Cape Peninsula University of Technology

AN APPROACH TO THE MANAGEMENT OF ROAD DETERIORATION ON NATIONAL ROUTE 12 BETWEEN BEAUFORT WEST AND KLAASTROOM, WESTERN CAPE, SOUTH AFRICA

by

Msawenkosi Mkoka

Dissertation submitted in fulfilment of the requirements for the degree

Master of Engineering in Engineering Management

in the Faculty of Engineering & the Built Environment
Department of Industrial and Systems Engineering

at the Cape Peninsula University of Technology
Supervisor: Prof Bronwyn Swartz

Bellville
October 2025

DECLARATION

I, Msawenkosi Mkoka, declare that the contents of this thesis represent my unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

		30/06/2025

Signed **Date**

ACKNOWLEDGEMENTS

This thesis could have been completed without God and the assistance and input from various individuals. I want to thank Prof Bronwyn Swartz, my supervisor, for her efforts and assistance. rendered during this period. Thank you to Mr Sithari for his continued motivation. I am grateful to my brother, Lizalisa Mkoka, for inspiring me to take on this journey. Special thanks to my mom, Sabekazi and sisters for caring, loving and supporting me from day one.

ABSTRACT

The present National Route 12 road (classified as the TR33/5) between Klaarstroom and Beaufort West in the Western Cape Province, South Africa, shows rapid deterioration. The road falls under the Western Cape Provincial Roads' jurisdiction. The deterioration is evident on the road pavement through surface deformation, severity in cracking, and surface disintegration.

Road pavement is defined as the entire structure of the roadway regardless of type or composition, including stabilised subbase and all the layers of construction, including the final wearing course and embankments. The deterioration of the road pavement affects the condition of the vehicles using it, thus increasing motorists' maintenance costs, and possibly leading to fatal incidents.

This research study thus sets out to develop a risk management approach to identify, evaluate, and manage different types of road distress on the TR33/5 road.

The study employed a mixed methods approach using both quantitative and qualitative data from the Western Cape Provincial Government, such as climate conditions, historical imagery, Conditional Survey Report data, Material Investigation Report data, traffic volume data, and any environmental factors. An integrated risk management approach aligned with ISO 31000:2018, incorporating quality tools such as gap analysis, an Ishikawa diagram, 5 Whys technique, and Failure Mode Effects Analysis (FMEA) was followed. A pilot study was conducted on Jakes Gerwel Drive, one of the City of Cape Town roads, to test for validity of this study.

After integrated risk management analysis, the National Route 12 was found to be 28 years old, and without adequate maintenance to prolong the design life, which resulted in moisture entering through the surface, causing supporting layer deterioration, despite the traditional means of repair. The current method used for the preventative maintenance of the road surface, which involves using cold mix asphalt to repair pavement deterioration, is not entirely adequate.

Introduction of infrared asphalt road repair maintenance is the recommended solution to overcome pavement deterioration on the TR33/5 road, and this study recommends that this solution should be implemented in South African roads as a whole. The study also recommends the implementation of industrial engineering management tools in the civil engineering management industry.

Keywords: Road pavement deterioration, pavement distress, risk management approach, Infrared repair approach

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

Abbreviation	Name
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
CFI	Corporate Finance Institute
ECSA	Engineering Council of South Africa
FMEA	Failure modes and effects analysis
FTA	Fault tree analysis
ISO	International Standards Organisation
QMS	Quality management system
RPN	Risk priority number
RNIS	Road Network Information System
SANAS	South African National Accreditation Services
SAPEM	South African Pavement Engineering Manual
TR33/5	Trunk Road 33 Section 5

GLOSSARY OF TERMS

TERM	DEFINITION
Behaviour	The function of the condition of a pavement with time.
Distress	The visible manifestation of the deterioration of pavement in respect of either serviceability or structural capacity.
Pavement	The entire structure of a roadway regardless of type or composition, including stabilised soil subgrade and all the layers of construction, including final wearing course and embankments. It must be noted that the pavement referred to in this document is not a sidewalk.
Pavement layers	The combination of material layers constructed over the subgrade to provide an acceptable facility on which to operate a vehicle.
Performance	The measure of satisfaction given by the pavement to the road user over a period of time quantified by a serviceability or age function.
Riding quality	The general extent to which road users experience a ride that is either smooth and comfortable or bumpy and thus unpleasant and perhaps dangerous.
Risk management	The process of identifying, analysing, and reducing threats, especially to organisational earnings, employees, and profits
Rut	A depression along the wheel path o n road pavement.
5 Whys Analysis	A problem-solving technique that involves asking 'why' multiple times (typically five) to determine the root cause of an issue.
Serviceability	The measure of satisfaction given by the pavement to the road user at a certain time quantified by factors of riding quality and rut depth.
Structural maintenance	Measures that will strengthen and correct a structural flaw in, or improve the riding quality of, an existing road.

CHAPTER ONE: INTRODUCTION

1.1 Chapter introduction

This introductory chapter briefly reviews the road pavement distress on National Route 12 from Klaarstroom to Beaufort West in the Western Cape Province, South Africa. It provides a background to the research study, including the research problem statement, research aim, research objectives and associated research questions. Furthermore, it concludes with an overview of the study design, considerations around research ethics in this study, a chapter outline and the research assumptions.

1.2 Study orientation

The National Route 12 (classified as the TR33/5) from Klaarstroom to Beaufort West, which falls under the jurisdiction of Western Cape Provincial Roads, shows rapid deterioration (Road Network Information System (RNIS), 2023). This deterioration is evident on the road pavement as surface deformation, severe cracking, and disintegration. It must be noted that the term ‘pavement’ as referred to in this dissertation is not a sidewalk. Rather, it is the surface of the road. Surface deformation, severe cracking, and disintegration are commonly referred to as road pavement distress (South African Pavement Engineering Manual (SAPEM), 2014). Ragnoli et al. *(*2018) state that road pavement distress could include the following:

- Road deformation,
- Edge defects,
- Potholes,
- Alligator cracks,
- Road rut
- Corrugated cracks, and
- Longitudinal cracks.

Kaare et al.,(2012) advance a view that the management of roads is a vital system to prevent pavement distress as outlined above. Furthermore, they argue that maintenance and repair costs can exceed the original costs of constructing new roads and create a financial burden. Therefore, it is important to identify and adequately manage road pavement distress before the financial burden of a repair outweighs the initial construction of the road. Accordingly, preventative maintenance plays an important role in extending the design life of road pavement.

Aside from the financial implications for Western Cape Provincial Roads of inadequate road maintenance, Belt et al., (2002) argue that the deterioration of the road pavement will affect the condition of the vehicles using it, thereby increasing the motorist’s maintenance costs, and it could also lead to an increase in fatal traffic incidents. Road pavement distress such as potholes pose a danger to motorists especially during rainy days when defects are not clearly visible (Ragnoli et al., 2018). Atiyeh (2019) argues that road deterioration such as road ruts can also cause aquaplaning during the rainy season, reducing the vehicle control on road pavement material. This happens when the water builds up in road ruts. A rut is a depression along a wheel path on road pavement. As the vehicle tyres drive over excessive water build-up at that place in the road, the tyres do not make proper contact with intact road pavement surface, resulting in the vehicle gliding on the road pavement (SAPEM 2014). Moreover, another consequence of the road pavement distress is an increase in the travelling times between Klaarstroom and Beaufort West, and as a result of delay, fuel consumption increases, which contributes to environmental air pollution.

With risk being defined as ‘a chance that something will happen with a negative effect’ (Virine and Trumper 2017), it may be surmised that at present, there are a significant number of risks faced by the Western Cape Provincial Roads’ team responsible for the TR33/5 between Klaarstroom and Beaufort West not to mention users of the road. This study sets out to explore if a robust risk management strategy such as those recommended by CFI Team (2022) and Schwartz (2025) can be used to overcome the aforementioned challenges.

1.3 Study background

Bhatti (2023) states that across the globe, road infrastructure plays an important role in the well-being of society as roads provide an essential means to move people and goods from one place to another. Thus, the road pavement is designed to provide structural support to withstand traffic loading under prevailing environmental conditions throughout the design life and at a minimum maintenance cost. Significantly, in the context of this South African study, the ultimate purpose of road pavement infrastructure is to provide a good rideable road within acceptable South African road standard specifications.

The TR33/5 road shows pavement deterioration, which is the result of pavement cracking or deforming of pavement layers that is evident on the road surface, such as shown in Figure 1. The stresses imposed on the road surface by the external loads of the vehicle together with environmental conditions gradually increase the deterioration. Kaare et al. (2012) argue that this effect depends on the technology and materials of the road, but the greatest effects depend on traffic loads and volumes.

Figure 1: Examples of pavement deterioration (Arrive Alive, 2019).

Abhijit and Patil (2011) argue that poor drainage can cause premature failure on road surfaces. The effect of poor drainage systems on the road also contributes to the formation of road distress as the high level of moisture tends to decrease the road pavement strength.

This research focuses on the management of road pavement distress using an integrated risk management approach taken from the standard on risk ISO 31000 (2018). The standard risk management approach that will be applied includes clearly identifying and defining the risk/s, analysing the extent of identified risk/s, evaluating the impact of risk/s, rendering risk treatment options and risk monitoring, and reviewing proposed solutions to manage the risk/s (Schwartz, 2025).

1.4 Research problem statement

The TR33/5 road between Klaarstroom and Beaufort West has deteriorated sections that require attention to prolong the road's design life and prevent possible road incidents, reduce road user costs as well as environmental impacts thus an approach to the management of road deterioration is addressed in this study.

1.5 Primary research question

Rooted in the research problem mentioned above, this research aims to develop an approach to managing road deterioration on National Route 12 between Beaufort West and Klaastroom. Therefore the primary research question of this study is: 'What are the engineering management tools that can be used to manage the risks of road distress on the TR33/5 road, and how should they be used to address this problem from an engineering management perspective?

1.6 Investigative research questions

The investigative research questions are:

1. What are the different types of road pavement distress on Trunk Road 33 section 5?
2. What are causes of the road pavement distresses and the risk priority associated with each contributory factor?

3. What are the elements (and tools that can be used) in the approach designed to manage road deterioration on National Route 12 between Beaufort West and Klaastroom?

1.7 Research objectives

To achieve the research aim (an approach to the management of road deterioration), this research has the following objectives:

1. Identify the different types of road pavement distresses and their severity on the TR33/5 road using secondary data from the Western Cape Provincial government.
2. Identify causes of distress and risk associated with the use of the risk management strategy.
3. Evaluate the process followed to meet Objective 1 and Objective 2 and develop and propose a new approach to the management of road distress considering quality and risk management.

1.8 The research process

Collis and Hussey (2003) propose that there are 6 fundamentals of the research process, which are:

1. Identification of research topic,
2. Definition of the research problem,
3. Determination of how the research will be carried out,
4. Collection of data,
5. Analysis and interpretation of research data, and
6. Writing up a thesis.

The above fundamentals have been broadly applied in this research study. This includes the identified road pavement deterioration problem, with the focus area being between Beaufort West and Klaastroom, and collection and data management through an ethical process. Quality tools were used for analysis and interpretation of data and a dissertation was formulated as outlined.

1.9 Conceptual framework on risk management

Several researchers (Zhang, 2022; Schwartz, 2025; Bin Abd Karim, 2014; Padro, 2014) have argued that road deterioration is a significant problem and needs to be addressed. The evaluation of the work of these scholars highlighted that several risk management frameworks can be applied to this project. However, the framework drawn from the work of Schwartz (2025) has been selected as a conceptual framework for this study as it in line with the ISO

31000(2018) standard which is not industry-specific but rather can be applied to different types of organisations. This framework consists of 6 management processes; 1) risk identification, 2) risk analysis, 3) risk treatment, 4) risk evaluation, 5) risk treatment and 6) risk monitoring.

This research proposes a new approach to the management of road distress considering quality and risk management. This will help to ensure a reduction in loss of life by the invention of a new management approach on the TR33/5 road and lower vehicle maintenance costs by promoting methodologies to ensure that the road pavement is kept safe and within quality standards.

1.10 Research study design

The research study design including the data collection strategy and the method of analyses for both qualitative data and quantitative data, using engineering management tools are discussed below.

1.10.1 Data collection

The population of this study includes all the electronic reports that belong to Western Cape Government containing data collected from 2013 to 2022 on the TR33/5 road. All the records for this period (from 2020 - 2021) were used. Thus, in accord with Nikolopoulou (2022), a census sampling technique was followed in this study. The author regards this sampling technique to be purposeful sampling which is a non-statistical sampling technique.

Furthermore, this study collected both qualitative and quantitative data from the reports provided by the Western Cape Government. The aim of analysing this data was to develop a management approach for addressing road pavement distress.

1.10.1.1 Reports used for qualitative data collection

Sixty-five photographs in a Conditional Survey Report were a part of the data set for this study (n=65), and used to perform a qualitative survey of the condition of the road pavement. A Conditional Survey Report is a report on the condition of the road pavement based on a Western Cape government examination of the road that took place in 2022. The report contains photographic images of the road pavement of TR33/5. It provides information about the area and highlights the distress in the road pavement. It also contains information related to the size of the road pavement and estimated area of the road pavement, including its width.

1.10.1.2 Reports used for quantitative data collection

Following the collection and analysis of qualitative data in the Conditional Survey Report described above, data was also collected from one Historical Weather Report, 24 Material Investigation Reports (n=24) and one Traffic Count Data Report (n=1). The Material Investigation Report contains information about the road pavement layers, the material classification information including the layer thicknesses. This report also contains photographic images of excavations of the road which were performed to establish the pavement thicknesses and material classifications. In the case of road pavements that were constructed in a period before records were maintained, it is necessary to perform a material investigation as part of a process to determine the condition of the road pavement, and whether or not it can withstand current road traffic conditions. The Material Investigation Report used in this study was compiled in 2022. Finally, the Traffic Count Data report includes traffic counts of vehicles using the road pavement from the initial stage when the road was open to traffic in the year 2021. Thus, in total the population size is ninety (n=91).

Thus, in summary of the data collected for this study in the order in which it was used is:

- 1 x Conditional Survey Report with 65 photographs was used to explore the research context in Chapter 2. Then it was also used as part of the identification of risk phase (thematic and gap analysis), as well as the risk analysis phase (Ishikawa and 5 Whys) in Chapter 5.
- An Historical Weather Report (n=1) was used, which contained quantitative values related to the weather 2013 to 2020, for the thematic and gap analysis.
  Material Investigation Reports were used for the identification of risk phase (thematic and gap analysis) as well as the risk analysis phase (Ishikawa and 5 Whys) in Chapter 5. A Traffic Count Data report was used for the identification of risk phase (thematic and gap analysis) as well as the risk analysis phase (Ishikawa and 5 Whys) in Chapter 5.

To assure the validity of the research, a pilot study was conducted using City of Cape Town Municipal Jakes Gerwel Drive road data, analysing the risk associated with road pavement deterioration including developing a management approach for the road.

1.11 Data analysis

This collection of documents (reports and photographs) served as a comprehensive basis for understanding the factors contributing to pavement deterioration and formulating effective engineering management strategies. Simplilearn (2024) states that data analysis is the process of scrutinising raw data to draw out a meaningful insight. The process involves deconstruction and reconstructing of raw data to convert the data into a format that is easier to understand.

Engineering management problems such as the one investigated by this study requires the use of engineering management tools (Rodriguez, 2023). This study draws on the research of Ilie and Ciocoiu (2010) who used a commonly known quality data analysis tool – the Ishikawa diagram – to successfully solve an engineering management problem in a systematic, scientific approach. The Ishikawa diagram is thus a tool that could be used in this study. Moreover, Ahmednani (2020) highly recommends the use of 5 Whys for root cause analysis as it is the simplest tool without statical analysis and has been successfully used in the manufacturing industries to determine the relationship between different root causes of problems. For this reason this study will use the Ishikawa diagram and the 5 Whys methods.

The engineering management tools will be applied in conjunction with the risk analysis technique which is in the steps in Table 1 below. This will be explained in detail in Chapter 4.

Table 1: Engineering management tools used for the study

Steps	Description	Engineering Management Tool	Data Sources
1	Identify the risk (Chapter 5)	Thematic analysis and gap analysis	Conditional Survey Report Weather report Material Investigative report Traffic Count data report
2	Risk analysis	Ishikawa diagram and 5 Whys	Conditional Survey Traffic Count Data report
3	Evaluate the risk	FMEA – Evaluation	Results from Step 2
4	Treat the risk	FMEA – Treatment	Results from Step 3
5	Monitor and review the risk	FMEA – Monitoring and review	Researcher analysis

1.12 Ethics

The researcher has ensured that the Faculty of Engineering and the Built Environment (FEBE) ethics guidelines were followed throughout the study period. In addition, as a registered candidate with the Engineering Council of South Africa, the researcher ensured compliance with the ECSA code of conduct 3.2 (a): 'must not engage in any act of dishonesty, corruption or bribery': and 3.2(h): 'must give engineering decisions, recommendations or opinions that are honest, objective and based on facts'. Further, the researcher has obtained a permission letter to collect data, and has submitted an ethics clearance application at CPUT for the research, which was approved by the institution (see Annexure A), and performed this research study in an ethical manner following both the FEBE and ECSA ethics guidelines. The researcher has followed Dawson (2002) Code of Ethics which signifies anonymity, confidentiality and data protection of research data.

