UNIVERSITY OF KWAZULU – NATAL

An Integrated Solution for Pavement Management and Monitoring Systems in South Africa

By

Verushka Balaram

Student Number: 219052894

A dissertation submitted in partial fulfilment of the requirements for the degree of Master's in Business Administration

College of Law and Management Studies

Graduate School of Business and Leadership

Supervisor: Dr S Taylor

Revised Submission

June 2022

Declaration

I ....Verushka Balaram... declare that:

- The research reported in this thesis, except where otherwise indicated, is my original work.
- This thesis has not been submitted for any degree or examination at any other university.
- This thesis does not contain other persons' data, pictures, graphs, or other information, unless specifically acknowledged as being sourced from other persons.
- This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

  a) their words have been re-written, but the general information attributed to them has been referenced.

  b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

  c) Where I have reproduced a publication of which I am author, co-author, or editor, I have indicated in detail which part of the publication was actually written by myself alone and have fully referenced such publications.

  d) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed:

[redacted]

29 June 2022

Name: Verushka Balaram

Date

PR Tech Eng.- Reg No: 2018300195

Student Number: 219052894

Acknowledgements

I would like to express my heartfelt gratitude firstly to God for giving me the strength to get through this experience which seemed like a never-ending journey. There are a host of individuals that I would like to appreciate and acknowledge for their contribution, assistance, and guidance as without them this project would not have been completed:

- My supervisor, Dr Simon Taylor, thank you for the guidance through this journey.
- My Husband, Yeshveer Balaram for his love, support, and strength during this project. He has supported me through my studies, guided, assisted and most of all looked over our sons (Veerav and Vedanth Ashirvad Balaram). Without you wearing that mum cap as well I would not have been able to complete this dissertation.
- Mr Jay and Kala Harrypersadh (parents), for being my rock throughout my academic years and for encouraging me to be the best I can be. My sisters (Samantha Harrypersadh and Melisha Mungaroo) for your support.
- Pradeep and Radhika Balaram (family in law), thank you for always being our support system during my studies.
- My friends and colleagues currently undertaking their MBA degree with me, thank you for the continued support through this journey
- My colleagues and clients who participated in the interviews and observation, for there unequivocal support and assistance.

Abstract

Globally, South Africa has the tenth longest road network. The current condition of the road network has been deemed poor to extremely poor and is deteriorating further as years progress. Road Authorities have a responsibility to understand the status quo of each road so maintenance and construction works can continue in a given time making roads safer for all road users. The aim of this study is to explore and understand the methodologies utilised in the Pavement Management System for collection of road condition data in South Africa. The road condition data is utilized to design roads, road safety improvements, construction methods, and financial evaluation for South Africa. This study is significant as the road infrastructure is considered as one of the key components that help organisations contribute to the development of the economy of South Africa. This qualitative study utilised stratified purposive sampling to identify and select a total of twenty-one pavement engineers at various Civil Engineering firms and a Roads Authority in South Africa as participants. Data was collected from selected pavement engineers having extensive knowledge on the subject and were able to provide pertinent data on the methods utilised in industry and their view on the gaps in relation to data collection and the viable solutions for the future. The data for this study was collected by an interview process which took place over an online platform due to COVID-19 protocols. The interview guide provided participants the openness that enabled the researcher to obtain dominant themes by using thematic analysis. The results exposed the shortcomings at government level regarding planning, systems in place, execution of projects and reasons why adequate pavement data has not been received in the required timeframes to make strategic decisions for the road network of South Africa. The research performed exposed the shortcomings of manual visual assessment methods which has been used in industry which slowed production and performance of various organisations. The results further highlighted the evolution to the existing Pavement Management System through technology. The contribution technology can make creating an effective and efficient Pavement Management System whereby synergising the components of the PMS life cycle creating an integrated solution for South Africa. This will include Designs, Construction, and a fixed Asset evaluation of the road network for forecasting and budget allocation at government level which in the future can dissolve the maintenance backlog that is experienced. The study exposed the notion that adapting to the fourth Industrial

Revolution for pavement engineering can improve businesses and effectively grow the economy as swift outputs of intelligent pavement technology can improve performance and increase profitability of businesses. The suggested recommendations will guide policy and decision makers for future planning making the South African Road infrastructure safer for all.

