19 : Statistical Analysis

No:	**Potential X**	**Hypothesis to be tested (practical problem)**	**Hypotheses defined (statistical problem)**		**Test(s) selected**	**Result (p value)**	**Conclusion**
1	Gauges not calibrated	Non calibrated gauges results in more bogie faults	Ho :	XY Matrix	2-Sample t Test	P=0,356	Non calibrated gauges do not significantly result in more bogie faults.
			Ha:	XY Matrix			
2	Outdated SOP	Non revised SOPs results in more bogie faults.	Ho :	FMEA	1-sample t Test	P=1,000	Non revised SOPs doesn't not significantly result in more bogie faults.
			Ha :	FMEA			
3	Unavailability of SOPs	Shortage of SOPs results in bogie faults.	Ho :	FMEA	1-sample t Test	P= 0,001	Shortage of SOPs results in bogie faults
			Ha :	FMEA			
4	Non- inspected CR Bogies	Non Inspected Bogies results in more bogie faults.	Ho :	XY Matrix	2 -Sample t Test	P=0,604	Check bogies does not significantly result in more bogie faults.
			Ha :	XY Matrix			
5	Non daily Jig Calibration	Not calibrating jig daily results in more bogie faults.	Ho :	XY Matrix	1-sample t Test	P=0,041	Not calibrating jig daily results in more bogie faults.
			Ha :	XY Matrix			
6	Final wagons examination	Lack of final wagon examination results in more bogie faults.	Ho :	XY Matrix	2-sample t Test	0.011	Lack of final wagon examination doesn't significantly result in more bogie faults.
			Ha :	XY Matrix			
7	Lack of Training	Lack of training results in more bogie faults	Ho :	XY Matrix	2-Sample t Test	0.001	Lack of training results in more bogie faults.
			Ha :	XY Matrix			
8	Faulty Crane	Crane downtime result in more bogie faults	Ho :	FMEA	2-Sample t Test	0.001	Crane downtime does not significantly result in more bogie faults.
			Ha :	FMEA			

Table 20 : Root Cause Summary

No:	Potential X	Source	Graphical relationship?	Statistical relationship?	Root cause?
1	Gauges not calibrated	FMEA	Yes	Yes	Yes
2	Outdated SOP	FMEA	Yes	Yes	No
3	Unavailability of SOPs	FMEA	Yes	Yes	Yes
4	Non-inspected Bogies	FMEA	Yes	Yes	No
5	Non daily Jig Calibration	FMEA	Yes	Yes	Yes
6	Final wagons examination	FMEA	No	Yes	Yes
7	Lack of Training	FMEA	No	Yes	No
8	Faulty Crane	FMEA	No	Yes	Yes

Table 20 indicates the summary of possible potential causes of failures such as Gauges not calibrated, Unavailability of SOPs, Non-daily Jig Calibration, Final wagons examination and Faulty Crane. These causes require more attention from the management, operations department, and maintenance department. Improve phase

This is the fourth phase of DMAIC, and it deals with determining the solutions for problems identified in the previous three phases. After the root causes were identified as indicated in Table 20, the team identified feasible solutions for the root causes and selected the best solutions.

Table 21 is a decision-making tool known as the impact effort matrix template. This template was used to prioritize the tasks that yield the best results in the least amount of time, tasks that will take longer and are worth doing and lastly tasks that will have little impact on the customer.

Table 21 : Ease-impact table

#	Potential solution	Ease of implementation	Rate	Impact of solution on Y	Rate
S1	Have dedicated employees for final wagon inspection.	Moderate	4	Medium	5
S2	Upgrade 10T crane to 12T	Easy	8	Medium	6
S3	Review all business SOP on weekly basis.	Easy	1	Medium	4
S4	Introduce bogie check sheet at bogie repair station	Easy	3	Medium	3
S5	create spreadsheet to track overdue calibration weekly.	Easy	3	Medium	6

The team is comprised of stakeholders and other subject matter experts because they have a firsthand perspective on how tasks are completed and how much effort is required. The four-quadrant chart in figure 26 was created, and the impact effort matrix was plotted on two axes: the level of effort involved in a task and the level of potential impact completion of the task we had. The individual task was added onto the matrix depending on how much effort and impact each can have. Each placement was reviewed, and everyone agreed. The action plan was created based on the results generated.