1.13 Chapter outline

The following is a brief outline of the chapters that appear in this research study.

- **Chapter One**

This chapter provides an introduction and motivation for the study, background to the research problem, primary research objectives, associated research questions, scope and limitation, and the research process or organisation.

- **Chapter Two**

This chapter presents a literature review, discussing the function and use of road pavement. It discusses pavement types and factors that influence the performance of a pavement. Pavement types of deterioration, causes and possible remedial solution are discussed in this chapter.

- **Chapter Three**

This chapter presents a literature review on risk management and engineering management tools.

- **Chapter Four**

This chapter focuses on the research methodology, focus area, study period, data collection, sample size and their procedure, data analysis and ethical considerations.

- **Chapter Five**

This chapter present both quantitative and qualitative data analysis of the study.

- **Chapter Six**

This chapter presents the conclusion and recommendations on an approach in road pavement distress.

1.14 Research assumptions

Leedy and Ormrod (2001) caution that assumptions made without careful consideration can lead to significant misunderstandings and substantially affect the outcomes of research. Therefore, this study meticulously considers its foundational assumptions to ensure the integrity and validity of the final results.

The assumption that was made was that:

- The research study analysis, results and recommendations were made on the assumption that the secondary data obtained from Western Cape Government in form of reports was accurate.

1.14 Chapter summary

This chapter presented the reader with a brief introduction on road pavement distress on the National Route 12 (classified as TR33/5) from Klaarstroom to Beaufort West. This chapter then presented the background to the research study, research problem statement, research aim, research objectives and associated research questions.

This chapter also outlined the research process followed, methodological aspects of the study including an overview of the data collection and analysis strategies, research ethics considerations, a chapter outline and finally the research assumption. The next chapter will present a literature review on road works.

CHAPTER TWO: LITERATURE REVIEW (ASPHALT PAVEMENT DISTRESSES)

2.1 Chapter introduction

This chapter introduces the reader to the technical aspects of road pavement works for this project. In order to reach research objectives, understanding the technical aspects of roads properly is of importance in this study. The chapter consist of five sections: the first section explains the general background on road pavement; the second section is a discussion on road pavement layers; the third is a discussion on road functionality and performance; the fourth section illustrates different types of road distress on the TR33/5; and the final section highlights the consequential effect of poor quality roads.

2.2 General background on road pavement

The road under study falls under the category of minor arterial and functional class level 2 secondary road with a flat and rolling topographic terrain (SAPEM, 2014). The study area is the National Route 12 (classified as TR33/5) from Klaarstroom to Beaufort West, which falls under the jurisdiction of Western Cape Provincial Roads. The start of TR33/5 (km 0.00) is located at the intersection with Trunk Road 34 Section 2 (TR34/2), while the end (km 110.0) is located at the intersection with National Route 1 Section 7 (N1/7). The total road pavement length under investigation is thus 110 kilometres.

As a point of departure for this study, it is important to outline the basic principles and requirements that govern road pavement design and construction. The road design philosophy is to produce a structurally balanced road pavement at minimum present worth of cost, while carrying the traffic for the structural design period in prevailing environmental conditions at an acceptable standard level of service without major structural distress (South African Pavement Engineering Manual (SAPEM) 2014).

Mathew (2009) states that an ideal road pavement must have sufficient thickness to distribute the load stresses due to wheel load to a safe value on the sub-grade soil; must be structurally strong enough to withstand all types of stresses imposed upon it; have an adequate coefficient of friction to prevent skidding of vehicles; a smooth surface to provide comfort to road users even at high speed; produce minimal noise from moving vehicles; must have a dust-proof surface so that traffic safety is not impaired by reducing visibility, an impervious surface so that sub-grade soil is well protected, and long design life with low maintenance cost.

The road design philosophy indicated in various research studies was important in finding the root cause of pavement distress, which enabled finding a better approach to road pavement distress in the TR33/5.

2.3 Asphalt pavement layers

Following the general principles discussed above, this study now concentrates on the specific components that comprise road pavement, illustrating the application of these principles in real-world contexts construction. A typical asphalt pavement structure consists of different layers including subgrade, sub-base, base and surfacing as shown in Figure 2 (Barry at el., 2006).

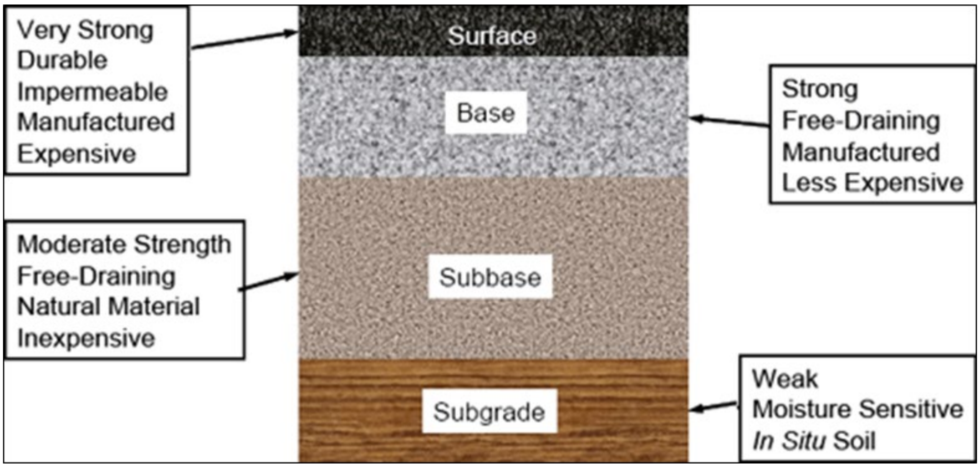


Figure 2: Layers of conventional asphalt pavement structure (Barry et al., 2006)

- **Subgrade**: this is the completed earthworks within the road prism prior to the construction of the pavement. This comprises the in situ material of the roadbed and any fill material. In structural design, only subgrade within material depth is considered.
- **Sub-base**: the layers beneath the base or concrete slab and on top of the selected layer or subgrade. Its function is to transfer the distributed load from the base to the subgrade**.**
- **Base**: the layers immediately beneath the surfacing and on top of the sub-base. Its function is to distribute the traffic loads onto the sub-base and subgrade.
- **Surfacing**: the uppermost pavement layer which provides the riding quality surface for vehicles; it also protects the base and may be designed to add strength to the pavement.

This study focuses on road pavement distress management using engineering tools. The road pavement layers as illustrated above assist in understanding different pavement layer functions. This is important as this research mainly focuses on distress affecting the TR33/5 road pavement layers.

2.4 Road functionality and performance

The road pavement layers are subjected to loading by motorists during a serviceability period of the road, thus including stresses relating to environmental load (Jefy, 2024). According to Bhandari et al., (2022) the loading stresses occurs through vertical stresses imposed by vehicle axle load transferred to the wheels and the surfacing in the road pavement layers and are subjected to tensile stresses of axle/wheel loads as the vehicle moves. The granular material normally used in the base, sub-base and subgrade cannot withstand significant tensile stresses which might cause the structure relaxations (Jefy, 2024). Road pavement failure is mostly initiated by fatigue cracking of surface associated with bituminous layer under loading. Road pavement failures can also be associated with imposed environmental effects like flooding (Bhandar et al, 2022).

According to Jefy (2024), tensile stress imposed on road pavements is denoted as (σ), resistance of an object tearing force. It is measured in Newtons/mm², therefore it is force per unit of material. Tensile stress is calculated by the force divided by cross-sectional area.

The purpose of design and construction of road pavement is to provide acceptable riding roads (SAPEM, 2014). The American Association of State Highway and Transportation Officials (AASHTO) (1993) *Guide for Design of Pavement Structures* provides a comprehensive set of procedures for new and rehabilitation design. AASHTO (1993) states that traffic data is a basis of road pavement design and performance analysis. Bhandari et al., (2022) argue that deterioration on the road pavement starts as soon as it is opened to traffic. SAPEM (2014) states that it is the responsibility of the appointed engineer to ensure that the road pavement does not only reach its design life but performs well during this time. Figure 3 illustrates the functional performance of a good and a poor road. The poor road reaches the serviceability index in less than 10 years since construction.

Figure 3: Functional performance of good and poor road pavement (SAPEM, 2014)

SAPEM (2014) states that structural performance of road pavement requires ensuring the needs of road users are met. These needs include safety, cost, comfort and sound environment. The safety of the road user is adhered to by ensuring that functional parameters such as skid resistance, road disintegration and rutting are acceptable, thus the texture depth of the surface, and number and size of potholes and rut depth respectively (SAPEM, 2014). The comfort of a motorist should be the riding quality of the road which is the roughness and sound environmental aspects such as noise pollution, measured by noise level. Bhandari et al., (2022) elucidate that traffic data is one of the major factors that contribute to road performance and sustainability. Road pavement deterioration increases with the increase of traffic loading.

According to Kaare et al., (2012) it is important to ensure that the road is designed and built to retain structural bearing capacity within its structural design period. The structural design period of the road includes maintenance thereof, and thus the condition of deterioration on the road pavement riding quality, surface condition and skid resistance alarm a maintenance strategy. Skid resistance is the friction force between the tyre and the surface of the road.

The conventional; road pavement must be constructed to avoid percolation of moisture into underlying granular material, thus, a good subsoil and open drain are required under certain conditions in road pavement (Bhandari et al., 2022).

The design integrity and serviceability of road pavement is to ensure the safety of road users. This research study also focuses on road user safety as it engages in a risk management approach for road pavement distress on the TR33/5.

2.5 Road pavement distresses on TR33/5

Drawing on the views of SAPEM (2014) discussed in Chapter 1, road pavement distress on the TR33/5 includes but is not limited to (1) road deformation, (2) edge defects, (3) potholes, (4) crocodile cracks, (5) road ruts, (6) raveling, (7) longitudinal cracks and (8) loss of skid resistance. The section below briefly outlines each of these pavement distresses based on the evaluation of the Conditional Survey Report as highlighted in Table 1.

2.5.1 Road deformation

Road deformation is the change of the constructed road profile due to imposed loading on the surface being greater than it was designed for. This can also be due to poor construction methods. Water normally ponds on the deformed surface and accelerates the impact.

Examination of the Conditional Survey Report indicated that there were two categories of base layer road deformation present on the TR33/5. The difference between the two categories is the average depth/thickness of the base layer deformation. The first type affected150mm of the TR33/5 and the second type was 75mm in depth. Evaluation of the Conditional Survey Report showed that the base layer distress contributed 8% of the total TR33/5 road pavement distress (refer to Chapter 5, Table 4 to see a summary of Conditional Survey Report).

Padro (2014) evokes that base layer deteriorations are the result of crocodile or fatigue cracks , and pumping of existing road is often limited to wheel paths that are accelerated by ingress of water into pavement layers and inability of road pavement to withstand traffic loading. SAPEM (2014) agrees that isolated patches of base layer distress are mostly caused by a poor drainage system and ingress of moisture to pavement layers that result in disintegration of the base layer. Figure 4 and Figure 5 show two examples of surface and base layers distress patches extracted from the Conditional Survey Report:

Figure 4: Base failures on the TR33/5 (Western Cape Government photos, 2021)

Figure 5: Base failures on the TR33/5 (Western Cape Government photos, 2021)

2.5.2 Edge defects

SAPEM (2014) advance that edge defects occur when the edge of the road starts to disintegrate as a result of traffic loading associated with poor base and shoulder material.

Evaluation of the Conditional Survey Report revealed that about 80% of the TR33/5 road edge has a shoulder drop more than 50mm as indicated in Table 4**.** A shoulder drop is caused by the erosion of shoulder material (gravel) due to rain and traffic resulting in no support or weak of the surfaced road edge. This erosion is accelerated by traffic driving on and off the shoulder of the pavement, which ultimately undermines the surface edge of the pavement (SAPEM, 2014). Figure 6 is a photograph extracted from the Conditional Survey Report that shows 50mm gravel shoulder drop:

Figure 6: Shoulder drop more than 50mm (Western Cape Government photos, 2021)

2.5.3 Potholes

Arrive Alive (2019) define potholes as a localised weakness, or a depression on a section of the road surface which is accelerated into pavement distress (pieces of the pavement broken off) by high rainfall and traffic. Other causes may be the inadequate thickness of the surface layer for intended traffic, porous surface and poor drainage.

The Conditional Survey Report noted that potholes account for 16% of the surface and edge distresses on the TR33/5 (see Table 4). According to SAPEM (2014), potholes commence on the surface through ravelling of the asphalt or the seal surface layer. Figure 7 and Figure 8 present two photograph extracted from a Conditional Survey Report that show two typical surface distresses on the TR33/5.

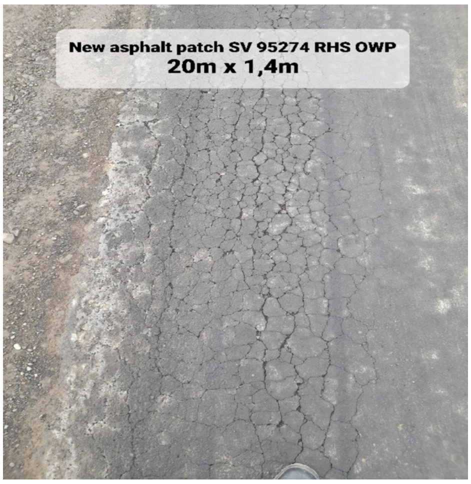


Figure 7: TR33/5 crocodile cracks failure without disintegration (Western Cape Government photos, 2021)

Figure 8: TR33/5 crocodile cracks with disintegration (Western Cape Government photos, 2021)

2.5.4 Crocodile cracks

Padro (2014) elucidates that crocodile cracks are a type of road pavement distress that appears as interconnecting cracks due to surface layer fatigue failure. In Chapter 1, crocodile cracks were highlighted in Section 1.2 as a type of distress, in addition to others; however, upon evaluation of the Conditional Survey Report, it was noted that the crocodile cracks on the TR33/5 could also be categorised as road deformation distress depending on the level of deformation outlined in the Conditional Survey Report.

2.5.5 Road Rut

Arrive Alive (2019) revokes that a road rut is a depression along the wheel path on a road pavement which might be caused by permanent deformation in granular layers and the surface layer due to traffic loading. Padro (2014) conducted a study to investigate the material layer thickness on road pavement distress, specifically on road rutting resistance and fatigue using layered viscoelastic pavement analysis software, and observed that an increase in the base layer thickness can reduce pavement distress. However, the level of performance improvement depends on the type of material sourced.

Evaluation on the Conditional Survey Report shows that road rut distress accounts for 12% of road pavement distresses shown in Table 4. According to Padro (2014), rutting occurs along the wheel path as the road changes profile under loading, resulting in deformation. Rutting is mainly caused by both compaction and shear deformation under traffic wheel paths. Rutting in a bituminous surface can be accompanied by small crocodile cracking (SAPEM, 2014). Rutting is measured with a 2 metre straight edge on the wheel path to check maximum deviation of the road profile. Figure 9 and Figure 10 present two photographs extracted from a Conditional Survey Report showing two typical road pavement on the TR33/5.

Figure 9: Road rut distress on the TR33/5 road (Western Cape Government photos, 2021)

Figure 10: Road rut distress on the TR33/5 road (Western Cape Government photos, 2021)

2.5.6 Raveling distress

This occurs when the bond between the bitumen and the aggregates (stones) lack stability resulting in disintegration of the road pavement (SAPEM, 2014). During the evaluation of the Conditional Survey Report in this study, like crocodile cracks, raveling with deformation were classified as either road deformation or road rut distress depending on the level of severity and are evaluated as such.

2.5.7 Longitudinal cracks

Padro (2014) refers to longitudinal cracks as distresses occurring parallel to the centre line of the road pavement as a result of tension stress on the road pavement surface under traffic loading. Like crocodile cracks and raveling described above, longitudinal cracks are classified in the Conditional Survey Report as road deformation or road rut distress depending on the level of severity and are evaluated as such in this research study.

2.5.8 Surface texture distresses

Surface texture distress is caused by aged bitumen binder that loses adhesion and results in the raveling of existing aggregates due to traffic (SAPEM, 2014). Surface texture distress accounts for 65% of existing road damage as evaluated in the Conditional Survey Report shown in Table 4. The aggregate loss can result in exposing the underlying layer, which might result in cracks and later develop into potholes (Padro, 2018). Figure 11 and Figure 12 show two photographs extracted from a Conditional Survey showing typical aggregate loss and bleeding on the TR33/5:

Figure 11: Aggregate loss on the TR33/5 (Western Cape Government photos, 2021)

Figure 12: Aggregate loss resulting to bleeding TR33/5 (Western Cape Government photos, 2021)

2.5.9 Asphalt pavement distress summary

Table 2 below illustrates a summary of different types of asphalt pavement distress, highlighting possible associated causes with proposed remedial actions.