Key words: *Strategic planning, performance, technology, Road Authorities*, pavement *engineers, Pavement Management System*

TABLE OF CONTENTS

Declaration ii
Acknowledgements iii
Abstract iv

CHAPTER 1 – INTRODUCTION OF RESEARCH

1.1 Introduction 1
1.2 Background 1
1.3 Problem Statement 3
1.4 Aim of the Study 4
1.5 Research Objectives 4
1.6 Research Questions 4
1.7 Justification of the Study 5
1.8 Limitation of the Study 5
1.9 Arrangment of the Dessertation 5
1.10 Summary of the Chapter 6

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction 7
2.2 Overview of the Road Network 7
2.3 Responsibility and Role of Road Authorities in South Africa 9
2.4 Understanding of Pavement Management System 10
2.4.1 Uses of Pavement Management Systems 18
2.5 Fuzzy Set Theory – Conceptual Framework 18
2.6 Defining Pavement Condition Survey 20
2.6.1 Benefits of Pavement Condition Surveys 21
2.7 Types of Data Collected 22
2.8 Data Collection Methods 26
2.8.1 Manual Method of Pavement Condition Survey 26
2.8.1.1 Advantages and Disadvantages of Manual Pavement Surveys 29
2.8.2 Collection of Data Through Automated Technology 30
2.8.2.1 Types of Equipment Utilised for Data Collection 32
2.8.2.1.1 Network Survey Vehicle 32
2.8.2.1.2 Traffic Speed Deflectometer (TSD) 36

2.8.2.2 Advantages and Disadvantages of Automated Data Collection and Processing , ...39
2.8.3 Cost and Time Frame Comparison between Manual Methods and Automated Methodology 41
2.9 Futher Research into the Analysis of Automated Pavement Condition Surveys 43
2.10 Pavement Survey Methodologies Utilised Around the World 45
2.11 Methodology Utilised in South Africa 47
2.12 Summary of the Chapter 48

CHAPTER 3 – RESEARCH METHODOLOGY

3.1 Introduction 49
3.2 Research Paradigm 49
3.3 Research Philosophy 52
3.4 Research Design 52
3.5 Research Approach 55
3.6 Research Methodology Choice 55
3.7 Research Strategies 56
3.8 Time Horizon 57
3.9 Target Population 58
3.10 Sampling 58
3.11 Data Collection 60
3.12 Analysis of Data 61
3.13 Limitation of the Study 62
3.14 Elimination of Bias 62
3.15 Ethical Consideration 63
3.15.1 Ensuring no harm comes across the participants during the study 63
3.15.2 Gatekeeper permission is obtained 63
3.15.3 Participants providing informed consent prior to questionnaire 64
3.15.4 Confirming anonymity and confidentiality with the study 64
3.16 Summary of the Chapter 64

CHAPTER 4 - RESEARCH FINDINGS AND INTERPRETATION OF DATA

4.1 Introduction 65
4.2 Demographics 66
4.2.1 Educational qualifications of participants 66
4.2.2 Years of experience in the Civil Engineering Industry 67

4.3 Analysis of the Data Collected 68
4.3.1 Themes about the perception of the importance of road condition assessments for strategic planning at government level for road infrastructure 68
4.3.1.1 Requirement for Suitable Systematic Strategic Planning 68
4.3.1.2 Procurement process at Road Authorities for maintenance projects 69
4.3.1.3 Limited budgets/ funding at governmental level for road infrastructure 71
4.3.2 Themes relating to the effectiveness of Pavement Management Systems on Maintenance Strategies 73
4.3.2.1 Obtaining objective big data to develop a beneficial financial and engineered solution 73
4.3.2.2 Lack of knowledge of pavement behaviour 74
4.3.3 Themes pertaining to the acceptable methodology chosen to conduct road condition assessments in organisations 76
4.3.3.1 Physical Visual Assessments 76
4.3.3.2 Post Rating Condition Assessments in engineering practice 77
4.3.3.3 Insight into the perspectives of the challenges and positives of manual methods 79
4.3.4 Themes relating to pavement technologies engineers can adopt to conduct road assessments 80
4.3.4.1 Awareness of pavement technology in industry 81
4.3.4.2 Prioritization of maintenance projects backed up by scientific, accurate data to make informed strategic decisions for implementation on South African roads 83
4.3.4.3 Acceptance to pavement intelligent technology 84
4.3.4.4 Improved Safety of Employees during field assessments 85
4.3.5 Themes relating to perspectives of the impact of an integrated solution to Pavement Management and Monitoring Systems in South Africa 87
4.3.5.1 Project deliverables are achieved much faster and issues arising are address timeously 87
4.3.5.2 Organisations adopting a long-term approach utilising technology for road infrastructure 89
4.3.6 Analysis of the field assessments between the two methods to collect pavement data 92
4.3.6.1 International Roughness Index (IRI) Comparison 93
4.3.6.2 Rutting of the Surface Comparison 97
4.4 Discussion of the Study 100
4.5 Summary of Chapter 104