Figure 26 : Ease-Impact Diagram

Table 22 : Implementation Plan.

#	Action to be implemented	Responsible	Target completion date	Issues / Barriers	Additional support required	Current status
1	Have dedicated employees for final wagon inspection.	Employee 1	30-Oct-24	NONE. No need to employ for more people	NONE	On target
2	Upgrade 10T crane to 12T	Employee 2	25-Sep-24	NONE. We have enough money on our capex budget.	NONE	On target
3	Review all business SOP on weekly basis.	Employee 3	31-Jul-24	NONE	NONE	On target
4	Introduce bogie check sheet at bogie repair station	Employee 4	12-Sep-24	NONE	NONE	On target
5	create spreadsheet to track overdue calibration weekly.	Employee 5	20-Jun-24	NONE	NONE	On target
6	Calibration due date remainder (Excel document)	Employee 6	10-Jun-24	NONE	NONE	On target
7	Lock away uncalibrated gauges	Employee 7	1-Sep-24	NONE	NONE	On target

4.4. Control phase

This is the last phase of DMAIC, and its main purpose is to ensure that all the items that were created and the gains that were obtained in the 'Improve' phase of the DMAIC cycle are maintained long after the project has ended. Completing this phase was not necessary to meet the objective of this dissertation. Even though carrying out this step did not occur, this part provides recommendations for controlling the unscheduled bogie-related faults after the implementation of improvements.

Examining the current process and systems uncovered a great deal of variation in the current process in the maintenance of wagons in the workshop. In an attempt to monitor the variation of future processes, the logistic company used the Statistical control (SPC) charts. The utilisation of the control charts allows the freight logistic company to monitor variations in the process over time as well as to detect any abnormalities or inconsistencies associated with the maintenance of the wagons.

4.4.1. Poisson Capability Comparison of bogies faults before/After improvements

A Poisson Capability Comparison evaluates process performance before and after improvements by analyzing the defect rates in systems where defects occur randomly and independently. Using the Poisson distribution, the comparison measures defects per unit (DPU) or defects per million opportunities (DPMO) to assess changes in quality. According to the diagnostic report in Figure 27, it is confirmed that the before and after process conditions are stable and at the point of level out, the defects of bogies faults are more stable.