Table 2: Asphalt pavement distress and possible remedial actions (SAPEM, 2014)

Asphalt pavement name	**Description**	**Cause(s)**	**Consequence(s)**	**Remedial action**	**Presence in TR33/5 (Yes/No)**
Cracking	This includes crocodile cracking, thermal and surface edge	Results from surface fatigue caused by traffic loads, temperature changes, causing ageing and poor drainage etc	If not attended leads to potholes, surface patch, and base patch.	Cracking sealing, asphalt patching and improvement of existing drainage	Yes
Potholes	Pot-shaped distress in a road surface	Mainly results from other distresses like cracking, raveling, where moisture enters the road pavement, causing it to dislodge	Leads to surface distress and major base distress that can cause damage to the vehicles	Removal of distressed material and repair it as a patch	Yes
Rutting/ Deformation	Depression along the road wheel track exceeding 10mm when measured with a straight edge	Often results from repetitive traffic loads on a poorly compacted road, with insufficient pavement thickness and excessive binder	This results in hydroplaning, endangering motorists	Coarse slurry, mill and patch, address subgrade issues	Yes
Raveling	Loose aggregates on the road surface	This occurs when the surface is placed during cold weather, resulting in poor compaction. Accelerated by water and traffic, it can be a result of contaminated aggregates	Loss of skid resistance	Fine-medium slurry, fog spray and ensuring the surface is placed at the correct temperatures and receives good compaction	Yes
Bleeding	Black, shiny, sticky film of excess binder	Results from excess binder on the surface, high temperatures and more fines than required	Loss of skid resistance	Microsurfacing or mill and inlay	Yes

2.6 Introduction of infrared road repair for optimisation of road distresses

The researcher deduces that due to the age of the road, minor cracks started developing, which resulted in surface failure (potholes) and due to ingress of water, later developed into base failures. Kaare et al.,(2012) state that a traditional method is currently utilised to repair surface failure (potholes), but it does not have long durability, especially with the current traffic on the road.

According to SAPEM (2014), the traditional method to repair distress is a relatively simple process but several challenges often occur that result in resurfacing of a distress days, weeks or months after it has been repaired. This is results of the following:

- Utilisation of cold material which is not at optimal temperature is inefficient and results in wastage,
- Porous edging of the patch prone to unravelling,
- Lower durability due to high and speedy volume traffic,
- The cold mix does not bond strongly enough, making it porous and prone to disintegrate in harsh weather,
- Requires continuous maintenance once repaired.

According to the Researcher (2025), there's another method called an infrared asphalt repair method, which uses heat to soften the surface before patching it. This includes cleaning the distressed area of debris and water, heating the distress with an infrared heater for about 5 to 10 minutes, raking the heated surface to remove any loose aggregates, adding rejuvenator to renew lost bitumen properties due to old age, adding new asphalt and mixing it, and compacting the area with a vibratory roller.

The use of an infrared repair method is quick and does not disrupt the traffic for long durations; heavy equipment like jackhammers and saw cutting is not required; compacting at warm temperatures makes it more durable in harsh weather; and it has a longer lifespan than the traditional method. The infrared repair method has lower labour costs and saves on material, as it reuses some of the old asphalt and focuses on the distress. After the use of the infrared repair method, a full reseal of the existing road is required due to the age of the road.

2.7 Consequences of poor quality roads

Road pavement deterioration can lead to serious road accidents, as reported by Haslam (2023). Vehicles entering a poor road condition section face multiple safety hazards that can result in serious accidents. These hazardous scenarios include instances where a vehicle swerves into oncoming traffic after driving on a road pavement defect. Alternatively, a hazardous scenario could also include situations where a vehicle swerves toward pedestrians, cyclists, or obstacles in an attempt to avoid road distress. This could potentially cause a tyre burst resulting from sharp edges of potholes or other defects. Further examples include instances where vehicle drivers make sudden stops after noticing hazardous potholes, or vehicle components malfunction following pothole impacts. These mentioned scenarios highlight the significant safety risks associated with deteriorated road conditions.

The distresses in these types of failures result in pavement roughness, which is the deviation from the intended road longitudinal profile. According to Mkwata and Chong (2022), pavement roughness results in inadequate skid resistance of the surface layer, thus causing a longer break distance and a high chance of following vehicle hits leading vehicle.

2.8 Chapter Summary

This chapter commenced by providing the reader with an understanding of road pavement profile, before defining different types of road pavement distresses. In addition to this, Chapter 2 also initiated the data analysis process by evaluating the Conditional Survey Report to gain an in-depth understanding of the research problem and to have an informed approach in solving the problem. The chapter concluded with a discussion on the consequences of poor road quality.

The next chapter will go into detail of the engineering management tools (or risk management tools) that can be used to solve the problems arising.

CHAPTER THREE: LITERATURE REVIEW (RISK MANAGEMENT AND QUALITY TOOLS FOR ASPHALT PAVEMENT)

3.1 Chapter introduction

This chapter provides the reader with a background on risk management, before it presents a discussion on tools used for risk management and quality management. The chapter evaluates the most suitable tools to address the research objectives of the study.

3.2 A background on risk management

A definition advanced by Gibson (2023) for the word 'risk' is the probability that an event will occur resulting in either a project schedule or resources being affected, or product quality and performance being affected. The researcher claims that eventually the risk could ultimately affect the business or organisation that produces or renders the product or service. With reference to the management of such risks, Wilson (2021) outlines 'risk management' as the process of identifying, analysing and reducing threats, especially to organisational earnings, employees and profits. Schwartz (2025) shares the same view, and also describes 'risk management' as the management of a positive or negative impact on a project or organisation caused by the occurrence of an event.

Boothe (2023) adds that, in addition to Schwartz (2025) assertion above, the organisation should focus on both risk identification and the impact. Ultimately, he opines that organisations must also consider additional mitigation strategies such as Acceptance, Avoidance, Control and Transfer. According to Boothe (2023) 'Acceptance' means being aware of the risk's existence and possible consequence without organising mitigation measures. 'Avoidance' means avoiding an event due to potentially unfavourable results. 'Control', on the other hand, means accepting the risk and putting the necessary measures to mitigate the risk impact. Finally, 'Transfer' means sharing with others through insurance or warranty. Comparing the views of Wilson (2021), Schwartz (2025) and Boothe (2023), a merger of the approaches suggested by Schwartz (2025) and Boothe (2023) is considered to be the most appropriate to meet the objectives of this research study. This method is applied when analysing and reviewing data analysis.

The broad evaluation of literature around risk management highlights that there are several risk management standards that can be applied in solving an engineering management problem. Professional Evaluation and Certification Board (2023) elucidates an ISO/IEC 27005 (2022) risk management standard that addresses a specific special framework to security risks information. Quality Management Certification (2023) argues a different risk-based standard, namely that ISO 45001 (2018) provides specific risks management guidance related to employees' well-being. Notably, ISO 45001 mainly focuses on health and occupational safety. Significantly however, Boothe (2023) advanced that ISO 31000 (2018) is a general risk management standard that can be utilised to address risk in all disciplines. Thus, the utilisation of the IS0 31000 (2018) standard is regarded to be adequate due to the nature of this study. It the only risk management standard that addresses the general process of all types of risks management (Boothe, 2023).

The ISO 31000 (2018) standard was developed by approximately 25 grouped countries led by an Australian chairman and Japanese secretariat. The standard was issued officially in 2009 by the International Standards Organisation (ISO), with the intent of acting as a risk management guideline for design, implementation and maintenance (Gjerdrum, 2016). ISO created a committee in 2011 to engage in implementation of ISO 31000 (2018) and open a platform for individual import and improvement to the standard. In the committee meeting held in 2014, it was agreed that the ISO 31000 (2018) would be revised every fifth year and the latest published revision was done in 2018 (Gjerdrum, 2016). Boothe (2023) cautions, however, that although the ISO 31000 (2018) is a general risk management standard, advocating a general risk management approach, this international standard requires customisation for it to be fully effective.

The ISO 31000 (2018) standard outlines the importance of communication and consultation during risk assessment in an organisation. Good communication and consultation supports the understanding of the entire scope of a project, considering context and project criteria prior to risk assessment. Risk assessment as per ISO 31000 (2018) therefore entails risk identification, risk analysis focused on the likelihood of occurrence, possible consequence and computing the risk level, risk evaluation, risk treatment and monitoring and review of risk.

As mentioned earlier in this section,, a risk management process approach developed on the basis of a merger of the work of Schwartz (2025) and Boothe (2023) is most suitable. That is, an approach, aligned with the ISO 31000 (2018) standard was followed in the study. A graphic depiction of the risk management process that was applied in this research can be seen in Figure 13.

Figure 13: Risk management process (Schwartz, 2025)

Expanding on research done by Schwartz (2025), she provides definitions for each stage of the proposed risk management process as seen in Figure 13. There are five steps in the risk management process in total. They are:

- **Risk identification**: this entails the identification of any risks that may influence the road operations and system for road users.
- **Risk analysis**: this involves analysing the scope of the risk to be able to comprehend the sort of threat posed.
- **Risk evaluation**: risks are to be ranked according to the severity and then prioritised accordingly. This stage helps to develop a risk management plan of action.
- **Risk treatment**: this involves analysing the risk to determine if it can be contained or eliminated.
- **Risk monitoring**: some risks require monitoring rather than elimination and the best monitoring solutions.

Ultimately, the risk management approach that was adopted by this research study was informed from the evaluation of various literature sources focusing on asphalt pavement structure distress. The approach that was selected is considered to be the one most suitable to protect an organisation's reputation from incidents that might affect its reputation, minimise major business financial losses, and motivate a need for organisational innovation and growth. It takes into consideration external factors like the environment, and provides a structured approached for enhanced decision making (Gibson, 2023; Boothe 2023).

3.1 Risk management and quality tools

Consistent with the five steps in the risk management process advanced by Schwartz (2025), as seen in Figure 13, this study now sets out to determine research activities for each step. The research activities for each step, which ultimately constitute the design of this study, are discussed in the section below. Concurrently, literature exploring various quality management tools that could potentially be used in each of the steps is also explored in the section that follows, in order to ultimately develop the most suitable risk management approach to address the research problem.

3.2.1 Step 1: Risk identification

Risk identification involve identification of any road pavement distress risk to achieve objective 1, which is to 'Identify the different types of road pavement distresses and their severity on the road using secondary data from the Western Cape Provincial government'. Various engineering management and quality tools are discussed in the section below to meet the goal of achieving objective 1.

3.2.1.1 Gap analysis

Gap analysis is an engineering management technique used to compare the estimated and the actual data performance of an activity and is normally presented graphically (Abdu, 2023). Chakravarty (2024) points out that gap analysis assists in closing five gaps, namely (1) customer expectations vs. managerial perceptions; (2) manager's expectations of quality vs. quality specifications; (3) communication with customers at point of service or sale; (4) service delivery vs. communication; and finally (5) perceived services vs. expected services. Branden (2022) reports that gap analysis was invented in the 1980s at the University of Aldo by J. Micheal Scott who successfully used the tool to assess endangered birds in Hawaii, which ultimately prevented the extinction of some species of birds and also led to the development of Hakaiau Forest National Wildlife Refuge.

Chakravarty (2024) elucidates that gap analysis can assist with the prioritisation of an organisation's needs by identifying any shortcoming within an activity at the organisation and then developing a way to address and mitigate the challenges. Furthermore, if properly done, gap analysis provides the user with a comprehensive overview of organisational operations such as distribution, accounting, sales, quality, life span, etc. This allows organisational stakeholders to ensure that organisational missions, goals and objectives are achieved. Chakravarty (2024) believes that this tool acts as a baseline of judgement about where you are and where you going thus adding value to an organisation. Moreover, Branden (2022) states that the implementation of gap analysis leads to enhanced organisational reputation, higher profits, more customer product satisfaction, and improved quality assurance, advanced technical skills, employee satisfaction and successful projects.

Therefore, it is deduced that gap analysis is suitable for application in the study as a quality assurance technique measuring the performance based on the estimated and actual data.

3.2.3 Step 2: Risk analysis

The risk analysis step in this study is aligned to meeting objective 2. Schwartz (2025) revokes that the ultimate aim of the risk analysis step is to assess the root cause of an event occurrence as well as the seriousness of the event and urgency required to address the event or risk (Schwartz, 2025). In the context of this study, this step should involve analysing possible causes of distress on the TR33/5. Therefore, this may be accomplished by exploring various quality tools that are designed to identify root causes, thereby meeting objective 2 which is to 'Identify causes of distresses and risk associated with the use of the risk management strategy'.

3.2.2.1 THE 5 Whys

Rodriguez (2023) suggests that a tool commonly used in industry to identify root causes is the 5 Whys. The 5 Whys tool was developed in the 1930s by a Japanese industrialist called Sakhithi Toyoda, the founder of Toyota Industries, and became popular in 1970s. Toyota is still utilising this quality tool to date to solve engineering-driven industrial challenges (Ahmedani, 2020). The success of Toyota as a high quality manufacturing company has made the 5 Whys tool adopted by companies worldwide (Lawless, 2024).

The 5 Whys is a technique used to identify and explore the actual root cause and effect of a problem like road distresses (Rodriguez, 2023). Ahmedani (2020) points out that this is achieve by asking the question 'Why' five times to establish the possibly sufficient root cause of a particular problem as it also contributes to understanding of a systematic failure that can help to develop sustainable correction actions.

Lawless (2024) elucidates that the 5 Why is a technique that does not require statistical analysis nor sophisticated methods, but its simplicity promotes deep thinking by uncovering underlying shortcoming within a method that improves process and contributes to enhanced team involvement that in turn promotes ownership of problems amongst team members. It thus encourages growth and improvement in teams, problems are solved in a very cost-effective way by preventing recurrence of problems, and it is a fast and efficient method allowing rapid development and implementation of solutions. It promotes understanding of process, systems or activity, improving insight and enabling identification of root cause of a problem, which allows facilitation of preventative measures. Upon evaluation of the literature above, the 5 Whys is regarded as a potentially suitable tool to use in Step 2: Risk analysis of this study.

3.2.2.2 Ishikawa diagram

Hayes (2023) suggests that another tool that can be used to identify root causes is the Ishikawa diagram. This tool and other engineering management tools were developed by Kaoru Ishikawa in the 1960s (Rodriguez,2023). Hayes (2023) avers that the Ishikawa diagram is a quality tool utilised to illustrate the causes of an event and outlines different steps in a process to demonstrate where quality problems may arise, and it determines the required resources. Ilie and Ciocoiu (2010) agree that Ishikawa diagram is used as a quality control technique to identify the cause of an event and determine the necessary resource for a specific time. The major categories of causes of the problem are methods, equipment, people, material and environment.

Hayes (2023) adds that the Ishikawa diagram is also known as the fishbone diagram, herringbone diagram or cause and effect diagram aside from being known as the Ishikawa diagram. This is because the tool resembles a fish skeleton to denote cause of event as shown in Figure 14 below:

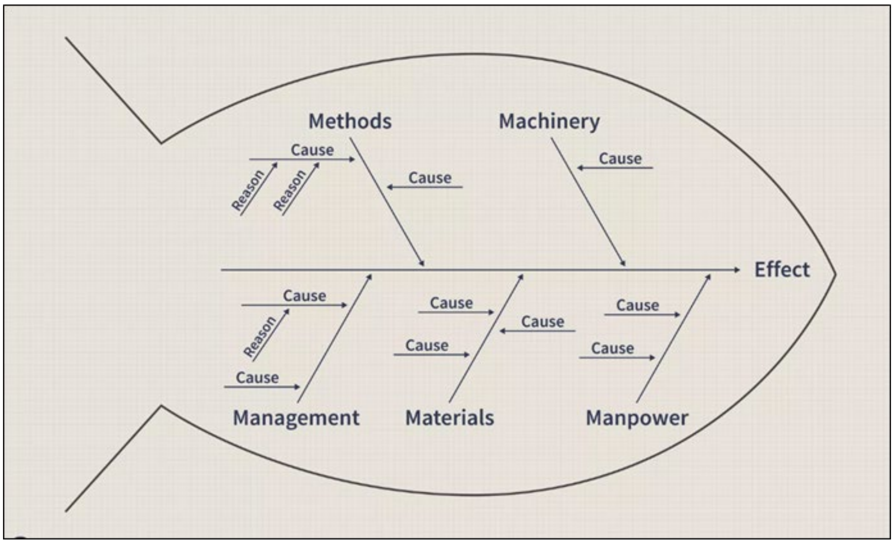


Figure 14: Ishikawa diagram (Hayes, 2023)

Hayes (2023) explains that when using the tool, the user brainstorms the major categories of problem causes as methods, machinery, management, materials, environment and people or manpower. Singh and Swartz (2024) found that the Ishikawa diagram is an adequate tool to use for root cause analysis, although it works best when used in combination with the 5 Whys. Thus, reflecting on the discussion of literature above, the Ishikawa diagram was considered to be a potentially suitable tool to use in Step 2: Risk analysis of this study.

