

A Risk Management Approach of Road Deterioration on the National Route 12 Between Beaufort West and Klaarstroom, Western Cape, South Africa

Msawenkosi Mkoka and Bronwyn Swartz

Cape Peninsula University of Technology
Bellville, South Africa

msawenkosimkoka@gmail.com, swartzb@cput.ac.za

Abstract

The National Route 12 (classified as TR33/5) between Klaarstroom and Beaufort West in the Western Cape, South Africa, shows signs of deterioration evident through surface deformation, cracking, and disintegration. This deterioration potentially affects vehicle conditions, increases maintenance costs for motorists, and may lead to fatal incidents. This research study aims to develop a risk management approach to identify, evaluate, and manage different types of road distress on the TR33/5 road. The study employs a mixed-methods approach using both qualitative and quantitative data from the Western Cape Provincial Government, including climate conditions, historical imagery, visual inspection reports, traffic volume data, and environmental factors. The research follows an integrated risk management approach aligned with ISO 31000:2018, incorporating quality tools such as Gap analysis, Ishikawa diagram, 5 Whys technique, and Failure Mode and Effects Analysis (FMEA). The research is currently in progress, with data collection and analysis underway. This paper outlines the methodological framework being implemented and discusses the expected contributions of the study. The implementation of the proposed risk management framework is anticipated to provide a systematic approach to identify, analyse, and prioritize road deterioration issues, enabling more effective maintenance strategies and resource allocation. This ongoing research is expected to contribute to the development of a new approach to investigating and managing road defects on National Route 12, aimed at ensuring good quality road standards, reducing the risk of accidents, and lowering vehicle maintenance costs through proactive maintenance strategies.

Keywords

Road pavement deterioration, pavement distress, risk management approach, quality tools, FMEA

1. Introduction

The National Route 12 (Classified as TR33/5) from Klaarstroom to Beaufort West, which falls under the jurisdiction of Western Cape Provincial Roads, shows signs of deterioration. The deterioration is evident on the road pavement through surface deformation, cracking, and disintegration. It must be noted that the term 'pavement' as referred to herein is not a sidewalk. Surface deformation, cracking, and disintegration are commonly referred to as road pavement distress (South African Pavement Engineering Manual 2014). Road pavement distresses could include road deformation, edge defects, potholes, alligator cracks, road rut, corrugated cracks, and longitudinal cracks (Antonella et al. 2018). Thorough investigation and accurate identification of road pavement distress play a vital role in the management of roads. Kati et al. (2012) 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 could also lead to an increase in fatal traffic incidents. Road pavement distresses such as potholes pose a danger to motorists especially during rainy days when defects are not clearly visible (Antonella et al. 2018). According to Andrew (2018), road deterioration such as road ruts can also cause aquaplaning during the rainy season, reducing the vehicle control on road pavement material. Moreover, another consequence of the road pavement distresses 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.

1.1 Research Objectives

This study aims to develop a risk management approach to managing road deterioration on National Route 12 between Beaufort West and Klaarstroom. To achieve this aim, the research has the following objectives:

1. Identify the different types of road pavement distresses and their severity on the road using secondary data from the Western Cape Provincial government.
2. Identify causes of distresses 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.

2. Background

Bhatti (2023) states that road infrastructure globally plays an important role in the wellbeing of society by providing the essential means to move people and goods from one place to another. To successfully do this, the road pavement is designed to provide structural support to withstand traffic loading at prevailing environmental conditions throughout the design life and at a minimum maintenance cost. 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 has pavement distresses, which is the result of pavement cracking or deforming of pavement layers that is evident on the road surface. The stresses imposed on the road surface by the external loads of the vehicle together with environmental conditions gradually increase the distresses. Kati et al. (2012) urge that this effect depends on the technology and materials of the road, but the greatest effects depend on traffic loads and volumes.

Patil and Jalindar (2011) allege 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 distresses 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 (Ray 2021).

3. Literature Review

3.1 Road Pavement Structure and Function

The road design philosophy is to produce a structurally balanced road pavement at minimum present worth of cost, while carrying 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 2014). Mathew (2009) states that an ideal road pavement has sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil, is structurally strong to withstand all types of stresses imposed upon it, has an adequate coefficient of friction to prevent skidding of vehicles, provides a smooth surface for comfort, produces minimal noise, has a dust-proof surface, is impervious, and has a long design life with low maintenance cost.

A typical flexible road pavement consists of surface course, base course, subbase course, and subgrade or in-situ materials. The pavement layer consists of different layers, each serving a specific function in the overall road structure.