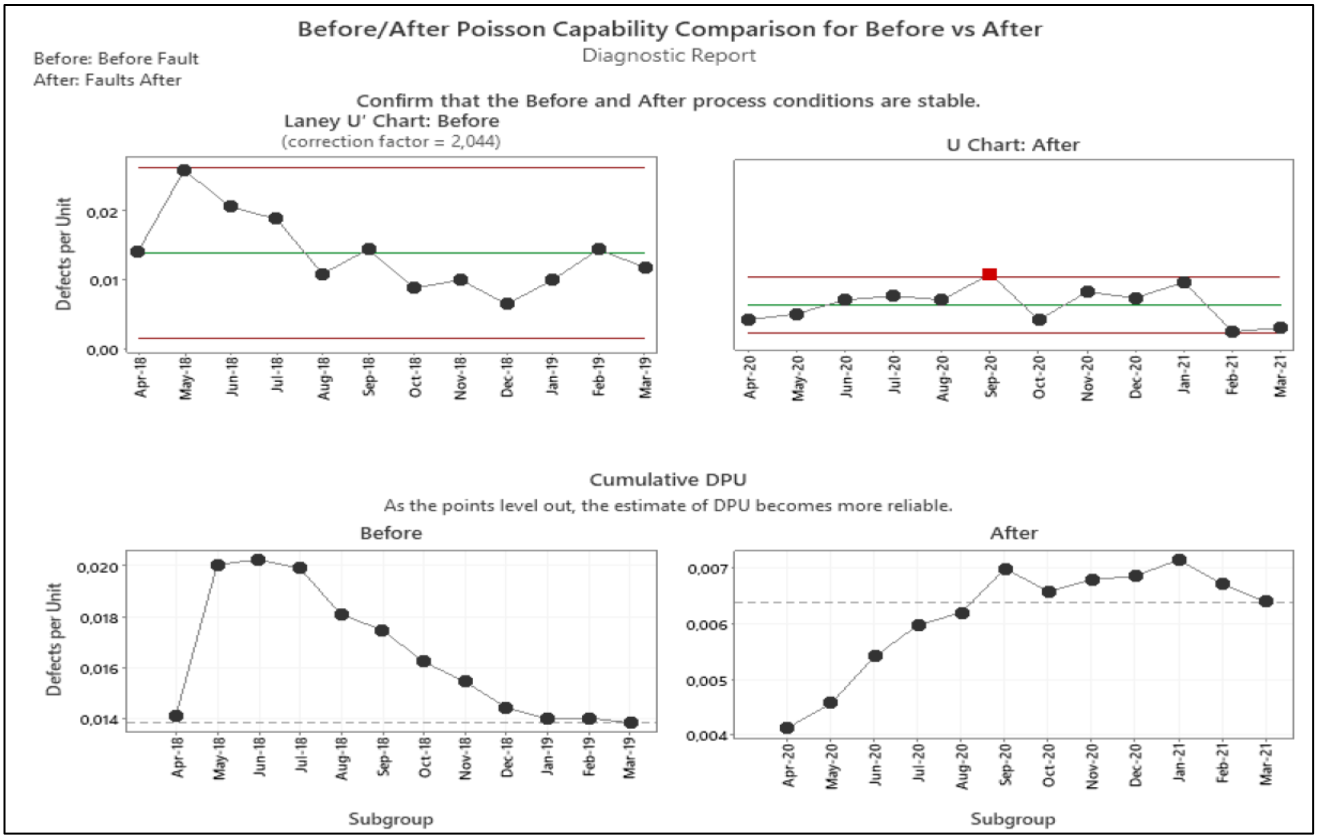


Figure 27 : Before /After Poisson capability comparison

Maintaining the gains made after achieving optimal outcomes is the main obstacle faced by any process owner. The standardization of improved methods and continuous outcome monitoring are crucial for ensuring the sustainability of results. In the improvement phase, after selecting the bogie line process flow and its associated parameters, the experimental operational time and cost can be adjusted to stable values (22 faults per month and a cost of R35,949.38 per wagon). Alongside time and cost metrics, accuracy is essential for reliability estimation in this study. Figure 28 presents a control chart that graphically validates the accuracy metric for the enhanced bogie faults process, both before and after implementation, to illustrate its stability. The findings demonstrate that the improved method for managing bogie faults is stable, showing a reduction in faults compared to before the study commenced.