3.2.2.3 Fault tree analysis (FTA)

A review of literature also highlighted the Fault Tree Analysis (FTA). The FTA is a type of failure analysis used to examine an undesirable state within an engineering system (Dongare, 2024). Lawless (2024) elucidated that FTA was developed in 1962 by Watson at Bell laboratories to evaluate a Minuteman Intercontinental Ballistic Missile (ICBM). The FTA mainly focuses on the safety performance of a system or process. FTA was also applied in many sectors including the aerospace, nuclear power, chemical and automotive sectors and many others. Lawless (2024) explains that the process of FTA includes creating a fault tree, identifying failure events, initiating events and contributing factors from the diagram and evaluating relationships between failure and initiating events. Significantly however, Dongare (2024) observes that the fault tree requires more time for complex engineering problems as requiring a larger tree. It is best used for small system analysis. FTA only allows one to examine one event at a time. Thus, it is deduced that while this tool is suitable for the purpose of this study, it is not the best one to use.

Evaluation of literature above, showcases the 5 Whys tool, the Ishikawa diagram and the FTA as adequate tools to use in Step 2: Risk analysis. Notwithstanding this, drawing on the views of Singh and Swartz (2024), this study however deduced that while all three tools could potentially be used. the use of the Ishikawa diagram, followed by the use of the 5 Whys tool, would provide this study with a more focused and timely approach to reach objective 2.

3.2.3 Steps 3, 4 and 5: Risk evaluation, treatment and monitoring

Steps 3, 4 and 5 of Schwartz (2025) risk management process, are risk evaluation, risk treatment and risk monitoring is aligned with objective 3 of this study, which is to 'Evaluate the process followed to meet objective 1 and objective 2 and develop and propose a new approach to the management of road distress considering quality and risk management'. In the specific context of this study, it involves considering root causes of road distress and aligning them with their risk priority. Thereafter one needs to determine if risk can be eliminated or managed and to consider actions to monitor the managed risk to reduce any negative impact to the organisation. This literature study thus now progresses to an evaluation of engineering management and a quality tool which may be suitable for application in this research study.

3.2.3.1 Failure Mode and Effects Analysis

Huber (2024) claims that the Failure Mode and Effects Analysis (FMEA) was developed by the American military in the 1940s to mitigate the root cause of munition malfunction. It was later adopted by the National Aeronautics and Space Administration for Apollo missions, and the Ford Motor Company used it to resolve safety and public relations issues (Huber, 2024). Rameriz (2023) explains FMEA as a powerful risk management tool to prevent challenges before they arise and develop sound solutions. Forrest (2025) points out that FMEA is the best and easiest way to analyse potential problem in the early development cycle of a product, allowing quicker measures for mitigation action.

Based on the descriptions of Ramirez (2023) and Forrest (2025) of how the FMEA may be used, this study deduced that the results of the 5 Whys analysis could serve as the input for the start of an FMEA. This might be done if qualitative data collected during the 5 Whys was converted to quantitative data for FMEA tool use. A triangulation of the research done by Huber, (2024), Ramirez (2023) and Forrest (2025), and drawing on the work of (Forrest, 2025), the failure mode identified by a 5 Whys analysis could be rated on occurrence probability on a scale of 1 to 10, where 1 represented a very low probability and 10 a very high probability. Each mode of failure was assigned to severity and detection ranking on scale of 1 to 10. The qualitative was thus changed to numbers. After the ranking and rating, the Risk Priority Number (RPN) was calculated as a multiplication of severity x occurrence and x detection.

Notably, Horvath (2025) explains that FMEA can be applied when designing a new process, thinking about improving an existing process performance, concerned with quality improvement within a process and when trying to get an understanding of process failure. Against this backdrop, one can surmise that FMEA is a tool that assists an organisation in multiple options of mitigation or elimination of risk and assists in lowering risk impact project costs. Ramirez (2023) concedes that FMEA assists in improving an organisation's methodical process by identifying design and process failure modes, promotes improvement of process safety, quality and reliability, and increases customer satisfaction.

The literature in this section above highlights the relevance of the FMEA within the context of this research. In other words, the FMEA may be used on road pavement distress problems, as it provides a systematic proactive method for identifying where and how a process might fail, and assesses the relative effect of different failures to enable development of an effective solution to the failure/s. Thus, it was chosen in this research project under process quality improvement as an aid to developing a road pavement distress management approach.

3.3. Chapter summary

This chapter provided the reader with a background on risk management and outlined an approach based on Schwartz (2025) that could be used to meet the intended research objectives. Thereafter the reader was introduced to the reviewing of potential engineering management and quality tool in order to make a selection of the most appropriate tools for this study.

The next chapter presents the research design and methodology.

CHAPTER FOUR: RESEARCH DESIGN AND METHODOLOGY

4.1 Chapter introduction

Chapter Four offers the reader the orientation of the research design including a diagrammatic overview of the research study, before discussing research philosophies and worldviews. It considers the objectives in Chapter 1 and literature review in Chapter 2 and 3 to develop a three-part research instrument to meet the three research objectives discussed under research design. This chapter also considers data collection and analysis methods. It discusses the pilot study and then outlines validity and ethical considerations.

4.2 Research orientation

Sreekumar (2023) clarifies that research design and methodology are two concepts that require clarification as confusion arises for emerging researchers. The concept of research design and methodology is presented below under research philosophies and worldviews but it is appropriate first to illustrate the research process of this study as shown in Figure 15 below. The research process of this study is adopted from Collis and Hussey (2003) as explained in Chapter 1, and comprises six fundamentals, which are: identification of the research topic, definition of the research problem, determination of how the research will be conducted, collection of data, and analysis and interpretation of the research data. These processes are utilised to identity the road pavement deterioration problem with the focus area being the TR33/5 road between Beaufort West and Klaastroom.

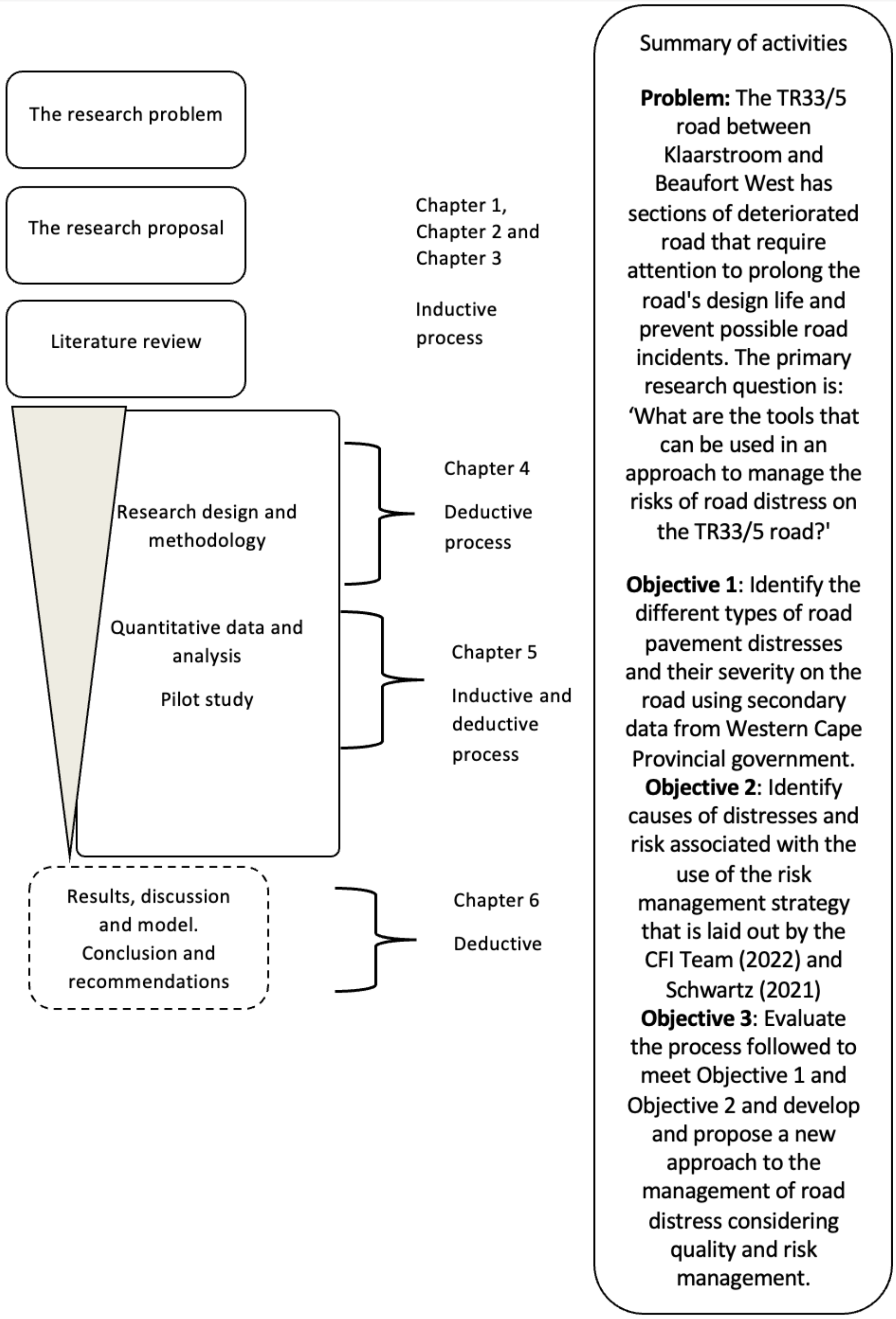


Figure 15: The research process (Researcher, 2025)

Figure 15 shows that Chapter 1 to 3 is inductive (as they introduce the reader to new information) and Chapter 4 and 6 are deductive (they reach conclusions based on previous information). Chapter 5 is both inductive and deductive. During empirical phases secondary data (weather data and photograph data, the Test Pit Investigation Reports, Traffic Data Reports, Condition Survey Reports) were collected from Western Cape Provincial Government which contained both first empirical and secondary empirical phase data. The research philosophy is thus presented below to better understand the research and how it can be used to close the gap the in theory of management approach to road pavement distress.

4.3 Research philosophies and worldviews

Research is a method used to investigate a topic to discover or add new information to the existing body of knowledge (Sreekumar, 2023; Collis and Hussey 2003) and is used for problem solving. The objective of this research is to add knowledge and empower improvements to facilitate and close the gap in road pavement distress management. Al-Saraf (2025) points out that closure of gaps is essential and the methodological approach chosen in a research study must be adequate to resolve unanswered questions or unresolved problems in any field. Therefore the chosen research design and methodology play a directing role in this study. Creswell (2014) agrees that the careful selection of methodological approaches is vital and points out three central methodological approaches which are illustrated in Figure 16 below, namely qualitative, quantitative and mixed methods approaches.

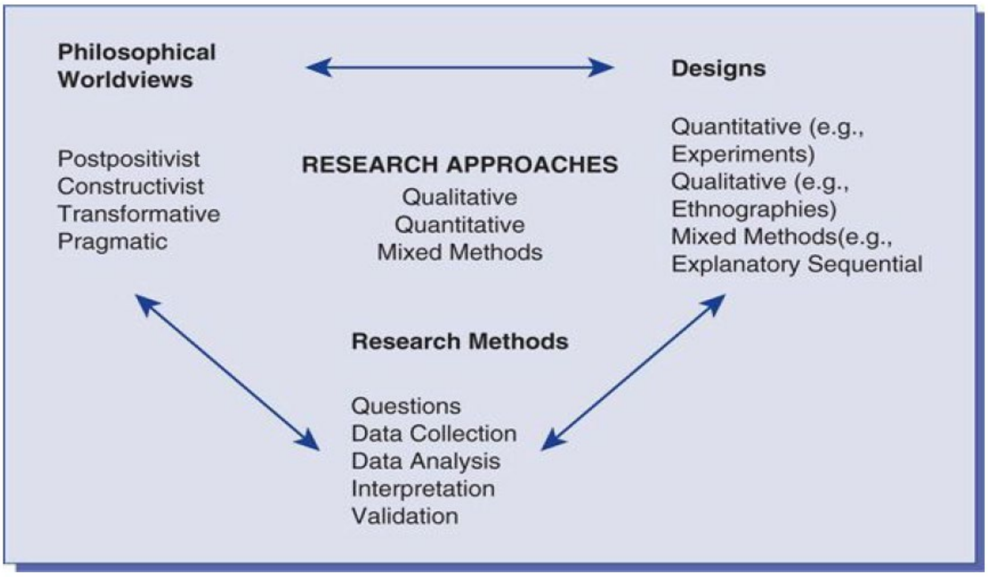


Figure 16: A framework for research – The interconnection of worldviews, design and research methods (Creswell, 2014)

Creswell's (2014) research framework above elucidates three research approaches, namely qualitative, quantitative and mixed methods. These are explained below and a conclusion is drawn on the approach that was followed in this study. Explaining the philosophical worldviews first will be of most importance as contributors in choosing research approaches.

Cresswell (2014) explains that the philosophical idea referred to as a ‘worldview’, also known as a paradigm, is a guideline to action based on the set of basic beliefs held by the researcher. The worldviews are sometimes presented as scientific methods or science research. The philosophical worldviews as presented by Creswell (2014) are post-positivist, constructivist, transformative and pragmatic.

Kivunja and Kuyini (2017) points out that positivists believe that the truth about research subjects are present in the world to be discovered by research, and comprehensive universal theory can be attained to assess human and social behaviour; however, the research needs to follow scientific methods of investigation in all its spheres. Cresswell (2014) elucidates positivism as a method that seeks to overcome researcher bias by including quantitative data in order to ensure validity and reliability of research evidence applied in both social and physical science.

The constructivist worldview is an approach used for qualitative research as it supports the assumption of the validity of individual experience in the historical or social world. Researchers tend to attend social gatherings to source knowledge and truth that are partial. Constructivists rely mainly on participants' view of a situation to solve a research problem and that causes limitations associated with reductionism. The gathering of data from a field makes it largely inductive (Cresswell, 2014).

The transformative worldview is an approach that considers the significance of social and empowering change with regard to marginalised groups through knowledge transfer and research. It encourages collaboration with participants and ensures that insight is obtained in the research process and outcome (Kivunja and Kuyini, 2017).

The pragmatic worldview is a perspective that emphasises practicality, utility and real life applications. It is less concerned with individual beliefs but seeks to solve real life problems and derive practical solutions (El Geddawy and Abouraia, 2014).

4.4 Types of research designs

There are there commonly used research designs, namely qualitative, quantitative, and mixed method research designs that are discussed in the section below:

4.4.1 Qualitative research design

Vasileiou, Barnett, Thorpe and Young (2018) refer to qualitative research as a method of collecting purposeful samples that are selected by virtue of their capacity to help with relevant detailed information about the phenomenon under investigation. It is information that cannot be easily expressed in numerical terms, and can be in the form of pictures, concept maps, infographics, etc. (Vasileiou et al., 2018). Elliott (2020) aligns with Vasileiou et al. (2018) and argues that qualitative research is represented by peoples' opinions and cannot be represented by numerical values such as standard deviations.

4.4.2 Quantitative research design

Sreekumar (2023) and Elliot (2020) refers to quantitative research as a question and answer of 'what', 'how many' and 'how often'. The quantitative research approach deals with data that require the use of calculation, algorithms or statistical analysis. Quantitative data provides insights to various phenomena by systematic strategies and observations. Quantitative data research represents data that can be measured or quantified.

4.4.3 Mixed methods research design

Mixed methods research is an approach that combines the both qualitative and quantitative research. The research data contains both approaches because the strength of this approach is greater than qualitative or quantitative research alone (Creswell, 2014; Sreekumar, 2023). According to Bazeley (2018), the mixed research approach enriches the understanding of a situation through confirmation of conclusions, extension of knowledge or the initiation of new ways of thinking about a subject of research.

4.4.4 Research design selected for this study

To comprehensively examine the South African road pavement industry or transportation and thereafter develop an approach for the management of road pavement distresses present on the TR33/5 road between Klaarstroom and Beaufort West, neither a post-positive nor constructivist worldview approach would work as a standalone approach. This study therefore adopted a mixed methods research design with associated pragmatic features. Pragmatism is an approach that is not a one-sided philosophy, but applies to quantitative data, and researchers used both qualitative and quantitative assumptions to solve a research problem (Creswell, 2014).

Mixed methods research maximises the strength of each data type by using diverse methods combining inductive and deductive thinking, thus increasing the validity or trustworthiness of the research. Mixed methods also increase the ability to address a research question in broad terms, thereby leading to limitation or mitigation of any risk associated with people. Mixed methods create robust descriptions and interpretation of data by balancing the limitations of both quantitative and qualitative research (Bazely, 2018).

The purposeful adoption of mixed methods must be very clear. Plano et al., (2008) identify four major models of mixed methods research designs, each with a different design as illustrated in Figure 17 below.