The subgrade is the completed earthworks within the road prism prior to the construction of the pavement, comprising the in-situ material of the roadbed and any fill material. Above this lies the subbase, which consists of layers beneath the base or concrete slab and on top of the selected layer or subgrade. Its primary function is to transfer the distributed load from the base to the subgrade. The base layer sits immediately beneath the surfacing and on top of the subbase or, if there is no subbase, directly on top of the subgrade. This layer's function is to distribute the traffic loads onto the subbase and subgrade. Finally, the surfacing forms the uppermost pavement layer, which provides the riding quality surface for vehicles, protects the base, and may be designed to add strength to the pavement. The road pavement layers are subjected to loading by motorists during a serviceability period (Anaswara 2020). According to Bhandari et al. (2022), loading occurs through vertical stresses imposed by vehicle axle load transferred to the wheels, and the surfacing in the road pavement layer is subjected to tensile stresses of axle/wheel loads as a vehicle moves.

3.2 Road Pavement Distresses

As identified by Alessandro (2018), road pavement distress encompasses a variety of structural and surface problems that affect road performance and safety. Road deformation refers to the change of the constructed road profile due to imposed loading on the surface being greater than designed for. 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. Potholes form on localized sections of the road surface when a localized weakness is removed in broken pieces by traffic. Alligator cracks, also referred to as crocodile cracking, appear as interconnecting cracks due to surface layer fatigue failure. Road rutting manifests as depression along the wheel path, caused by permanent deformation in granular layers and surface layer due to traffic loading. Surface texture issues can arise due to old binder that results in raveling of existing aggregates as a result of abrasion action of traffic. Each of these distresses contributes to the overall deterioration of the road pavement and requires specific approaches for effective management.

3.3 The Consequences of Poor Quality Roads

Road pavement distresses 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 impact with a road defect, situations where a vehicle swerves toward pedestrians, cyclists, or obstacles in an attempt to avoid road damage, cases of tire bursts resulting from sharp edges of potholes or other defects, instances where vehicle drivers make sudden stops after noticing hazardous potholes, and malfunctions of vehicle components following pothole impacts. These various 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 affecting the serviceability of the road.

3.4 Risk Management Approach

Wilson (2021) outlines risk management as the process of identifying, analyzing, and reducing threats, especially to organizational earnings, employees, and profits. Stephan (2021) agrees and considers risk management as the management of a positive or negative impact on a project or organization caused by the occurrence of an event. International Organization for Standardization (ISO) 31000 standard will be utilized in this study to ensure an adopted standard frame for the research is feasible. ISO 31000 outlines the importance of communicating and consultation for risk assessment within an organization, supports the understanding of the entire scope of a project, and considers context and project criteria prior to risk assessment.

The ISO 31000 risk management process encompasses a comprehensive framework for addressing potential threats. This process begins with risk identification, which involves identifying any risks that may influence road operations and systems for road users. Following identification, risk analysis is conducted to analyze the scope of the risk and comprehend the sort of threat posed. The next stage, risk evaluation, involves ranking risks according to severity and prioritizing them accordingly to establish a clear hierarchy of concerns. Once risks are evaluated, risk treatment follows, which entails analyzing the risk to determine if it can be contained or eliminated through appropriate interventions. Finally, risk monitoring is implemented, particularly for risks that cannot be eliminated but must be continuously tracked to ensure they remain within acceptable parameters.

3.5 Engineering Management Tools

To implement the risk management approach, a selection of engineering management tools will be applied. These include Gap analysis, the 5 Whys analysis, Ishikawa Diagram and Failure Modes Effects Analysis (FMEA).

3.5.1 Gap Analysis

Gap analysis compares the current performance with designed or expected performance. It was invented in the 1980s at the University of Aldo by J. Michael Scott. In this study, gap analysis will be used to compare the estimated and actual data presented graphically, specifically the accumulated traffic growth data annually with the Actual Annual Average Daily Traffic.

3.5.2 Ishikawa Diagram

The Ishikawa diagram was developed by Kaoru Ishikawa in the 1960s. It is used to illustrate the causes of an event and outlines different steps in a process to demonstrate where quality problems may arise and determine the required resources (Hayes 2023). The major categories of causes are Methods, Equipment, People, Material, and Environment.

3.5.3 The 5 Whys Technique

The 5 Whys technique was developed in 1930s by Japanese industrialist Sakhithi Toyoda, the founder of Toyota Industries. This method is used to identify and explore the actual root cause and effect of a problem like road distresses (Rodriguez 2023). This is achieved by asking the question "Why" five times to establish a possible sufficient root cause of a particular problem. 5 Whys is 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 is implemented in the study.