4.4.2. Graphical validation

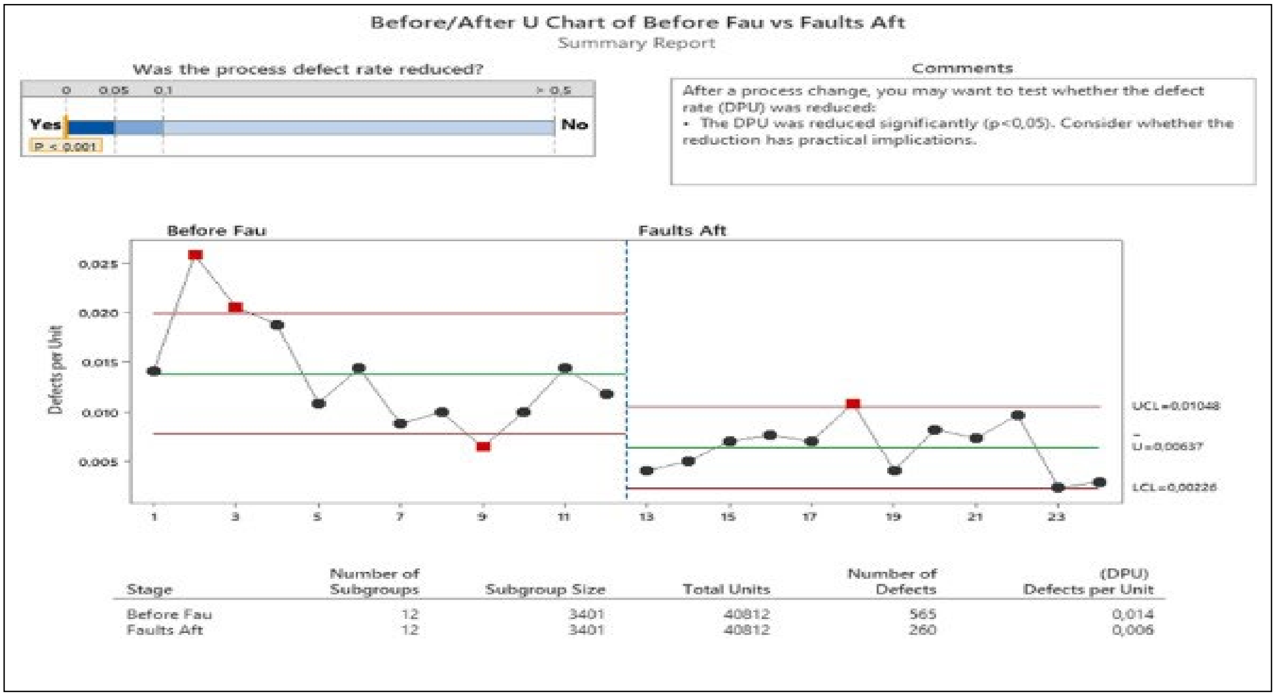


Figure 28 : Before/After U chart of before faults vs faults after improvements

Figure 28 is a control chart utilized to monitor the variation in the number of defects or nonconformities per wagon in a process with a non-constant sample size. It assisted in monitoring and evaluating whether our processes operated within statistical control. The U Chart facilitated the identification of patterns or deviations beyond control limits, allowing teams to detect issues and implement corrective measures to uphold process quality. The defects per unit were significantly reduced because the P-value exceeded 0.05.