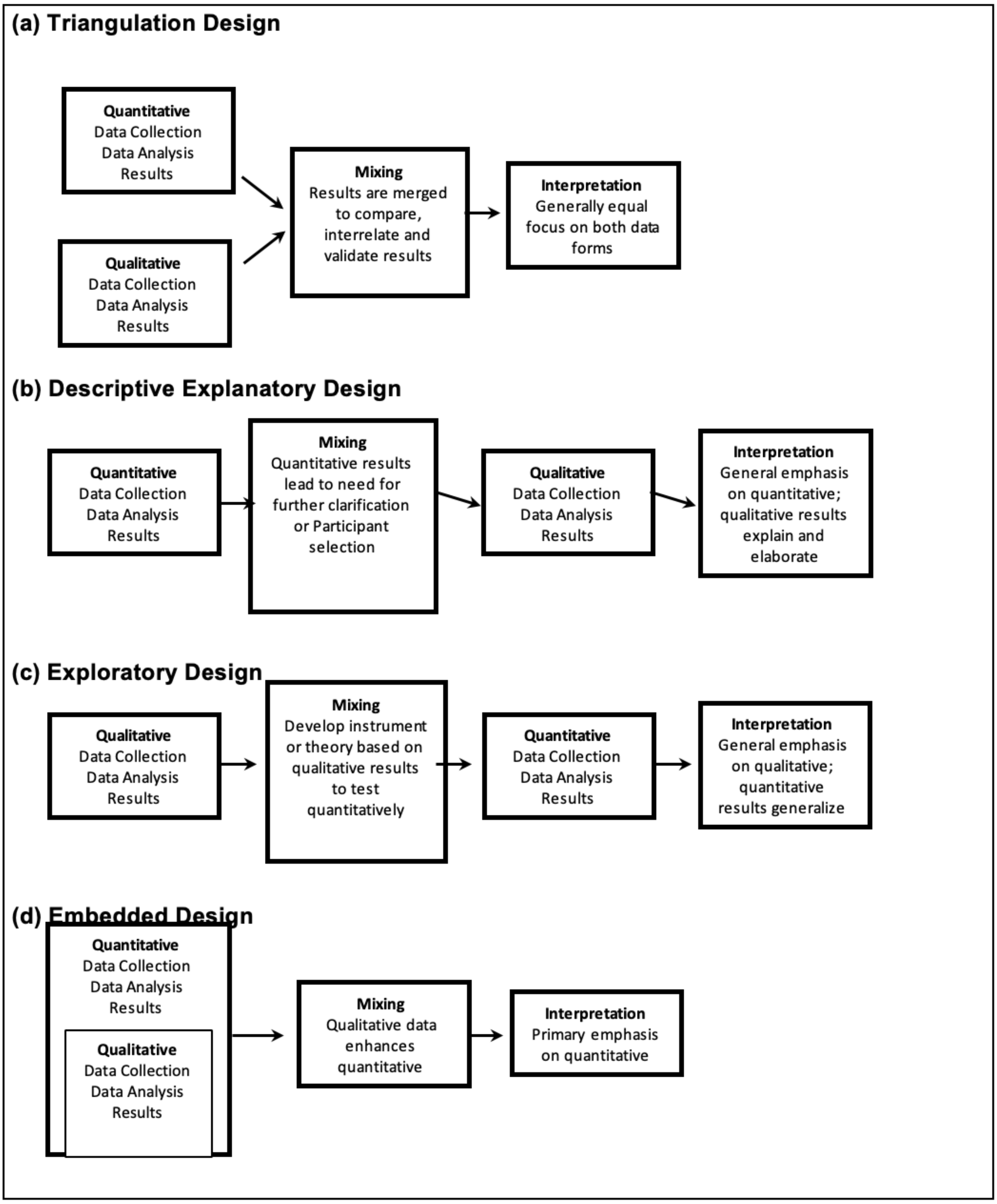


Figure 17: Four models of mixed method research design (Adapted from Plano at el., 2008)

Referencing from Figure 17 above, this study can be referred to as a triangulation design as the research will focus on analysis and combining of both quantitative and qualitative data, and results will be drawn from combined interpretations of data. Therefore this study is a triangulation design mixed method study that used secondary data obtained from the Western Cape Provincial Government to reach its ultimate goal, which is to develop an approach in the management of road pavement distress on the TR33/5 road. The collected data for this study research is photographs of the site and Material Investigation, Traffic Count and Historical Weather Reports, which is a combination of quantitative and qualitative information that were analysed using engineering management tools to be explained further in this chapter. Sileyew (2019) concludes that research design assists in providing an appropriate framework of a study.

4.5 Data collection in this study

As discussed in Chapter 1, the research study employed a non-probability sampling method which is purposive sampling, for which the researcher used his knowledge based on consultation of various studies to understand the research question and focus on specialised data documents (Nikolopoulou, 2022). The purposive sampling was applied in the research due to the limited number of resources for data, and as it is commonly used for qualitative research with the mixed methods technique. All data was obtained from Western Cape Government with a description of each data source that is provided below.

4.5.1 Population and sample information

The population of this study includes all the electronic documents that belong to Western Cape Government containing data collected from 2020 to 2021 on the TR33/5 road. As all the records for this period (2020 - 2021) were used, the sampling technique of this study is a non-statical sampling technique (Nikolopoulou, 2022).

4.5.2 Qualitative data collection

Qualitative data used for this study was obtained from the reports listed below:

- Photographs in a Conditional Survey Report

Qualitative data such as photographs have been changed or converted into quantitative data represented in a Test Pit investigation for soil properties and conditional survey.

4.5.3 Quantitative data collection

The quantitative (numerical) data was obtained in the following reports:

- Weather data
- Material Investigation Report,
- Traffic Count Data Report

4.5.4 Data analysis

The analysis of the data was conducted using the engineering management tool listed in Table 3 below, in conjunction with the adopted risk management approach from Schwartz (2025) that is in accordance with the ISO 31000 standard as explained in Chapter 2.

Table 3: Risk steps linked to engineering management tools

Steps	Description	Type of Data	Engineering Management Tool (Sub-Steps)
1	Identify the risk	Qualitative data in the Conditional Survey Report converted to quantitative data	Sub step 1.1: Thematic/Pie chart analysis and Sub-step 1.2: Gap analysis
2	Risk analysis	Quantitative data in the Traffic Count Data Report changed to qualitative data	Sub-step 2.1: Ishikawa diagram Sub-step 2.2: The 5 Whys analysis
3	Evaluate the risk	Qualitative data obtained in Step 2 is analysed to provide quantitative data	Failure Mode Effects and Analysis (FMEA)
4	Treat the risk	Qualitative data obtained in Step 2 is analysed to provide quantitative data	Results of FMEA
5	Monitor and review the risk	Qualitative data	FMEA

4.5.4.1 Quantitative data analysis

Step 1 consists of two sub-steps of quantitative data analysis, namely Sub-step 1.1 Thematic analysis (a pie chart) and Sub-step 1.2 Gap analysis. These will be explained in the sections that follow.

4.5.4.1(a) Step 1 Risk identification

- Sub-step 1.1 Thematic analysis

Thematic analysis is a qualitative analysis technique that focuses on identifying, analysing and interpretation of patterns or recurring themes within a research study (Jansen, 2021). Thematic analysis is applied by looking at site pictures, comments and textual data to detect common problems (Clarke and Braun, 2014). Thematic analysis was favoured in this research as used for analysis of secondary field observations and secondary visual methods or observations. Mainly pictures were used to determine the various types of distresses with their severity.

- Sub-step 1.2 Gap analysis

Gap analysis was used in this study to compare the current performance with designed or expected performance. Gap analysis compares the estimated and actual data that is presented graphically (Abdu, 2023). The gap analysis was applied to the accumulated traffic growth data annually with the Actual Annual Average Daily Traffic (AADT) that was presented graphically. Therefore, the gap analysis approach was used to measure the actual compared to the estimated traffic growth with road performance in this research study.

4.5.4.1(b) Qualitative data analysis

Step 2 is risk analysis which includes Sub-step 2.1 Ishikawa diagram, and Sub-step 2.2 5 the Whys analysis. These are explained in the section that follows:

4.5.4.1 (c) Step 2 Risk analysis

Risk analysis assesses the root cause of an event occurrence, seriousness and urgency of each risk. As aforementioned in Chapter 3, the analysis of the scope laid out of TR33/5 with associated possible causes was accomplished using 5 Whys and the Ishikawa diagram to reach objective 2, which was to 'identify causes of distresses and risk associated with the use of the risk management strategy that is laid out by the CFI Team (2022) and Schwartz (2025).'

- Sub-step 2.1 Ishikawa diagram

For qualitative data, Ishikawa is a cause and effect diagram for specific events or processes. This helps in identifying possible causes of a problem and brainstorming possible solutions (Forrest, 2025) and will be was applied in this study

- Sub-step 2.2 5 Whys

5 Whys is a root cause analysis technique that contributes to the understanding of a systematic failure that can help to develop sustainable correction actions (Ahmedani, 2020). 5 Whys was used in this study as it is easy and flexible to implement in problem solving and can be used with other problem solving methods, such as the Ishikawa diagram that was implemented in the study.

4.5.4.2 Quantitative data analysis

There are three steps (Step 3, 4 and 5) of quantitative data analysis with the utilisation of FMEA for risk evaluation, treatment and motoring. These will be explained in the sections that follow:

4.5.4.2.1 Step 3, 4 and 5 Risk evaluation, treatment and monitoring

Risk evaluation, treatment and monitoring consider root causes of road distress and aligning them with their risk priority, determining if risk can be eliminated or managed and considering actions of monitoring managed risk to reduce any negative impact to an organisation. This was actioned to achieve objective 3 which was to 'Evaluate the process followed to meet Objective 1 and Objective 2 and develop and propose a new approach to the management of road distress considering quality and risk management'.

- Failure Mode Effects and Analysis (FMEA)

FMEA is used on road pavement distress risk as a systematic proactive method for identifying where and how a process might fail, and assessing the relative effect of different failures to produce an effective solution to the failure (Forrest, 2025).

Step 3 dealt with inputting data on the FMEA based on the severity, occurrence and detection. The results of the FMEA-based calculation of risk priority number was addressed in Step 4 and Step 5 to revisit the overall judgment of the FMEA results and address any recommendations.

4.5 The pilot study

The pilot or 'feasibility' study is described by Yin (2014) as a small scale preliminary study to reveal risks, mistakes or flaws in the design of the research instrument. Cooper and Schindler (2014) agree, adding that the purpose is to highlight unknown factors or overlooked assumptions that might potentially have a negative impact on the study and then to improve the research instrument design prior to deployment in a full-scale main study.

A pilot study of this desk top research was conducted in February 2024 to collect quantitative and qualitative data as part of the pilot study. The research instrument was tested by using City of Cape Town data for Jakes Gerwel Drive carriageway Northbound from Bluegum Street to Viking Way. Climate data was provided by Molteno Reservoir Station (Station number 0020746A0, Latitude: 33 56'13"S, Longitude: 18 24' 36" E, Height: 93) recorded from 2001 to 2014. The material report provides three Material Investigation Test Pit Reports and visual assessment of pictures of the road to determine the effectiveness of the research design. After conducting the pilot study, results indicated that the research instrument was appropriate for this research study, and no amendments were required for the main study.

4.6 Validity, reliability and ethical considerations

Validity, reliability and due ethical considerations are widely regarded as cornerstones of good scientific research (Dobakhti, 2019). The following section is an outline of the validity, reliability and ethical considerations of this study.

4.6.1 Validity and reliability

The concepts of 'validity' and 'reliability' of research data are concerned with the prevention of error in the data. Dobakhti (2019) points out that the 'correctness' of one method or both methods in a mixed research design does not render the research valid or invalid since all methods produce results that are valid under certain circumstances and invalid under other circumstances. Validity and reliability are thus not inherent properties pertaining to a method, but pertain to the data, the manner in which the data was collected, as well as the conclusion reached by using that method in a particular context for a particular purpose. This foregrounds the necessity of adequately ensuring the quality of results in the applied mixed method study. Duly, each part of this study design, as well as the interface of the two methods, was assessed in terms of validity and reliability and presented in the following sections.

4.6.1.1 Validity and reliability of the quantitative study

This study notes that a purposive sample ensures validity in the study design by use of secondary documents that were reviewed and approved by professional engineers and industry specialists, which allows a researcher to draw the most accurate and thorough conclusions. The targeted population ensured that the collected data was rich and relevant to the projected objectives, leading to focused findings.

Taherdoost (2016) is of the opinion that a pilot study imparts external validity on a study. Testing by means of a pilot study ensures that there is not a mismatch between research questions and the type of analysis used. External validity is also compromised if the sample is not representative of the population (Collis and Hussey 2003).

4.6.1.2 Validity and reliability of the qualitative study

To ensure validity in a qualitative study, the researcher needs to ask '*How might your results and conclusions be wrong*?' (Maxwell, 2009), and then take the necessary measures to ensure credibility of the results. With this goal in mind, the research obtained from the Western Cape Provincial Government contained laboratory results conducted by a South African laboratory accredited by the South African National Accreditation System signed by professional engineers accredited by the Engineering Council of South Africa (ECSA).

All factors were considered in terms of their potential to influence the data obtained. Finally, following data analysis, the findings of data analysis were peer-reviewed by the supervisor.

4.6.2 Ethical considerations

Ethical clearance to perform this research was obtained from Cape Peninsula University of Technology (CPUT) and the researcher ensured that CPUT's Research Ethics Policy and Guidelines were strictly adhered to as FEBE FREC 1.1 Ethical Compliance for Engineering Students.

All ethical issues, aligned with those mentioned above, were considered during each empirical phase of this study, namely in the quantitative phase and the qualitative phase of both the pilot and the main study.

4.7 Chapter summary

This chapter outlined the empirical plan that was followed by this research study. The methodological approach was discussed before the comprehensive details of the embedded mixed method research design to meet research objectives of this study. Validity, reliability and ethical considerations pertaining to the study were also discussed. The next chapter presents the qualitative and quantitative data analysis.

CHAPTER FIVE: QUALITATIVE AND QUANTITATIVE DATA ANALYSIS

5.1 Chapter introduction

This chapter presents the findings of qualitative data and quantitative data analysis. It is a demonstration of how engineering management tools may be used for data analysis, namely the gap analysis, pie chart, Ishikawa analysis, the 5 Whys analysis and FMEA.

5.2 Qualitative data analysis

Qualitative data analysis commenced in Chapter 2 with the evaluation of photographic images in the Conditional Survey Report. Notably, aside from the photographic images, the Conditional Survey Report included an estimated size of the distressed area. This data (estimated size) enabled the researcher to perform the data analysis depicted in Table 4 and Table 5. Thus, essentially, the photographic images (qualitative data) in the Conditional Survey Report were examined and by considering the estimated sizes of the area, converted into percentages as seen in Table 3 and Table 4. It is worth noting that the conditional survey was conducted in 2022.

Table 4: Summary table of data of TR33/5 pavement surface (RNIS, 2023)

Type of distress on 7.4m width surface road	**Estimated area (as per Conditional Survey)**	**Percentage (road 110 km)**	**Cumulative percentage**	**Degree of distress**
Surface distress	39 400 m²	5% of the surfaced road	5	High
Rut on the road	94 341 m²	12% of the surfaced road	17	High
Base distress (150mm)	34 641 m²	4% of the surfaced road	21	High
Base distress (75mm)	2 294 m²	1% of the surfaced road	22	High
Surface edge distress	23 552 m	11% of surfaced road	33	Medium
Deformation of bridge approaches	12 798 m²	2% of existing road	35	Medium
Road texture correction	542 838 m²	65% of existing road	100%	Medium

Table 5: Conditional survey along on the TR33/5 along gravel shoulder (RNIS, 2023)

TYPE distress on 2.5m wide gravel shoulder	Areas	Percentage (road 110 km)	Cumulative percentage	Degree of distress
Shoulder drop more than 50mm	440 000 m²	80% of gravel shoulder	80	High
Non-functional subsoil	82 500 m²	15% of part of gravel shoulder	95	High
Existing minor structures	27 500 m²	5% part of gravel shoulder	100	Low

5.3 Quantitative data analysis

As mentioned in Chapter 4, quantitative data in the form of secondary data was extracted from documents obtained from the Western Cape Government. The secondary data was data collected in the Karoo district representing the TR33/5 road between Klaarstroom and Beaufort West. The quantitative data for this study consisted of numerical weather data, numerical data generated from the analysis of the Conditional Survey Report data (seen in Table 4 and 5), test pit investigation data on soil properties, and traffic count data.

The section below presents the analysis of the quantitative data mentioned above.

5.3.1 Weather data

The climate data presented in Figure 18 below was obtained from Beaufort West weather station.