3.5.4 Failure Mode Effects Analysis

FMEA was developed by the American military in the 1940s to mitigate the root cause of munition malfunction. It is a systematic proactive method for identifying where and how a process might fail, assessing the relative effect of different failures to enable the development of an effective solution (George 2010). It involves rating identified failure modes on occurrence probability, severity, and detection on a scale of 1 to 10, then calculating the Risk Priority Number (RPN). Rostich (2022) explains FMEA as a powerful risk management tool to prevent challenges before they arise and develop sound solutions. Forrest (2024) 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 Rostich (2022) and Forrest (2024) of how the FMEA may be used, this study deduces that the results of the 5 Why's analysis can serve as the input for the start of an FMEA. This may be done if qualitative data collected during the 5 Whys is converted to quantitative data for FMEA tool use.

4. Methods

This study employs a mixed-methods approach, utilizing both qualitative and quantitative data to develop a comprehensive understanding of road pavement distresses on TR33/5 and to formulate an effective risk management approach. The qualitative component involves the analysis of visual inspection reports, test pit investigations, and condition surveys to identify types of distresses and their severity. The quantitative component focuses on traffic data, roughness measurements, and weather data to establish patterns and correlations between various factors and road deterioration.

4.1 Data Collection

The population of this study includes all electronic documents belonging to the Western Cape Government containing data collected from 2020 to 2021 on the TR33/5 road. As all the records for this period are being used, the sampling technique of this study is a non-statistical sampling technique (Nikolopoulou 2022). The data sources encompass several complementary types of information (both qualitative and quantitative data) essential for a comprehensive analysis. Test pit investigation for soil properties provides crucial insights through excavation and determination of thickness of different road pavement materials, extraction of individual layer samples for laboratory testing, identification of relationships between pavement layer results and identified distress patterns, and identification of possible causes of distresses. Condition survey data offers records of different types of distress along the test road, represented in a strip map format for spatial analysis. Roughness measurement and analysis data includes measurements of road roughness "bump count" displayed in International Roughness Index (IRI), measured along the longitudinal road profile to quantify ride quality. Traffic data comprises Annual Average Daily Traffic (AADT) figures from the initial stage when the road was opened to traffic to the year 2021, allowing for analysis of usage

patterns and loading. Weather data provides average daily maximum and minimum temperature records from 2013 to 2020, enabling assessment of environmental factors affecting road performance.

4.2 Data Analysis Framework

The data analysis follows the risk management approach outlined in ISO 31000:2018 and employs engineering management tools in five stages. These are Stage One known as Risk Identification, Stage Two known as Risk Analysis, and Stage Three known as Risk Evaluation, Stage Four known as Treatment and Stage Five known as Monitoring.

4.2.1 Stage One Risk Identification

For risk identification, thematic analysis and gap analysis will be utilized as the primary tools. The objective of this step is to identify different types of road pavement distresses and their severity on the TR33/5 road. This process involves comprehensive analysis of condition survey data, visual inspection reports, and traffic data to systematically categorize and quantify the various types of road distresses present on the route. By applying these analytical tools to the collected data, patterns of deterioration can be identified and prioritized according to their prevalence and severity.

4.2.2 Stage Two Risk Analysis

The risk analysis step employs the Ishikawa and then the 5 Whys technique as analytical tools. The objective here is to identify the underlying causes of the observed distresses and the associated risks they present. This process starts with the careful categorization of these causes into major groups including Methods, Equipment, People, Material, and Environment. This is followed by a process that entails conducting root cause analysis of each identified distress identified in the Ishikawa. This structured approach allows for a comprehensive understanding of the factors contributing to road deterioration and facilitates the development of targeted interventions.

4.2.3 Stages Three to Five, Risk Evaluation, Treatment and Monitoring

For risk evaluation, treatment, and monitoring, Failure Mode Effects and Analysis (FMEA) serves as the primary tool. The objective of these combined steps is to evaluate the process, develop, and propose a new approach to road distress management. The process involves systematically rating each identified failure mode based on occurrence probability, severity, and detection capability using a standardized scale. Risk Priority Numbers are then calculated to prioritize risks and develop appropriate treatment strategies for high-priority issues. This approach ensures that resources are allocated efficiently to address the most significant threats to road pavement integrity.