CHAPTER 5 - CONCLUSION AND RECOMMENDATIONS

5.1 Introduction 105
5.2 Overview of the Study and Findings 105
5.3 Conclusion of the Study 107
5.4 Summary of the Chapter 111
5.5 Recommendations for the Future 112

References 113
Appendix A1 - Gatekeepers Permission Letters – Nankhoo Engineers 125
Appendix A2 – Gatekeepers Permission Letters – ARRB SYSYEMS 126
Appendix A3 - Gatekeepers Permission Letters – VNA Consulting 127
Appendix A4 - Gatekeepers Permission Letters – Endecon Consulting Engineers 128
Appendix A5 - Gatekeepers Permission Letters – GIBB Engineering 129
Appendix A6 - Gatekeepers Permission Letters – Department of Police, Roads and Transport , Free State 130
Appendix B - Participants Consent and Introduction Form 131
Appendix C – Ethical Clearance Approval Letter 134
Appendix D – Interview Guide 135
Appendix E – Turnitin Report 137

LIST OF TABLES

Table 2.1: Overview of the South African Road Network 8
Table 2.2: Comparison of savings vs cost for each scenario 43
Table 4.1: Themes focusing on the perception of the importance of strategic planning at governmental level at Provincial level 68
Table 4.2: Theme focusing on the influential factors of Pavement Management Systems on Maintenance Strategies) 73
Table 4.3: Themes focusing on the acceptable methodology chosen to conduct road condition assessments...76
Table 4.4: Themes relating to pavement technologies engineers can adopt to conduct road assessments)...81
Table 4.5: Theme relating to the perspectives of the impact of an integrated solution to Pavement Management and Monitoring Systems) 87
Table 4.6: Description of degree and roughness of a road 94
Table 4.7: Data collected from Assessors and Network Survey Vehicle – IRI 94
Table 4.8: Description of degree and rutting of an assessed road 97
Table 4.9: Data collected from Assessors and Network Survey Vehicle – Rutting 97

LIST OF FIGURES

Figure 2.1: Pavement Management System Cycle 11
Figure 2.2: Process of the Pavement management system..12
Figure 2.3: Road Deterioration..17
Figure 2.4: Conceptual Framework...19
Figure 2.5: Deterioration of Serviceability Over Time..20
Figure 2.6: Image indicating crocodile cracks 23
Figure 2.7: Image indicating Longitudinal Cracks 23
Figure 2.8: Image indicating Transverse Cracks..24
Figure 2.9: Image indicating Block Cracks (Source: Pavement Interactive, 2018).........24
Figure 2.10: Image indicating a severe pothole 25
Figure 2.11: Image indicating severe Rutting of road below straight edge.....................26
Figure 2.12: Components of the Network Survey Vehicle..32
Figure 2.13: Typical laser Layout..34
Figure 2.14: Positioning of high-resolution cameras 35
Figure 2.15: Technology within an Intelligent Pavement Assessment Vehicle (iPAVe) .38
Figure 3.0-1: Research Onion...51
Figure 4.0-1: Qualification of participants in the study 66
Figure 4.2: Years of Experience of participants 67
Figure 4.3: Graph illustrating participants that are aware of intelligent pavement technology 81
Figure 4.4: Integration for a Pavement Management and Monitoring System 89
Figure 4.5: Comparison of data for Assessor 1..95
Figure 4.6: Comparison of data for Assessor 2..95
Figure 4.7: Comparison of data for Assessor 3..95
Figure 4.8: Comparison of data for Assessor 4..96
Figure 4.9: Comparison of data for Assessor 5..96
Figure 4.10: Comparison of data for Assessor 1 – RUT 98
Figure 4.11: Comparison of data for Assessor 2 – RUT 98
Figure 4.12: Comparison of data for Assessor 3 – RUT 98
Figure 4.13: Comparison of data for Assessor 4 – RUT 99
Figure 4.14: Comparison of data for Assessor 5 – RUT 99