4.4.3. Statistical validation

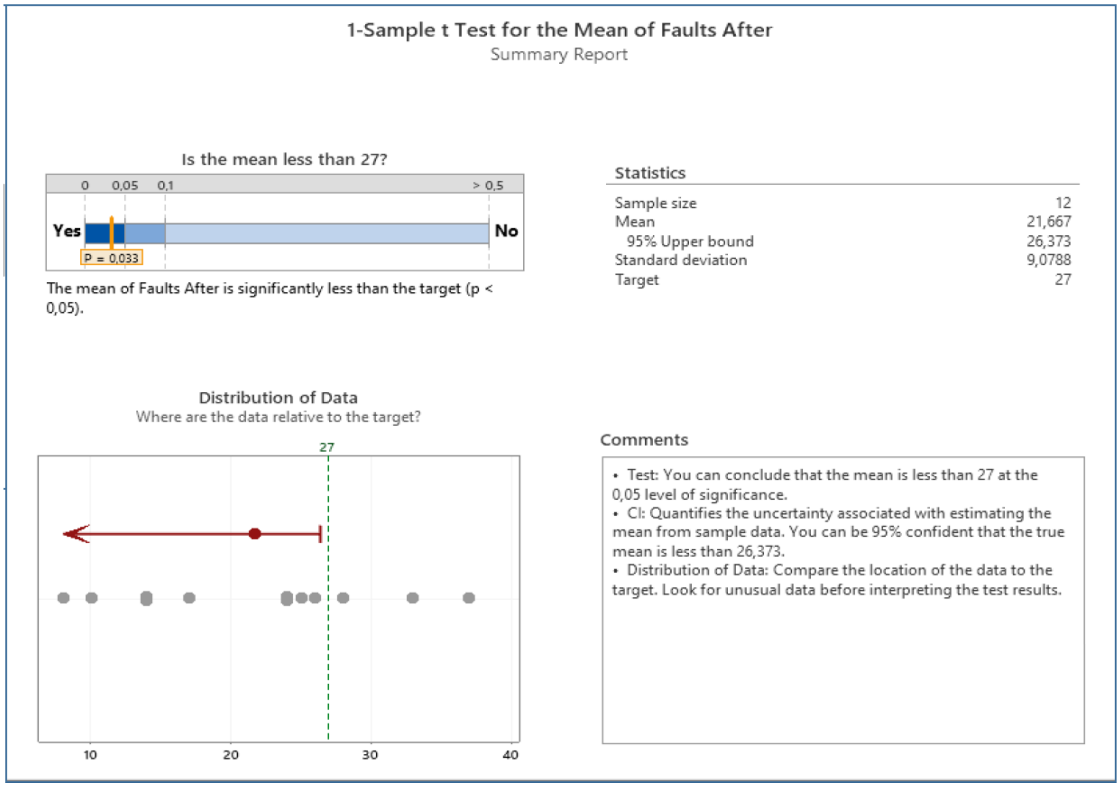


Figure 29 : 1-sample t Test for the mean of faults After the improvements

Figure 29 presents a 1-sample t-test for the Mean that was used to determine whether the mean of a single sample is significantly different from a known or hypothesized population mean. The test compared the sample mean to the bogie faults before the study, calculated a t-statistic, and evaluated the p-value to determine if the difference was statistically significant. This test is valuable in the bogie faults processes for assessing process and validating assumptions about process performance.

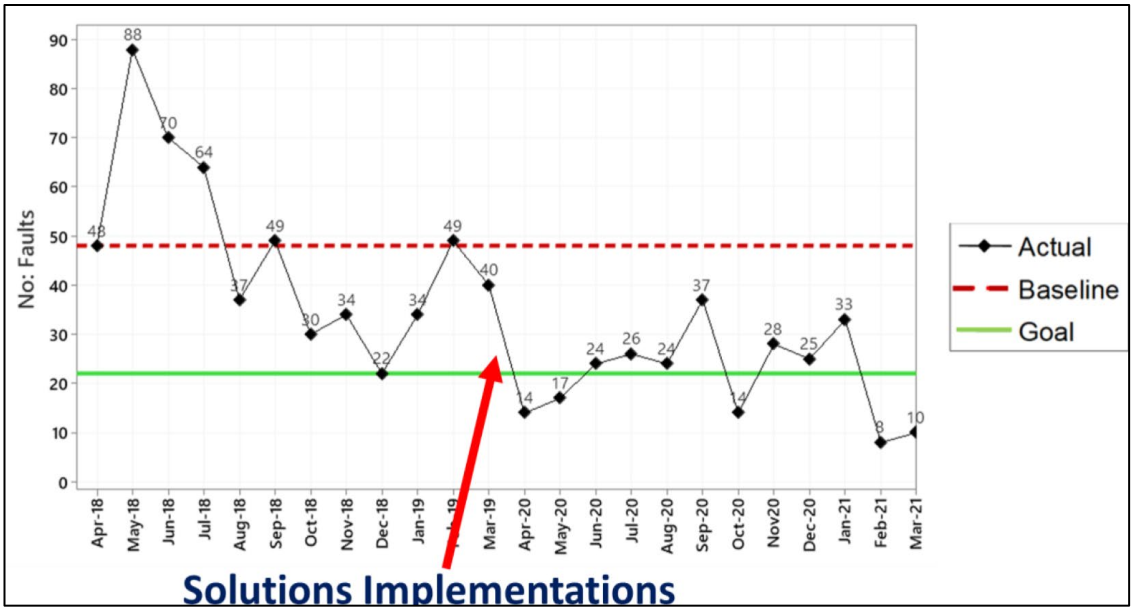


Figure 30 : Run Chart after Solution Implementation

The run chart in Figure 31 demonstrates the trends and shifts in a process. In this case, the goal of reducing bogie faults by an average of 27 was achieved. Furthermore, the mean of faults after the improvements is significantly less than the goal.