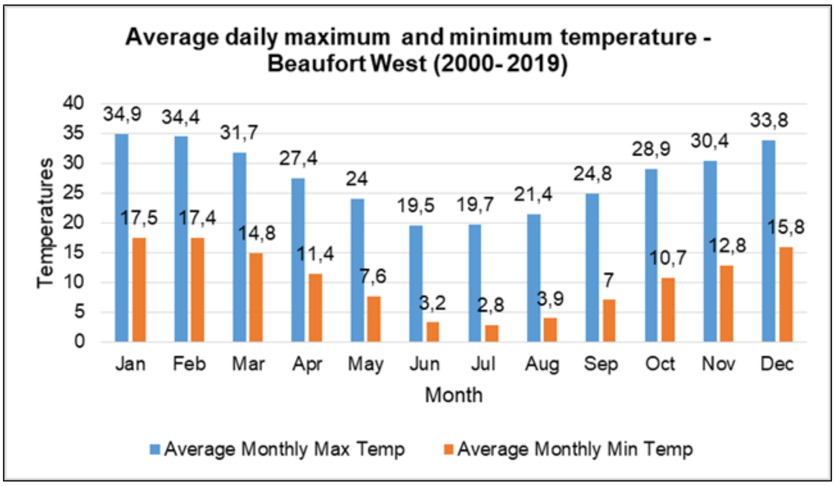


Figure 18: Average daily maximum and minimum temperature (RNIS, 2023)

Figure 18 illustrates the summary data of average monthly maximum air temperature and average monthly minimum air temperature that was further analysed using engineering management tools to find road cause for pavement distresses.

5.3.2 Conditional survey data

The conditional survey data illustrated in Table 3 and Table 4 indicate the estimated percentage of different defects on the entire roadway along with the associated degree of distress. These tables facilitate the visualisation of road distresses and aid in generating the root cause analysis of these distresses.

5.3.3 Test pit investigation for soil properties

The road pavement evaluation under this research was based on 110 km of road. Twenty-four material test investigations were conducted at different intervals along the road. All population data provided on the material investigation reports for soil properties documents were used. The data presents road pavement layer works based on material investigation data of the existing road layer works' thickness were drawn from a scaled photographic images of excavated existing road material. The data was used to analyse the root cause analysis using engineering management tools, namely the Ishikawa diagram and the 5 Whys.

The tabulated pavement layerworks data in Table 6 and Table 7 indicate existing road pavement on the TR33/5.

Table 6: Existing Road pavement – from stake value 0 to 28 and stake value 54 to 78.

Layer	Thickness	Description
Surfacing	30 mm	13.2 mm single seal, S1(13), 28 years old
Base	150 mm	G4 base
Sub-base	100mm	G5 sub-base
Selected subgrade	150 mm	G 7 Selected
Subgrade	-	G9 Subgrade

Table 7: Existing Road pavement – from stake value 28.00 to stake value 54.00 and stake value 78.00 to stake value 110.00.

Layer	Thickness	Description
Surfacing	30 mm	9.5 mm single seal, S1 (9), 28 years old
Base	150 mm	G4 base
Sub-base	100 mm	G5 selected
Selected subgrade	150 mm	G7 Selected
Subgrade	-	G9 Subgrade

5.3.4 Traffic data

Traffic data was obtained from the Western Cape Government RNIS website (2023), with the latest counts conducted in 1974/2022. The Figure 19 overleaf presents the average annual daily traffic (AADT) expected versus the actual AADT traffic. The data was therefore analysed using the gap analysis engineering management tool to draw road bearing capacity design realisation.

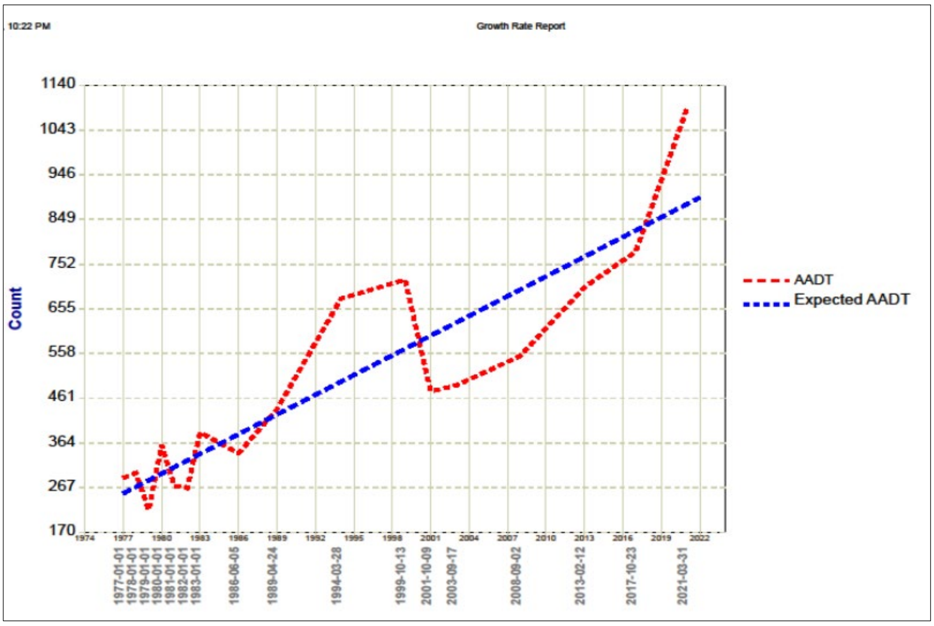


Figure 19: AADT expected versus the actual AADT traffic (RNIS, 2023)

5.4 Qualitative and quantitative data analysis based on risk management and engineering tools

A risk management approach adapted from the research of Schwartz (2025) (in compliance with the ISO 31000:2018 standard) was used in the study and is presented in the sections that follow below. The data analysis aligns to the 5 steps as described in Table 2 of Chapter 4. Step 1 was to identify the risk using thematic analysis and gap analysis. Step 2 involved risk analysis using Ishikawa and 5 Whys analysis Step 3 entailed a risk evaluation using the FMEA tool, while Step 4 was treating the risk using results from FMEA. Finally Step 5 was to monitor and review the risk using FMEA.

5.5 Step 1 - Risk identification (Qualitative data changed to quantitative)

5.5.1 Pie chart

The pie chart represents quantitative data generated from the analysis of qualitative data derived from a Condition Survey Report to assist in visualisation of the whole road pavement distress in the TR33/5 road**.** The pie chart enables summarisation of large data sets in visual form to draw attention to analysis of a high level of distress, as also illustrated in Table 3 and Table 4.

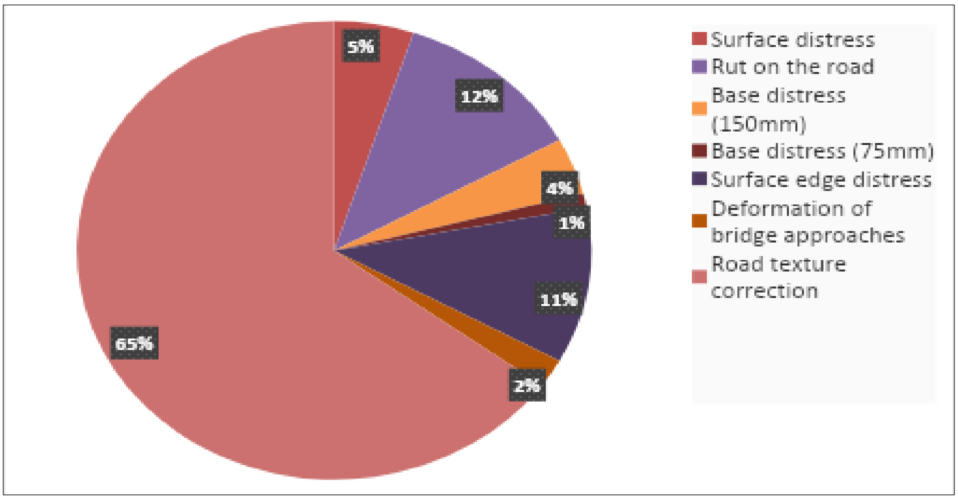


Figure 20: Road pavement distress distribution (RNIS, 2023) along TR33/5 surface road with 7.4m combined road width

Figure 20 illustrates road distress with a high level of risk/high degree of distress equating to 35%, with 65% of the road requiring texturing correction to increase the skid resistance of the road and result in good vehicle braking distances.

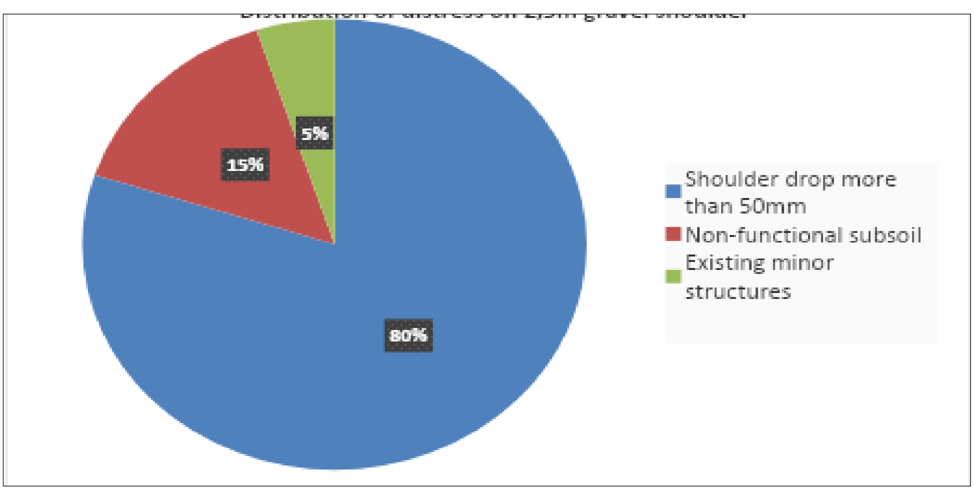


Figure 21: Distribution of distress on the TR33/5 along gravel shoulder (RNIS, 2023)

Figure 21 illustrates the distribution of distress, with 80% risk as a result of shoulder drop more than 50mm.

Based on Figure 20, emergency maintenance should be prioritised, followed by more consideration of a preventative maintenance approach to ensure a method with longer duration under traffic. However based on the survey data, full rehabilitation of the road to ensure the safety of motorists should be prioritised after emergency maintenance. Based on Figure 21 reinstatement of the road shoulder to existing road level is required to ensure safety of motorists.

5.5.2 Gap analysis

In this study, gap analysis was used to compare the estimated and actual data presented graphically, specifically the accumulated traffic growth data annually with the Actual Annual Average Daily Traffic.

5.5.2.1 Traffic data on road pavement distresses

The road pavement distresses, such as rutting, loss of surface texture, and various types of road cracks, as discussed in Chapter 2, occur if the road cannot withstand the traffic loading (fatigue stresses due to repetitive heavy wheel loading) imposed on it, including environmental contributions. Traffic loading is a major design component of roads required to be evaluated with regard to material layer thickness. Components such as subgrade, selected subgrade, sub-base, base and surfacing layer thickness will assist in evaluating the road pavement performance with traffic data.

The evaluation of traffic data in Figure 19 displays that the actual Annual Average Daily Traffic (AADT) of 1092 recorded between 2019 and 2021 exceeds the estimated AADT of 849. The design standard according to the Department of Transport (1996) indicates that the road can withstand the traffic loading of 1092 AADT based on the current pavement thickness reported in Table 5 and Table 6.

5.5.3 Summary of data analysis in Step 1

This study therefore deduces that the road can withstand the traffic load. However, based on the life of the road without adequate preventative measures, bitumen ages over time through oxidation, evaporation and physical hardening. This promotes cracks on the road and later potholes develop when exposed to traffic. Ingress of water compromises the pavement layer properties and further promotes more subsequent failures. The road pavement therefore requires adequate preventative maintenance and rehabilitation.

5.6 Step 2: Risk analysis using Ishikawa and 5 Whys (quantitative data changed to qualitative data)

5.6.1 Ishikawa analysis

The Ishikawa diagram enabled the researcher to explore the problems identified on the road Conditional Survey data, Weather data and Material Investigation data results. The Ishikawa diagram as illustrated in Figure 14 in Chapter 3, is an engineering tool that enables the visualisation of the potential causes of all problems, allowing the discovery of root causes and identifying viable best solutions (Miro Team, 2017). The steps followed in the Ishikawa diagram are as follows:

- Step 1: the problems which are ‘road distresses’ are clearly identified and placed at the head of the fish in Figure 22 and lines are drawn connecting to the head representing a backbone,
- Step 2: possible contributing factors are drawn linking the to the main problem,
- Step 3: Contributing factors are categorised based on Method, Man, Material, Machine, Measurement and Environment. These are placed in boxes connecting to the body of the fish with the possible causes linked to each of them.
- Step 4: brainstorming of possible causes to the main research problem. The project team found out that all the listed main categories might have an influence on the main problem, therefore no amendment of the fishbone was required.

  Step 5: the Ishikawa diagram was reviewed for accuracy and competence and the project team identified three areas of concern which were Maintenance method, Material and Drainage.

  Step 6: all reviewed potential causes were left out with their category on the Fishbone diagram in Figure 22.

The Ishikawa diagram was first conceptualised in Table 8 below and addressed all the possibilities on the road pavement distress to help draw more tangible solutions in bringing an approach to the management of road pavement distress.

Table 8: Ishikawa for TR33/5 road distresses (Researcher,2025)

Type of distress	Method	Man	Material	Machine	Measurement	Environment
Surface distress	Maintained potholes failing again.	None.	Surfacing seal at least 28 years old, causing it to be brittle	None.	Increase in traffic promotes acceleration of distress.	Ingress of water promotes potholing.
Rut on the road	None.	None.	Road deformation along the wheel path resulting in deformation leads to hydroplaning risk.	None.	Traffic exceeding estimated design required with heavy load can result in road deformation along the wheel path.	Hydroplaning on cars during heavy rain and water ponding on deformations.
Base distress (150mm)	100mm non-cement stabilised sub-base. No adequate maintenance to prevent cracking to base distress.	None.	Visible cracking with deformation on material more than 30mm.	None.	Accelerate the growth from distress.	Ingress of water promotes potholing.
Surface edge distress	Similar to surface distress.	None.	Similar to surface distress.	None.	Similar to surface distress	Similar to surface distress.
Deformation of bridge approaches	Similar to base distress.	None.	Similar to base distress.	None.	Similar to base distress.	Similar to base distress.
Road texture correction	No rejuvenation of binder done.	None.	Minor loss of aggregates due to binder age.	None.	Promote loss of aggregate with time.	Weather promotes age of binder.
Shoulder drop more than 50mm	None.	None.	Erosion of gravel closer to road edge.	None.	Accelerated by traffic.	Rain promotes erosion.
Non-functional subsoil	Subsoil design should be in cutting.	None.	Clogged subsoil pipe and no subsoil in cutting areas.	None.	None.	None.
Existing minor structures	None.	None.	Minor cracks, no significant impact.	None.	None.	None.

In Table 8, it was noted by the project team that distress started from a minor crack or deformation and thereby was promoted by the ingress of water. This led to summarising the most common and impaction distress as illustrated in Figure 22 below.

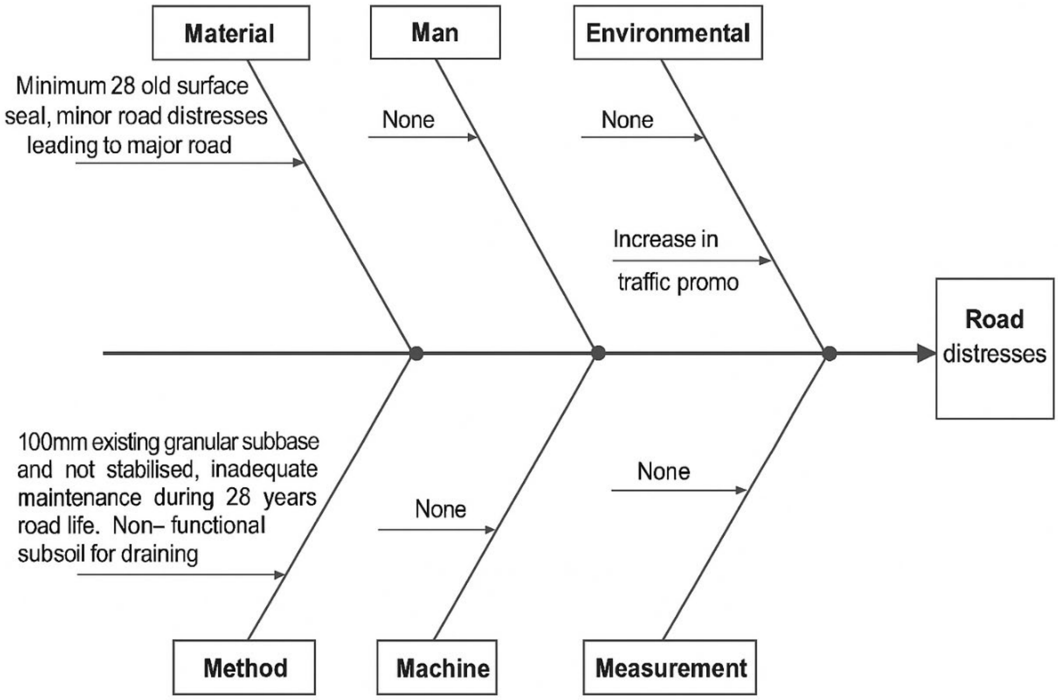


Figure 22: Fishbone diagrammed for TR33/5 road pavement distress (Researcher, 2025)

Under the categories Material and Method, a 28 year old road surface with inadequate maintenance during the road life was highlighted, which concerns the major attributes of road pavement distresses. All the findings are further investigated in the 5 Whys section below, which is the next qualitative data analysis.