CHAPTER 1

INTRODUCTION OF RESEARCH

1.1 INTRODUCTION

Globally, South Africa has the tenth longest road network in the world (Ross and Townshend, 2019) and like most countries, road authorities all have a common goal and responsibility of managing its road network in a good "engineered" condition and safe "functional" condition for vehicular and pedestrian traffic. Nevertheless, this can be achieved by the collection of data in a resourceful way. This research provides insight into the practices of road condition assessments currently undertaken for Pavement Management System in the Civil Engineering Industry, in South Africa.

To have well-informed solutions for decision making, there needs to be an integrated Pavement Management System and a soundproof solution for monitoring road condition, maintaining and creating new infrastructure productively. Manual methods of road assessments have been the norm for decades and have been the commonly utilised method (Ragnoli, Blasiis, and Benedetto,2018). As time progressed there have been an evolution to automated road assessment systems (Okine and Adarkwa,2013).

The purpose of this chapter is to discuss the overview of this study. The discussion will include the background, aim, objectives, research questions, and limitation of the study. It is important to note this study was conducted by Civil engineers with Civil engineers in mind to help create and encourage efficiency in pavement engineering organisations.

1.2 BACKGROUND

Road authorities around the world, including South Africa have a responsibility to understand the status quo of the road network, to be able to upgrade and maintain the infrastructure on an annual basis (Underwood, Kim, and Corley-Lay, 2011). The structural and surface condition of a road will either be in a poor, fair, or good condition. Good condition is deemed a well-maintained standard of road i.e., a newly upgraded road or a well taken care road TMH 9 (Committee of Transport Officials (COTO), 2016), To undertake this type of evaluation, civil engineering organisations undertake visual assessments of roads and analyse the condition of the data obtained to notify road authorities what percentage of the network requires light rehabilitation to heavy rehabilitation to a whole new upgrade of the road prism. The system used for evaluation is called the Pavement Management System which provides critical information to establish the maintenance and rehabilitation obligations (Cafiso, D'Agostino, Delfino, and Montella, 2017). A Pavement Management System (PMS) is a tool used for planning and guiding road agencies through strategic decision-making and planning to efficiently maintain the road network in an appropriate and cost-effective way ensuring safety is enhanced for road users at all times (Ragnoli et al, 2018). From this assessment undertaken within the Pavement Management System, roads are prioritized to be maintained in financial years over a period of five years at a time (Government Gazette, 2013). Within the South African Road authorities for example, the KZN Department of Transport is regulated in accordance with the Division of Revenue Act (DoRA) (Government Gazette, 2013) or specifically the Provincials Roads Maintenance Grant (PRMG). The strategic goal of the PRMG is to ensure efficient and effective investment in provincial roads which must be aligned with the S'hamba Sonke Road program. This programme was launched by the Department of Transport in 2011 to address the backlog in road repairs in each province of South Africa with the allocated funds for the region (South Africa Yearbook, 2015 and National Treasury,2018)

Network level road condition surveys are an essential aspect of Road Asset Management Systems (RAMS) and have been systematically undertaken in South Africa since early 1980's. To undertake the type of planning for the department, condition surveys which is also known as visual assessments must be completed. There are two major data collections methods which can used for pavement condition assessments, manual and automated systems (Bogus, Giovanni, Migliaccio and Cordova, 2010).