4.5. Chapter Summary

In conclusion, this chapter illustrates the efficacy of the Six Sigma methodology in resolving the identified issue. It underscores quantifiable enhancements in process efficacy, consistent with project goals and corroborating the employed methodologies. The results validate the effective execution of data-driven strategies to diminish defects or inefficiencies. Identified limitations and opportunities for future improvements ensure ongoing process optimization and strengthen the value of Six Sigma methodologies.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0. Chapter Overview

This chapter presents a concluding remark with some definitive observations. The observations provide some descriptive analysis of the primary research inquiries and their corresponding outcomes. Furthermore, a research gap was recognized, and prevalent limitations associated with the bogie faults in Company X were emphasized and deliberated as suggestions for future investigation.

5.1. Deductive observation

The results of an analysis of the wagons' bogie faults that resulted in high maintenance costs are presented in this study. The primary challenge identified by Company X was the tools employed to assess the quality of bogies on the production line. Concerning this significant gap, the failures documented in this study were eight in 2018 and four in 2020. Concerning this significant gap, three components—bogie, brakes, and hollow wear—during 2021/2022 constituted 50% of the faults in the wagon fleet.

The wagon fleet at Company X ensures the reliability and availability of wagons to facilitate the safe and prompt transportation of tonnages, thereby ensuring customer satisfaction. Additionally, the wagons consist of three primary hardware components and their subcomponents: the wheels, bogie, and body. These components were initially recognized and categorized as essential elements through the problem definition tree. This tool systematically analysed the problem into its fundamental causes and contributing factors. The VOC was conducted to comprehend and prioritize customer requirements and expectations. The three Critical to Quality (CTQ) metrics were 97.5% availability, a cost limit of 21 hours per service, and a maximum monthly average of 40 faults per bogie. The failure of wagons and the primary potential factors, along with their sub-factors, were extracted from the organization's root cause analyses and illustrated using a fishbone diagram. The identified issue was initially addressed, followed by the delineation of all potential causative factors, culminating in the development of a fishbone model. Furthermore, the average cost of faults per wagon was assessed from the perspective of production loss.

The cause and effect matrix facilitated the prioritization of potential causes of a problem according to their influence on customer requirements (CTQs). It facilitated the connection between process inputs and outputs, ensuring conformity with customer priorities. The FMEA was utilized to formulate a thorough maintenance strategy aimed at reducing production losses due to bogie failures. This reliability technique was methodically implemented via the bogie mode of failure analysis, examining potential causative factors and their impact on overall process operation. This systematic tool facilitated the identification and mitigation of potential risks in a product. It concentrated on examining possible failure modes, their impacts on results, and the underlying causes of these failures. Each failure was assessed according to its severity, probability of occurrence, and detectability, resulting in a calculated Risk Priority Number (RPN) to prioritize interventions. Upon completing the FMEA, a Pareto Chart was employed to identify the most critical failure modes for prioritization. The chart visually illustrates the 80/20 rule by categorizing data according to frequency or impact, demonstrating that a limited number of causes contribute to the majority of issues. In FMEA, Pareto Charts can rank failure modes based on their Risk Priority Numbers (RPNs), allowing teams to allocate resources efficiently and tackle the most critical issues first. Insufficient training, Inability to restrain bogie, Lack of Standard Operating Procedures, Daily jig trammelling, obsolete standard operating procedure. Gauges are uncalibrated. The defective crane and jacks had a Risk Priority Number of 243. Inadequate examination of light repair bogies, Trammelling procedure. Critical gauges were not utilized, resulting in a Risk Priority Number of 81. Inadequate inspection of finished wagons, substandard wheels, and a deficiency in the bill of materials resulted in a Risk Priority Number (RPN) of 9.

A Pareto chart was created, concentrating on the initial eight potential factors that could substantially impact the outcome or performance of a process. Hypothesis testing was performed on the eight potential factors to ascertain whether the observed data substantiates a specific hypothesis or if the variations are attributable to chance. Among the eight potential factors, the calibration of gauges, the unavailability of standard operating procedures, non-daily jig calibration, final wagon examination, and faulty cranes were identified as possible causes of failures. These issues necessitate increased focus from management, the operations department, and the maintenance department. The constructed ease and impact diagram includes a potential solution: assign dedicated employees for the final wagon inspection. Enhance the 10T crane to a 12T capacity. Conduct a weekly review of all business Standard Operating Procedures (SOPs). Implement a bogie check sheet at the bogie repair station and develop a spreadsheet to monitor overdue calibrations every week.