5. Expected Outcomes and Contribution

This research is expected to make several significant contributions to the field of road pavement management, including the development of a structured Risk Management Framework, the development of an approach to using engineering tools in the management of roads, and the development of practical guidelines for the implementation of the framework. The primary outcome of this study will be the development of a structured risk management framework specifically tailored for road pavement distress. This framework will integrate quality management tools with risk management principles to provide a systematic approach for identifying, analyzing, and addressing road distresses. By implementing this framework, road maintenance authorities will gain several significant capabilities. They will be able to prioritize road sections requiring immediate attention based on objective risk assessments rather than reactive maintenance.

The framework will enable more efficient resource allocation by focusing on high-priority issues identified through systematic analysis. Additionally, authorities will be positioned to implement preventive measures to extend road pavement life through early identification of potential issues before they develop into major problems. Ultimately, this approach is expected to reduce the overall lifecycle cost of road maintenance through more strategic intervention planning and reduced emergency repairs. Ultimately this will help identify the most common types of distresses affecting the road, the primary factors contributing to deterioration, the interrelationships between different factors (traffic load, climate, drainage, etc.) and the progression patterns of different types of distresses over time, specifically in the Western Cape region.

Furthermore, the demonstration of the application of specific engineering management tools applied in this study (gap analysis, Ishikawa diagram, 5 Whys and FMEA) will serve as an example that can be adapted specifically for road pavement management. The development of this approach will be a practical demonstration of how to conduct

systematic assessments of road conditions, identify root causes of distresses rather than treating symptoms, quantify risks associated with different types of distresses and develop targeted intervention strategies based on risk priority, using engineering management tools – thus advancing the engineering management discipline in the area of road management. Moreover, the FMEA will be adapted specifically for road pavement management.

The final expected outcome of this research study will serve as a foundation for the development of guidelines for implementing the proposed risk management approach. These envisage guidelines will outline step-by-step procedures for conducting road pavement assessments, templates and tools for data collection and analysis, decision-making frameworks for selecting appropriate interventions and monitoring protocols to evaluate the effectiveness of interventions

6. Current Progress and Next Steps

6.1 Current Status of the Research

The research is currently in the data collection and preliminary analysis phase. Several key activities have been completed or are in progress as part of this initial phase. A comprehensive review of literature on road pavement distresses and risk management approaches has been conducted to establish the theoretical foundation for the research. The conceptual framework integrating risk management principles with engineering management tools has been developed to guide the subsequent phases of the study. Collection of secondary data from the Western Cape Provincial Government is underway, focusing on obtaining comprehensive records of road conditions, traffic patterns, and environmental factors. Additionally, an initial assessment of the condition of TR33/5 road based on available documentation has been performed to identify preliminary patterns and areas of concern.

6.2 Next Steps

Several critical activities are planned for the next phases of the research to build upon the foundation established thus far. The data collection process will be completed to ensure a comprehensive dataset for analysis. The engineering management tools outlined in the methodology will be systematically applied to analyze the collected data and derive meaningful insights about road distresses patterns and their causes. Based on these findings, a risk management framework tailored to road pavement management will be developed, incorporating the principles of ISO 31000 and the insights gained from the data analysis. This framework will be validated through consultation with experts in road pavement management to ensure its practical applicability and effectiveness. Practical guidelines for implementation will be formulated to facilitate the adoption of the framework by road authorities. Finally, the findings will be documented comprehensively, and the final research report will be prepared to communicate the outcomes and implications of the study.

7. Conclusion

Road infrastructure plays a vital role in the economic and social well-being of communities. The deterioration of National Route 12 between Beaufort West and Klaarstroom presents significant challenges for road users and maintenance authorities. This research aims to address these challenges through the development of a comprehensive risk management approach that integrates quality management tools. By systematically identifying, analyzing, and prioritizing road pavement distresses, this approach will enable more effective allocation of resources and implementation of targeted interventions. The expected outcomes include not only a better understanding of the specific issues affecting TR33/5 but also a transferable framework that can be applied to other road networks facing similar challenges.

The ongoing research adopts a mixed-methods approach, combining qualitative and quantitative data to develop a holistic understanding of road deterioration patterns and their underlying causes. The integration of engineering management tools such as thematic analysis, Ishikawa diagram, 5 Whys, and FMEA provides a structured methodology for analyzing complex road pavement issues. Upon completion, this research will contribute to the body of knowledge in road pavement management and offer practical tools for road authorities to improve the condition, safety, and sustainability of road infrastructure. The ultimate aim is to enhance road user safety, reduce vehicle maintenance costs, and optimize the use of public resources allocated to road maintenance.

References

Anaswara A., Road Pavement Layer Components and Functions: Roads Transportation Engineering, Available: <https://vincivilworld.com/2020/12/22/road-pavement-layers-components-functions/>, December 22, 2024.