For decades civil engineers in South Africa have been undertaking manual road condition assessments which entails a team physically assessing each road of a network, this had become the familiarised methodology (Saeed, Dougherty, Nyberg, Rebreyend and Jomaa, 2020).

In the last decade, the use of automation for road assessments created an advantageous positive to field work (Bogus et al, 2010). The automated survey method had obtained popularity in various international countries in the past decade as researchers have improved the technology (Underwood et al, 2011), but have not been fully incorporated and utilised in data collection plans in various developing countries (Moola and Tetley, 2021). The introduction of sophisticated, efficient equipment mounted on vehicles to measure distress and obtain a classification is opening new perspective in road pavement analysis and management (Cafiso et al, 2017). The automated intelligent vehicles utilised are called the Network Survey Vehicles (NSV) which utilizes digital laser profiles to measure riding quality, texture, lane widths and rut depth together with high-definition digital georeferenced imaging to record the road surface condition and geometry. The Network survey vehicle technology further progressed into an integrated equipment that measures surface as well as structural defects all at once at traffic speed. This vehicle incorporates the Falling Weight Deflectometer measurements with the road profiles and laser measurement system (LCMS) for crack detection and image recording (Underwood et al, 2011).

1.3 PROBLEM STATEMENT

As per research, there is a huge backlog of conducting road infrastructure maintenance and rehabilitation projects in South Africa (Ross and Townshend, 2019). Roads surpassing their design life due to delayed maintenance measures hence causing major deterioration which is hindering on the safety of road users and the economy as roads are the lifeline to many organisations. Road Authorities and road agencies across South Africa needs the necessary tools in place. Providing the existing road condition information is required to make vital decisions within a Pavement Management System to improve the condition and safety on all road networks. According to Chang, Rodriguez, Yapp, and Pierce, (2018) a manual data road collection system causes a delay in obtaining pavement condition data for road maintenance and rehabilitation which has had a ripple effect on the various components or layers of the Pavement Management System. This causes a delay to road authorities making strategic decisions and planning for their road networks in each financial year. An elevated rate of efficiency is imperative to reduce the backlog, by creating or enhancing a system which develops prioritisation schedules and providing an integrated solution for businesses and road authorities to work in a systematic way.

1.4 AIM OF THE STUDY

The aim of this study is to explore and understand the methodologies utilised in the Pavement Management System for collection of road condition data, the approach taken towards these methodologies and its extended use beyond pavement condition data to synergise components such as design, road safety, construction, and financial evaluation for South Africa.

1.5 RESEARCH OBJECTIVES

This research study looked at accomplishing the following objectives:

a) To understand the importance of road condition assessments for strategic planning at government level.
b) To explore the value of Pavement Management Systems in identifying maintenance and rehabilitation requirements of the countries road infrastructure.
c) To observe the perceptions of the accepted methods of conducting road condition assessments by pavement engineers in South Africa.
d) Identify the key road-testing technologies pavement engineers can use and adopt to conduct road condition surveys in South Africa.
e) To understand the impact an integrated solution to Pavement Management and Monitoring Systems have on the South African economy.

1.6 RESEARCH QUESTIONS

a) How important is road condition assessment for strategic planning at government level in South Africa?
b) How does Pavement Management Systems influence road maintenance strategies?
c) What are the accepted methods of conducting road condition assessments by pavement engineers in South Africa?
d) What are the key road-testing technologies pavement engineers can utilise and adopt to conduct road condition surveys on various types of road networks of South Africa?
e) What impact will an integrated solution to Pavement Management and Monitoring Systems have on the South African economy?

1.7 JUSTIFICATION OF THE STUDY

Road Infrastructure is a vital component of our society's infrastructure system where adequate functioning of the asset is crucial for improvement and development. Similar to various other categories of infrastructure assets, pavements deteriorate over time. Therefore, there is a requirement to discover ways to preserve these capital-intensive assets to ensure they perform as expected (Okine and Adarkwa,2013). As a developing country, South Africa should explore various aspects of strategies for a functional Pavement Management System of creating an efficient integrated system in Civil Engineering. Road Asset Management portrays great opportunities in the Civil Engineering industry as it is the backbone to road infrastructure maintenance and upgrade plans. Maintaining or building new roads from well informed decision making is the direction KZN along with the rest of the country should strive for, as allocated funding will be utilised in a systematic manner.