5.6.2 The 5 Whys analysis

The 5 Whys analysis is a root cause analysis, used to get an understanding of contributing system failure that can help to develop sustainable correction actions (Ahmedani, 2020). The engineering quality tool used in this study peels off the layers of the problem and is compared with the Ishikawa data information for creating possible solutions to the problem. The 5 Whys of the study is illustrated in Figure 23 below.

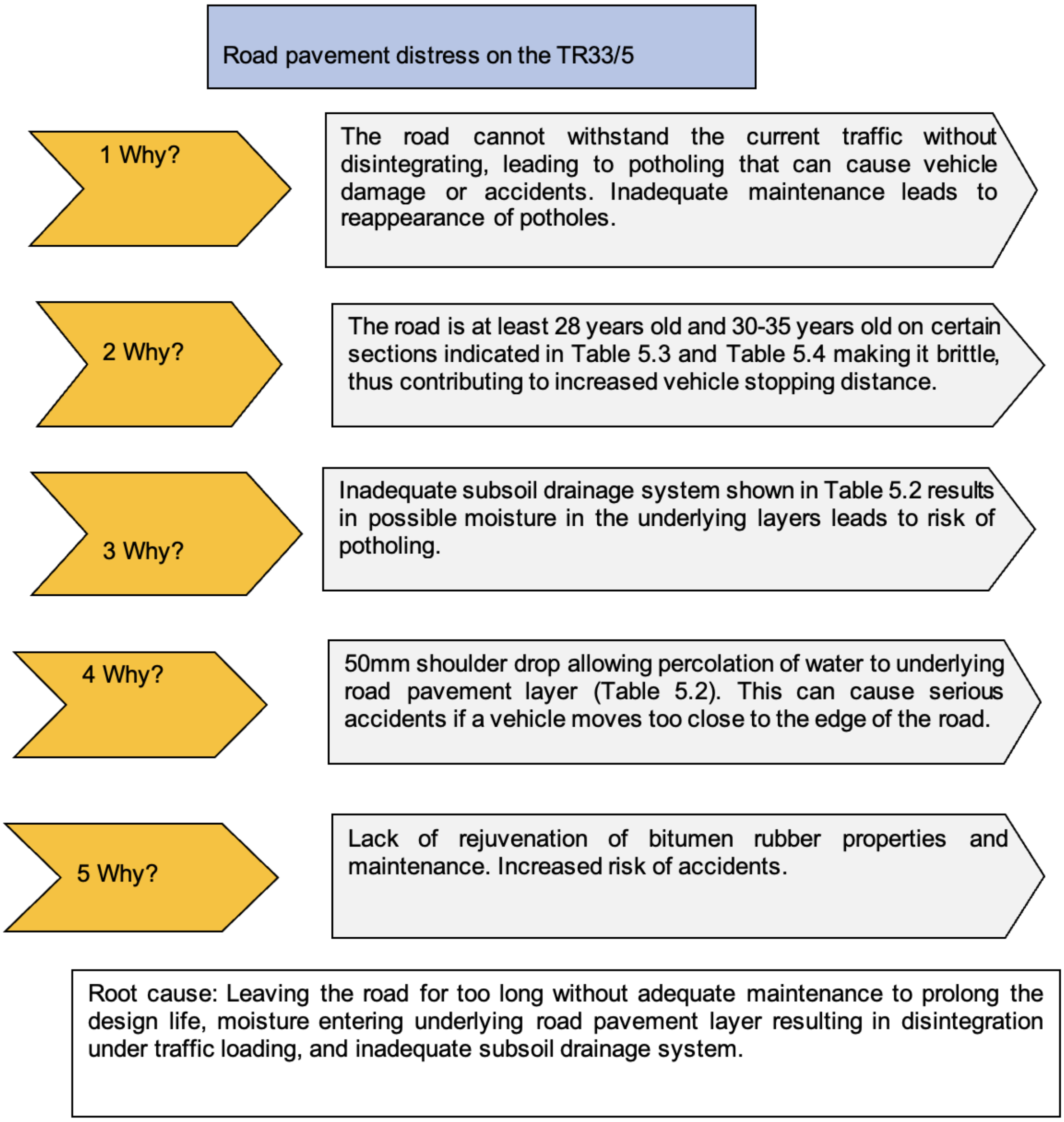


Figure 23: The 5 Whys on road pavement distress (Researcher, 2025)

5.6.3 Summary of the findings of Step 2

Ultimately the Ishikawa and 5 Whys analyses indicated that the road pavement is 28 years old and without adequate maintenance. This resulted in moisture penetration to underlying road pavement layers and resulted in disintegration under traffic.

5.7 Step 3: Evaluate the risk using Failure Mode Effects and Analysis (quantitative data)

5.7.1 Failure Mode Effects and Analysis

As noted in Chapter 4, collected qualitative data which were converted to quantitative data for FMEA tool use, the identified failure mode as described in the five Whys, were rated on occurrence probability on a scale of 1 to 10, where 1 represented a very low probability and 10 a very high probability (Forrest, 2025). Each mode failure was assigned a severity and detection ranking on a scale of 1 to 10. The qualitative was thus changed to numbers. After the ranking and rating, the Risk Priority Number (RPN) was calculated as a multiplication of severity x occurrence x detection.

Table 9: Failure Mode and Effects Analysis (Researcher, 2025)

FMEA							
Process	**Potential Failure Mode**	**Effects of the Failure**	**Probability**	**Impact**	**Detect-ability**	**Risk Level**	**Risk Control Measures**
Surface patches and base patches	Compressive, disintegration, roughness and deformation failure.	Road surface and base disintegration can lead to vehicle accidents.	10	10	1	100	Continuous inspection and monitoring of the construction process and installation of subsoil drains .
Road Rut	Deformation (compressive and tensile) failure.	Hydroplaning leading to accidents.	10	10	1	100	Monitoring and maintenance of the road using a coarse slurry product to prevent further failures.
Road texture correction	Skid resistant failure.	Vehicle stopping distance increase can lead to accidents	5	10	1	50	Texture correction required.
Shoulder drop	Shear failure.	Disturbance in vehicle control with change of elevation can lead to accidents.	5	10	1	50	Rework shoulder to level and stabilise where applicable.
Quantifying risk level							
● Rate the probability of the risk item occurring as high (H), medium (M) or low (L)							
● Rate the impact or severity of the risk item if it does occur. Again, use high (H), medium (M) or low (L)							
● Quantify the risk level of each risk item by multiplying its ratings of probability and impact.							
H is assigned a score of 10, M is 5, and L is 1							
● The product is the risk level of the item							

5.7.2 Summary of the findings of Step 3

The FMEA indicated that road pavement distress, such as deformation (surface and base patches) and road rut, shows high risk due to compressive strength issues, disintegration, roughness, deformation failure, and hydroplaning with road rut. This indicates an emergency repair method approach.

5.8 Step 4: Treat the risk – Results of FMEA (quantitative data)

The RPN results from FMEA tool provided a premise for analysis of data in this step. Therefore the method to treat the risk was based on the FMEA tool results and a new approach to the management of road pavement distress was presented with the use of FMEA tool to provide the guidance and direction on development of action plan on analysed data.

It can be noted that South African roads have many road pavement failures which are typically in the form of potholes, layer failure, failure around water services, utility trenches, surface roughness, crocodile cracking, etc.

The current method used in preventative maintenance of surfaced roads using cold mix asphalt to repair pavement distresses do not last long. The big voids in the mix allow ingress of water to the base layer and result a pothole repairs disintegrating under traffic loading. Saw cutting of joints leaves a weaker link for water percolation (SAPEM, 2014).

The introduction of a new approach to the management of road distress is vital in this generation. Road pavement deteriorates over time with the effect of traffic loading, environmental impact and the absence of preventative maintenance. Good timeous preventative preservation or preventative intervention can ensure that road life is extended and preserved. Figure 24 shows the effect of timeous preventative maintenance.

Big road pavement distresses start off as a small pothole, which is normally repaired with cold mix asphalt that does not last long (SAPEM, 2014).

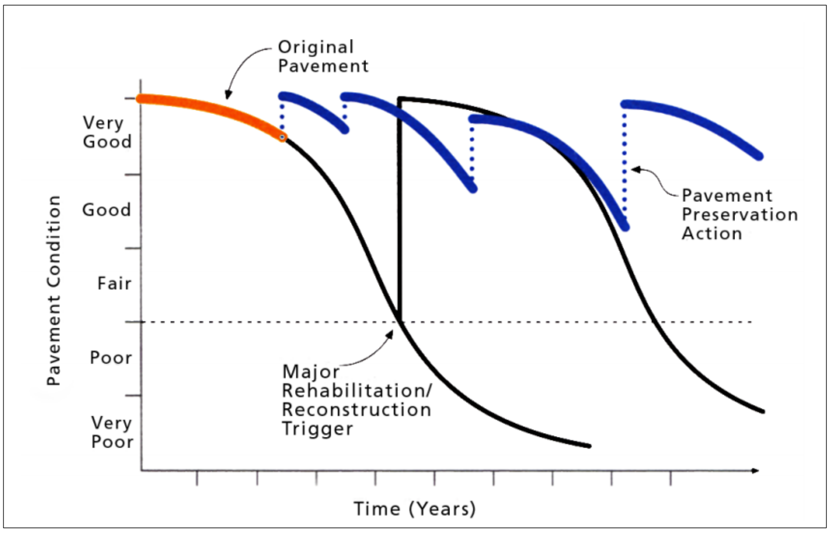


Figure 24: Pavement condition verse time (SAPEM, 2014)

The introduction of an infrared asphalt road repair maintenance solution can assist to overcome pavement distress challenges for prevention on the TR33/5 road and South African roads as a whole. This system repairs surface defects by recycling existing road pavement surface with the use of standard infrared technology to create a long lasting repair. This method includes heating and softening of existing affected surface areas and turning them into a workable condition. After heating is complete, the affected area is raked into a level surface, and more hot mix is added when necessary; the levelled surface is compacted to create a strong thermal joint between it and surrounding areas. This method is more cost-effective than the traditional method of cutting out and replacing with cold asphalt.

Advantages of Infrared pothole repair are as follows:

- Fewer voids in the repaired work than the traditional cold mix method, preventing water from getting into the underlying material.
- Seamless joint with the existing material.
- Repair time is faster than the traditional method.
- Less traffic accommodation disruption.
- Offers more permanent solution and reduces additional cost of future repairs.

This will eliminate the current traditional method of repairing potholes that does not have a long design life before major maintenance of the road is required.

5.8.1 Summary of the findings of the analysis in Step 4

The Step 4 analysis deduced that the traditional method of preventative maintenance is not entirely adequate due to the cold mix asphalt used. An Introduction of an infrared asphalt road repair maintenance solution can assist to overcome pavement distress challenges for prevention on the TR33/5 road and South African as a whole. This method can be reduce the safety risk quickly as it mainly uses a machine with minimal labour.

5.9 Step 5 - Monitor and reduce the risk (Quantitative data)

5.9.1 FMEA results

Based on the FMEA, most of the distress with higher severity starts as a pothole. It is therefore better to attend to those risks at early stages before they become a major concern, in order to increase the design life through preventative maintenance. The road under study has been left for too long with inadequate maintenance techniques. The implementation of the drawn approach to the management of distress should be monitored using road long conditional survey. The design period of the new approach must be monitored to ensure the durability of the strategy is acceptable for the comfort of the motorists. This will be done after the implementation trial of the infrared asphalt road repair maintenance solution.

5.9.2 Summary of the findings derived from the analysis of Steps 4 and 5

The suggested new approach to the management of road distress is proven to be functional. The TR33/5 road will require major rehabilitation of the layer works to enable it to carry the current traffic load. This includes installation of subsoil to avoid the water table getting into underlying layers, and reworking of shoulder works. It is only after this rehabilitation that the approach can successfully work on preventative maintenance, as the road in certain sections is 30 to 35 years old and has gone without reactive maintenance.

The infrared asphalt treatment can assist to reduce safety risks from the design stage to the construction stage of the road. It is also a fast method that can be implemented with minimal labour. This will ensure repair works done will last longer than those done by the traditional method.

5.10 Chapter summary

This chapter outlined the both quantitative and qualitative data analysis, providing information on the road condition and material properties and age. Engineering management tools are outlined such as the Ishikawa diagram, 5 Whys, and FMEA tools. The next chapter will draw conclusions and make recommendations for further study.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Chapter introduction

This chapter revisits the study's research objectives and findings and considers the limitations of the research study. It also outlines the conclusions and final recommendations of this research study. This research was undertaken using secondary data from the Western Cape Government focusing on TR33/5 road pavement distresses. The research aim was to develop an approach to managing road deterioration on National Route 12 between Beaufort West and Klaastroom. The literature review together with quantitative and qualitative data analysis enabled the researcher to reach the intended research objectives and questions resulting in recommendation for this study and future research study.

6.2 Conclusions

6.2.1 Objective 1: Identify the different types of road pavement distresses and their severity on the road using secondary data from the Western Cape Provincial government**.**

A conditional survey presented in the charts reveal that the most significant factors contributing to road pavement distress, considering associated risk are surface distresses, ruts on the road, base distress as well as shoulder drop and non-functional subsoil.

Data analysis in the form of gap analysis indicated that the existing 28-year-old road without maintenance was a major contributor. As the bitumen ages over time through oxidation, evaporation, and physical hardening, cracks start developing, which resulted in major failures like surface distress, ruts on the road, and base failures.

The conclusion from Objective 1 is derived from both qualitative and quantitative data analysis, which is from gap analysis and the conditional survey which rated degree and risk of distress. This indicated surface failures, ruts on the road, base distress, and shoulder drop as the highest degree of distress. Objective 1 was achieved; however the causes of problems identified in Objective 1 are still unknown. The root causes are discussed in Objective 2 below.

6.2.2 Objective 2: Identify causes of distresses and risk associated with the use of the risk management strategy that is laid out by the CFI Team (2022) and Schwartz (2025)

Data analysis illustrated by 5 Whys and the Ishikawa diagram indicated that the possible root causes of road deterioration in the TR33/5 road were leaving the road for too long without preventative maintenance to prolong the design life and development of cracks leading to moisture entering underlying road pavement layers without functioning subsoils pipes for drainage, and resulting in disintegration of the road under traffic load, especially with increased traffic as presented in the gap analysis.

The conclusion from both qualitative and quantitative analysis was that the road was 28 years old without adequate maintenance, and with ingress water from unattended minor cracks on the road which promoted further development of road pavement distress into extreme high risk major road distresses. Therefore, an approach to the management of distresses is required especially before they become major high risk distresses.

6.2.3 Objective 3: Evaluate the process followed to meet Objective 1 and Objective 2 and develop and propose a new approach to the management of road distress considering quality and risk management.

The preventative control measure and new approach for road pavement distress management on the TR33/5 road between Beaufort West and Klaarstroom was discussed in the conclusion of Objective 3. Data analysis from FMEA revealed that there was a high risk level for surface distress, base distresses and road rut.

The road pavement distresses identified through achieving Objective 1 and root causes identified through achieving Objective 2 support the argument that preventative maintenance on the road is vital. At present, only minor preventative maintenance is done on the TR33/5 using the traditional method of cold asphalt mix, which has not prevented surface failure from further development and does not seem to be functional. The results of the FMEA demonstrate that the introduction of an infrared asphalt road repair maintenance solution that can assist to overcome pavement distress challenges before they pose major risks.

Ultimately, the research aim and three research objectives have been accomplished. The final conclusion derived from achieving the research objectives is that a new approach for preventative measure should be introduced. Infrared asphalt road repair maintenance will contribute to less road pavement distress.

6.5 Recommendations

The recommendation for future research is the implementation of an infrared asphalt repair method on the TR33/5 road between Klaarstroom and Beaufort West as a trial section in South Africa. The trial section should be implemented, and the life span of the repair should be monitored after two years of service to ensure the durability of the product. Thereafter the product can be recommended in South Africa for all preventative maintenance that will reduce the high number of incidents associated with road distresses. Future research may investigate self-recovering asphalt using recent technologies.

REFERENCES

Abdu, M. 2023. Gap Analysis tools to help a business analyst in strategic management. Available: https://pestleanalysis.com/gap-analysis-tools/ [2023, May 18].

Abhijit P. and Patil, J. 2011. Effects of bad drainage on roads. *Civil and Environmental Research*, 1(1): 1-18).

Ahmedani, M.S. 2020. Root cause analysis: A quality tool using 5 Whys. http://dx.doi.org/10.13140/RG.2.2.24886.73288

Al-Saraf, E. 2025. The research gap (Literature Gap). How to find the elusive research gap – with practical examples. Available: https://gradcoach.com/research-gap/ [11/10/2024]

American Association of State Highway and Transportation Officials (AASHTO) (1993).*Guide for Design of Pavement Structures.* American Association of State Highway and Transportation Officials.