- Andrew K., Vehicle Fitness for Driving on Roads with Potholes. Arrive Alive Campaign. Available: <https://www.arrivealive.mobi/safe-driving-on-roads-with-potholes-and-avoidingpotholedamage#:~:text=Vehicle%20Fitness%20for%20Driving%20on%20Roads%20with%20Potholes&text=A%20properly%20inflated%20tyre%20creates.the%20rigours%20of%20the%20road>, April 06, 2024.
- Antonella, K., Maria, R.D.B., and Alessandro, D.B., Pavement Distress Detection Methods: *A Review*. Roma Tre University, Rome: Italy. September, 2018.
- Belt, J., Lamsa, V.P., Savalainen, M., and Ehrola, E., Road Deterioration and Condition of the Road Network. *Tielaitos (finnish national road administration)*. Opastinsilta 12 A Helsinki: Finland, 2002.
- Bhandari, B., Luo, W., & Wang, Y., Road pavement deterioration and loading mechanism. *Journal of Road Infrastructure*, vol.45, no. 3, pp. 213-228, 2022.
- Bhatti, M., The importance of road infrastructure in economic development. *Journal of Infrastructure Development*, vol.15, no. 2, pp.78-92, 2023.
- CFI Team., Risk Management identification, analysis and response to risk factors affecting a business. Available: from <https://corporatefinanceinstitute.com/resources/risk-management/risk-management/>, May 20, 2023.
- George, F., FMEA (Failure Mode and Effects Analysis) Quick Guide. Minimizing Defects and Faults in Your Projects. Available: [FMEA \(Failure Mode and Effects Analysis\) Quick Guide \(isixsigma.com\)](https://www.isixsigma.com/resources/whitepapers/fmea-quick-guide/), October 06, 2024.
- Hayes, J., Understanding and implementing the Ishikawa diagram in quality management. *Quality Management Journal*, Vol. 30, No. 1, pp. 45-62, 2023.
- Haslam, K., What to know when claiming for accident caused by potholes in South African. News24. 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/, June 22, 2024.
- Kati, K.K., Kristjan, K., & Ott, K., Tire and pavement wear interaction monitoring for road performance indicators. *Estonian Journal of Engineering*, vol. 18, no. 4, pp. 324-335, 2012.
- Mathew, V., Introduction to pavement design. Indian Institute of Technology Bombay. Available: https://www.civil.iitb.ac.in/tvm/1100_LnTse/401_InTse/plain/plain.html, March 05, 2024.
- Mkwata, R., & Chong, E.M., Effect of pavement surface conditions on road traffic accident - A Review. *E3S Web of Conferences 347 Faculty of Engineering Computing and Science, Swinburne University of Technology Sarawak Campus*, Kuching, Malaysia, 2022.
- Nikolopoulou, K., What is purpose sampling? Available: <https://www.scribbr.com/methodology/purposive-sampling/>, August 15, 2024.
- Patil, A., & Jalindar, P., Effects of Bad Drainage on Roads. *Civil and Environmental Research*, Vol. 1 no. 1, 2011.
- Ray, S., The Risk Management Process in Project Management. Available: <https://www.projectmanager.com/blog/risk-management-process-steps>, October 15, 2022.
- Rodriguez, A., What are the 5 whys. Available: <https://www.mlean.com/blog/what-are-the-5-whys/>, November 01, 2024.
- South African National Roads Agency., *South African Pavement Engineering Manual (SAPEM)*, 2nd Edition, South Africa, Pretoria, 2024.
- Stephan, R., Risk management process. Project Management Institute. Available: <https://www.360factors.com/blog/five-steps-of-risk-management-process/>, February, 10, 2025.
- Virine, L., & Trumper, M., Project Risk Analysis Made Ridiculously Simple. *World Scientific Publishing*: Singapore, 2017.
- Wilson, M., Risk Management – Definition, Strategies and processes. Available: <https://www.pcwldd.com/definition/risk-management>, September 15, 2022.

Biographies

Msawenkosi Mkoka is a Student Researcher in the Department of Industrial and Systems Engineering at the Cape Peninsula University of Technology. His research interests include risk management, quality improvement, and infrastructure management. He holds a Bachelor's degree in Civil Engineering and is currently pursuing a Master's degree in Engineering Management.

Dr. Bronwyn Swartz is a Senior Lecturer in the Department of Industrial and Systems Engineering at the Cape Peninsula University of Technology. She earned a DPhil in Quality Management from the Durban University of Technology. Her research expertise encompasses the fields of engineering education and operational excellence.