In executing an effective bogie maintenance strategy, as both primary and secondary causative factors would inform the development of a suitable strategy. Table 23 presents a summarized collection of sections that address the research questions.

Table 23 : Research Objective and Results

S/ N	Research Objective	Results
1	Identification and prioritization of drivers affecting the implementation of Six Sigma methodologies in the rail freighting industry of developing economies.	The first research objective results are presented in Chapter 4; Sub-section 4.2.4; Table 15; Figure 23
2	Development of a Six Sigma-centric model premised on the DMAIC approach for performance enhancement of rail freighting operations.	The second research objective results are presented in Chapter 4; Section 4.3; Sub-section 4.3.1 to 4.3.3
3	Validation of the effectiveness of the developed Six Sigma models through data deployment and performance analysis.	The third research objective results are presented in chapter 4; Section 4.4; sub-section 4.4.1 followed; Figure 27;

5.2. Recommendations

Improving bogie faults in the freight logistic company means improving wagon reliability and enhancement of performance. The total amount of bogie faults recorded can be continuously monitored and reduced using appropriate managerial techniques. Improving the reliability of wagons to the customer may also assist in maintenance cost reduction.

It is important to improve quality characteristics such as preventative maintenance, Efficient maintenance scheduling, Move to Automated Processes, and Opportunity for skills transfer, to realize Six Sigma qualities in the freight logistics company. Statistical process control assists in monitoring the processes in the system to obtain the goal of introducing the methodologies of Six Sigma. To improve the characteristics relating to the freight logistics company, it is required to focus on the following elements to realize good quality maintenance in the observed company:

5.2.2. Efficiency maintenance scheduling

It is important to reduce unscheduled downtime by ensuring that planning is done proactively, and resources are allocated for solving issues and maintenance tasks before turning into big breakdowns. It would also assist in improving overall operational efficiency and increase the lifespan of equipment. Healthy equipment enables the operations team to meet customer demands.

5.2.3. Move to Automated Process

When systems are automated, it’s easy to free up employees’ time by automating activities that are repetitive and make employees focus more on strategic, value-adding activities. Processes that are automated are likely to have improved customer satisfaction as they have quicker turnaround times.

5.2.4. Opportunity for skills transfer

The foundation for the success of any organization is the skills they possess. It’s important for skills transferring to take place because it helps the organization to exploit the potential that is hidden and produce a stronger workforce that is flexible. Lack of necessary skills can lead to poor workmanship as well as bad quality products or services. There are two types of skills. Hard skills and soft skills. The fundamental difference between hard skills and soft skills is how they are obtained and utilized at work. Soft skills are the way a person thinks and behaves, and hard skills are gained through education or specific training. Creative and skilled professionals like Engineers, Artisans Technical workers amongst others are important in the maintenance environment to ensure the reliability and availability of a fleet of wagons. For an organization to maintain a good quality product for the customers, there should not be a shortage of those skills.

5.2.5. Suggestions for further studies.

After evaluating the limitations of the study, some areas needing exploration and enhancement were identified. These areas are capable of providing several inspirations for possible research activities and thus recommended as follows:

- Explore the relationship between Six Sigma flexibility and stability in the introduction of the strategy, to ensure that the structures are more practical and applicable to the ever-changing technologies and ways of conducting business.
- Consider data that can cover a larger population with various available resources and include more companies in the instant future will assist in the good validity of the findings from this research. This will help in drawing more accurate conclusions from the study.
- Conducting similar research in different logistic industry and maintenance industries in South Africa. Sreedharan and Raju (2016); Kurnia and Purba (2021) literature support this approach by indicating that Six Sigma has been adopted by a wide range of industries such as manufacturing, Services and construction. If a similar study is conducted in different sectors, it will help to understand if other sectors in South Africa are experiencing the same challenges as the freight logistics industry.

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