Arrive Alive. 2019. Safe Driving on Roads with Potholes and Avoiding Pothole Damage. Available: https://www.arrivealive.mobi/safe-driving-on-roads-with-potholes-and-avoiding-pothole-damage/ [18/07/2022]

Atiyeh,C.2019 Why your car hydroplanes, and what to do when it happens. Available: https://www.caranddriver.com/shopping-advice/a26311127/hydroplaning-definition-prevent-recovering/ [20/06/2022]

Baker, S.E., Edwards, R. and Doidge, M. 2012. How many qualitative interviews is enough? Expert voices and early career reflections on sampling and cases in qualitative research. National Centre for Research Methods Review Paper.

Barnes, J.A. 1979. *Who should know what? Social science, privacy and ethics*, Harmondsworth: Penguin

Barry R. Chrisropher M., Charles,S., and Richard,B. 2006. Geotechincal Aspects of Pavements. *National Highway Institute Federal Highway Administration U.S. Department of Transportation Washington, D.C.*

Bazeley, P., 2018. Integrating Analyses in Mixed Methods Research. *Sage. Paperback, 328 pages.*

Belt, J., Lamsa, V.P., Savalainen, M. and Ehrola, E. 2002. Road deterioration and condition of the road network*. Opastinsilta 12 A Helsinki: Finland*

Bhandari, B., Luo, W., & Wang, Y., 2022. *Road pavement deterioration and loading mechanism.* Journal of Road Infrastructure.

Bhatti. 2023. Importance of Road Network and its Regular Maintenance for the Economic Development of a Country. Available: https://www.linkedin.com/pulse/importance-road-network-its-regular-maintenance-economic-bhatti/ [03/03/2024]

Bin Abd Karim, S.B. 2014. *The development of an empirical-based framework for project risk management.* Doctoral Dissertation, University of Manchester.

Boothe, K., 2023. Risk management. Doctoral thesis, LIGS University, Hawaii.

Brandon. M.,2022. What is gap analysis. Available: https://www.investopedia.com/terms/g/gap-analysis.asp/ [02/10/2024]

CFI Team. 2022. Risk Management identification, analysis and response to risk factors affecting a business. Available:https://corporatefinanceinstitute.com/resources/risk-management/risk-management/ [2022, October, 15]

Chakravarty, S. 2024. Gap analysis. Available: https://www.projectmanagement.com/wikis/233055/gap-analysis#_=_ [26/10/2024]

Chan, C.Y. Huang, B. Yan X. and Richards, S. 2010. Investigating effects of asphalt pavement conditions on traffic accidents in Tennessee based on the pavement management system (PMS). *Journal of Advanced Transportation,* 44(3): 150-161

Clarke, V. & Braun, V. (2014) Thematic analysis. In A. C. Michalos (Ed.), *Encyclopaedia of Quality of Life and Well-Being Research* (pp. 6626-6628). Springer, Dordrecht, Netherlands: Springer.

Creswell, J. W. (2014). Research Design: Qualitative, Quantitative and Mixed Methods Approaches (4th ed.). Thousand Oaks, CA: Sage.

Collis, J. & Hussey, R. 2003. *Business research: A practical guide for undergraduate and post graduate students*. Palgrave: Macmillan

Committee of Transport Officials (COTO). 2020. *Standard specifications for road and Bridge works for South African road authorities.* Pretoria: Department of Transport South Africa.

Cooper, D.R. and Schindler, P.S. 2014. *Business Research Methods*. 12th Edition, McGraw Hill International Edition, New York

Dawson, C. 2002. *Practical guide to research methods. A user-friendly guide to mastering research techniques and projects.* How to Books.

Department of Transport. 1996. TRH4: Structural design if flexible pavements for interurban and rural roads. South Africa. Pretoria

Dobakhti, L. 2019. The process of enhancing validity, reliability, and ethics in research. *Iranian Journal of Applied Language Studies*, 12(2): 59-88.

Dongare, V. 2024. What is fault tree analysis? Available: https://www.proptorapp.com/blog/what-is-fault-tree-analysis [19/05/2025]

El Geddawy, M, and Abouraira, M. 2024. Pragmatism as a research paradigm. *Proceedings of the 23rd European Conference on Research Methodology for Business and Management* Studies 23(1):71-74

Elliott, J.2024. Using narrative in Social Research: Qualitative and quantitative approaches. London

Forrest, G. 2025. FMEA (Failure Mode and Effects Analysis): A quick guide to minimising defects and faults in your projects. https://www.isixsigma.com/fmea/fmea-quick-guide/ [06/10/2024]

Gibson, K. 2023. What is risk management & why is it important? Available: https://online.hbs.edu/blog/post/risk-management [06/09/2024]

Gjerdrum, D. 2016. A brief history of ISO 31000 – and why it matters. Available: https://riskandinsurance.com/a-brief-history-of-iso-31000-and-why-it-matters/ [22/09/2024]

Haslam, K. 2023. News24: What to know when claiming for accident caused by potholes in South African. Available: https://www.news24.com/life/motoring/news/guides_and_lists/what-to-know-when-claiming-for-accidents-caused-by-potholes-in-south-africa-20230919-3/ [06/04/2024]

Hayes, J.,2023. Understanding and implementing the Ishikawa diagram in quality management.Quality Management Journal, Vol. 30, No. 1, pp. 45-62.

Horvath, I. 2025. What is FMEA? An overview of Failure Mode Analysis. Available: https://www.invensislearning.com/blog/failure-mode-and-effects-analysis/ [28/10/2024]

Huber, Z. 2024. FMEA history: https://www.superengineer.net/blog/fmea-history [04/10/2024]

Ilie G. and Ciocoiu, C.N., 2010. Application of fishbone diagram to determine the risk of an event with multiple causes. *Knowledge Management Research & Practice*. 2(1)1-20.

ISO 31000:2018, Risk management. Guidelines.

ISO 45001:2018. International Standard for Occupational Health and Safety Management Systems.

Jansen, D. J. 2021. What (exactly) is thematic analysis? A plain-language explainer with examples + free template. Available: https://gradcoach.com/what-is-thematic-analysis/ [25/10/2024]

Jefy, J.A. 2020. Road pavement layers – components and functions. Available: https://vincivilworld.com/2020/12/22/road-pavement-layers-components-functions/ [22/12/2020]

Kaare, K.K., Kuhi, K. and Koppel, O. 2012. Tire and pavement wear interaction monitoring for road performance indicators. *Estonian Journal of Engineering,* 18(4): 324–335.10.3176/eng.2012.4.04

Kivunja,C.,Kuyini,C.D.,2017. Understanding and Applying Research Paradigms in Educational Contexts. *University of New England, Australia.*

Lawless, J. 2024a. Fault analysis tree. Available: https://purplegriffon.com/blog/fault-analysis-tree-fta [19/05/2025]

Lawless, J. 2024b. 5 Whys Analysis- A detailed guide. Available: https://purplegriffon.com/blog/5-why-analysis [27/10/2024]

Leedy, P. and Ormrod, J. 2001. *Practical research, planning and design.* Upper Saddle River, NJ and Thousand Oaks, CA: Merrill Prentice Hall and SAGE Publications..

Mathew, T. V. 2009. *Introduction to pavement design*. Indian Institute of Technology, Mumbai. Available: https://www.civil.iitb.ac.in/tvm/1100_LnTse/401_lnTse/plain/plain.html/ [01/06/2023]

Maxwell, J. A. (2009). Designing a Qualitative Study. In L. Bickman, & D. J. Rog (Eds.), *The SAGE Handbook of Applied Social Research Methods (2nd ed., pp. 214-253). SAGE*

Miro Teams, 2017. How to build a fishbone diagram and get the most out of it. Available: https://miro.com/blog/how-to-get-most-of-fishbone-diagram/[21/03/2024]

Mkwata R. and Chong, E.E.M. 2022. *Effect of pavement surface conditions on road traffic accident - A Review.* 2nd International Conference on Civil and Environmental Engineering (ICCEE 2022). Article no: 01017.

Nikolopoulou, K. 2022. What is purpose sampling? Definition & examples. Available: https://www.scribbr.com/methodology/purposive-sampling/ [2024, July 20}

Padro, F. 2014. A conceptual framework on establishing a risk management framework within existing university assessment and evaluation practices. Studies in Learning, Evaluation, Innovation & Development, 10(1): 1-20.

Plano Clark, V. L., Creswell, J. W., Green, D. O., & Shope, R. J. (2008). *Mixing quantitative and qualitative approaches*: An introduction to emergent mixed methods research. In S. N. Hesse-Biber & P. Leavy (Eds.), Handbook of emergent methods (pp. 363–387).

PECD, 2023. ISO/IEC 27005:2022 Risk Manager. Available: https://pecb.com/pdf/candidate-handbooks/pecb-candidate-handbook-iso-27005-risk-manager-mc.pdf/ [09/07/2023]

QMS Certification, 2023.Risks and Opportunities in ISO 45001. Available: https://qms-certification.com/risks-and-opportunities-in-iso-45001/ [01/09/2023]

Ragnoli A., De Blasiis, M.R. and Di Benedetto, A. 2018 Pavement distress detection methods: A review. *Infrastructure*, 3(4): 58.https://doi.org/10.3390/infrastructures3040058

Ramirez, T., 2023. The what, when, why and how of FMEA (Failure Mode Effects Analysis). Available: https://www.simplexitypd.com/blog/the-what-when-why-and-how-of-fmea-failure-mode-effects-analysis/ [28/10/2024]

Road Network Information System (RNIS), 2023. Available: https://www.google.com/search?q=RNIS&rlz=1C1CHBF_enZA1078ZA1078&oq=RNIS&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQABiABDIHCAIQABiABDIJCAMQLhgKGIAEMg8IBBAuGAoYxwEY0QMYgAQyCQgFEAAYChiABDIJCAYQABgKGIAEMgcIBxAAGIAEMgkICBAAGAoYgAQyDwgJEC4YChjHARjRAxiABNIBCDIzMDJqMGo3qAIAsAIA&sourceid=chrome&ie=UTF-8/ [20/06/2023]

Robert K. Yin. (2014). *Case Study Research Design and Methods (5th ed.*). Thousand Oaks, CA: Sage. 282 pages.

Rodriguez, A. 2023. What are the 5 whys. Available: https://www.mlean.com/blog/what-are-the-5-whys/ [16/07/2024].

Schwartz, B. 2025. *The risk management process in project management*. Available: https://www.projectmanager.com/blog/risk-management-process-steps [2022, October 15].

Simplilearn. 2024. What is data analysis: A comprehensive guide. Available: https://www.simplilearn.com/data-analysis-methods-process-types-article [2024, July 20]

Singh, N. and Swartz, B. 2024. Analysis of risks associated with laboratory error rates of COVID-19 testing at The NHLS Paarl Laboratory. 5th African International Conference on Industrial Engineering and Operations Management in CSIR Pretoria, 23 – 25 April 2024.

Sileyew, K. J. 2019. *Research Design and Methodology*. In Cyberspace (pp. 1-12). IntechOpen.

South African Pavement Engineering Manual (SAPEM) 2014, *South African National Roads Agency Ltd.* South Africa. Pretoria.

Sreekumar,D., 2023. What is Research Methodology? Definition, types, and examples. Available:https://paperpal.com/blog/academic-writing-guides/what-is-research-methodology/ [20/09/2024]

Taherdoost, Hamed. (2016). Validity and Reliability of the Research Instrument; How to Test the Validation of a Questionnaire/Survey in a Research. *International Journal of Academic Research in Management. 5. 28-36. 10.2139/ssrn.3205040*.

Vasileiou, K. Barnett, J., Thorpe, S. and Young, T. 2018. Characterising and justifying sample size efficiency in interview-based studies: systematic analysis of health research over a 15 – year period. *BMC Medical Research Methodology, 18): 148*.

Virine, L., and Trumper, M. 2017. *Project risk analysis made ridiculously simple.* Singapore: World Scientific Publishing.

Wilson, M. 2021. Risk Management – Definition, Strategies and processes. Available: https://www.pcwdld.com/definition/risk-management#wbounce-modal [2022, September 15]

Zhang, L., 2022. Risk management framework to guide off-site manufacturing process: a Chinese perspective. Doctoral thesis, University of Strathclyde, UK.

.

Annexure A: Ethic Clearance

Cape Peninsula University of Technology

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

On 6 June 2023, the Faculty of Engineering and the Built Environment Ethics Committee of the Cape Peninsula University of Technology granted ethics approval **MSAWENKOSI MKOKA** student number **214198308** for research activities related to his research proposal at the Cape Peninsula University of Technology.

Title of proposal	An approach to the management of road deterioration on National Route 12 between Beaufort West and Klaastroom, Western Cape, South Africa

Comments:

Data collection permission is required, permission letter to collect data attached.

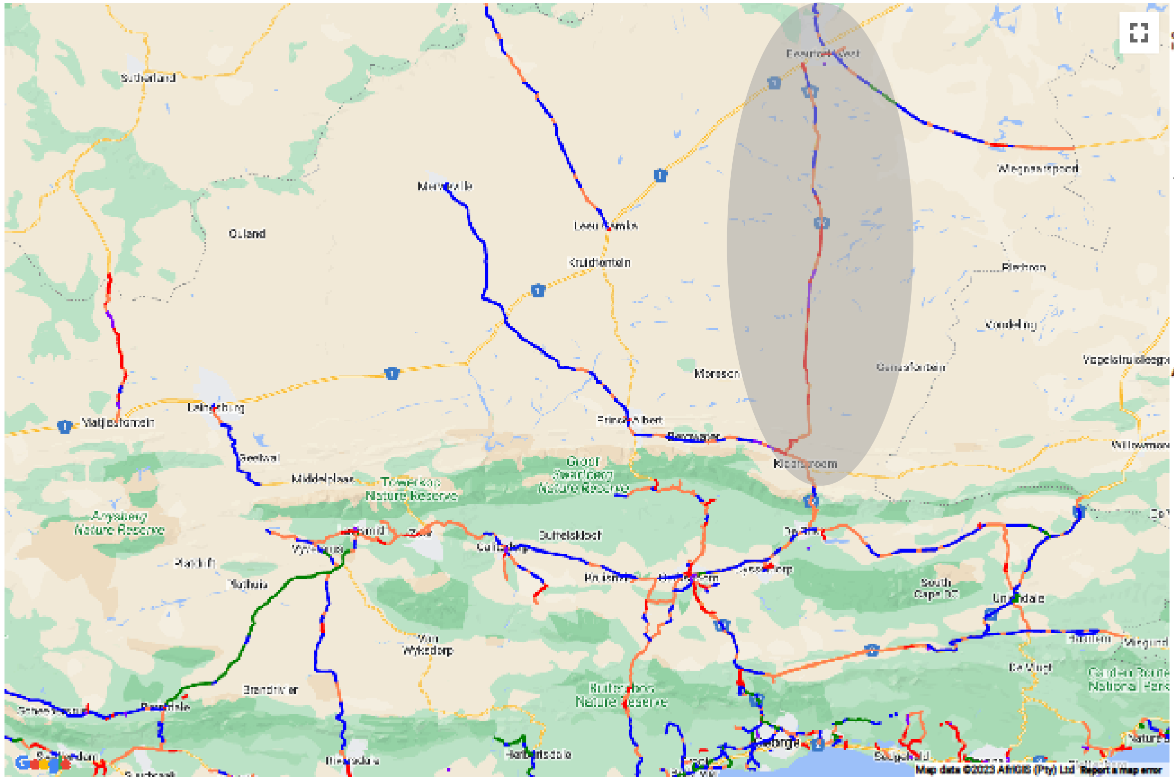
[signature]	21 June 2023
Prof Veruscha Fester **Assistant Dean: Research, Technology, Innovation & Partnerships (RTIP)** **Faculty of Engineering and the Built Environment**	**Date**

2023FEBEFREC-STD-011

Annexure B: Road Conditions

Western Cape Government

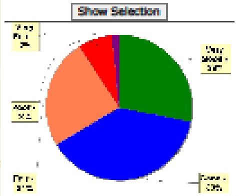
Surfaced Road Conditions



Click on the link(s) below to download the kml into Google earth

- [x] Very Poor
- [x] Poor
- [x] Fair
- [x] Good
- [x] Very Good

Show Selection



Assessment Year : 2022

Annexure B: Editing Certificate

Ken Barris, PhD

Editing and research writing services

18 Doris Road, Claremont 7708, Cape Town, South Africa
ken.barris@gmail.com
+27(0)829289038

21 August 2025

To whom it may concern

This is to certify that I have edited the following thesis by Msawenkosi Mkoka titled:

AN APPROACH TO THE MANAGEMENT OF ROAD DETERIORATION ON NATIONAL ROUTE 12 BETWEEN BEAUFORT WEST AND KLAASTROOM, WESTERN CAPE, SOUTH AFRICA

Please note that this does not cover content, conceptual organisation or textual changes made subsequent to the editing process.

I further certify that I have not made use of any generative AI software in the editing process.

Best regards

KEN BARRIS