1.8 LIMITATIONS OF THE STUDY

The research that is being undertaken, is confined only to the Civil Engineering sector working with road infrastructure. The study is further limited to engineers working with road investigations, pavement designs, construction of roads and evaluating the road network within public and private sectors for example, road authorities who make budgetary decisions and engineering organisations undertaking the works.

1.9 ARRANGMENT OF THE DESSERTATION

The design of this study outlines the arrangement of the dissertation which will be presented in five chapters described below:

Chapter 1 – Introduction

Chapter one provides an outline of the research that will be undertaken. An introduction is provided with the background to the topic, the research problem, study aims, study objective, research questions, and limitations of the research.

Chapter 2 – Literature Review

The second chapter analyses the literature applicable to the study. This chapter will provide an in-depth understanding of the various Pavement Management components concepts, key definitions, an overview of the topic, the conceptual framework, the advantages and drawbacks of the methodologies and new developments.

Chapter 3 – Research Methodology

Chapter three provides the methodology undertaken for this study. It covers the selected approach that was applied to the study and research rationale. This chapter explains the location of the site, target population, sampling strategy, sampling size, design of the interview process, and data collection via interviews and field analysis. This chapter further reviews the ethical clearance and the data analysis that will be used for the study.

Chapter 4 – Research finding and Interpretation of data

This chapter will present the results from the qualitative study and observation of data. Results will be presented, discussed and interpretated for full understanding of the results. This chapter will assess the participants feedback in relation to literature and aim of the research. In addition to this, a site investigation will be undertaken to analyse and compare the data collected between manual and automation methods

Chapter 5 – Conclusion and Recommendation

This last chapter will outline the conclusion for the study. It will evaluate if the objectives and questions posed have been addressed and answered by the study undertaken. A further discussion on the recommendations are given for future undertakings.

1.10 SUMMARY OF THE CHAPTER

Chapter one sets the tone for the study which intends to evaluate an integrated solutions to be used in Pavement Management Systems creating an efficient and effective benchmark to monitor and collect data for road condition. This chapter outlines the overview of the study by discussing the background to the research, the aim of the study, objectives, the limitations, and arrangement of the research paper. The subsequent chapter will detail the literature review.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides insight and detailed analysis of the theoretical perspective that will underpin this research study. The objective of presenting this in-depth theory will provide the reader with a full understanding regarding the importance of efficient and effective road condition survey methodologies to utilise. Road condition data is one component of the holistic Pavement Management System as this is vital in decision making for governmental road authorities to provide structurally sound road networks for all road users. The topics that will be covered in this chapter are, overview of the road network, the understanding of Pavement Management Systems and its life cycle components, definitions of road network, pavement condition surveys, purpose of pavement condition data, understanding the concept of manual visual assessments, the process of this method, issues raised with this method. The research goes on further to discuss road technology, the importance of it, the various technologies that can contribute to collecting data, types of distresses collected, comparison of the methodologies, approaches used in developed and emerging countries and finally what is being undertaken in South Africa for collection of data for infrastructure development measures.

2.2 OVERVIEW OF THE ROAD NETWORK

Road infrastructure is considered to be a vital prerequisite of social and economic development of any country (Masarova, 2013). The road infrastructure carries goods, raw material, people, food, semi-finished and finished products intended for sale via exports or within the country. The road infrastructure affects the mobility and flexibility of any workforce which can be seen in the employment levels of the country (Masarova, 2013). As we understand, a higher employment level will increase the gross domestic product and standard of living for all resulting in a positive outlook on the economy. This statement holds true for South Africa as most of the travel takes place on roads. Hence it is vital for expansion and upgrade to continuously occur as this is pertinent to increase performance and contribute to an economic boost.

South Africa’s total length of roads equates to seven hundred and fifty thousand (750 000) kilometres which is the tenth longest road network and the eighteenth longest paved road network in the world (Department of Transport, 2021). The Figure of 750 000 kilometres is inclusive of un-proclaimed roads. The road network consists of national, provincial, and municipal roads. The South African National Road Agency Limited (SANRAL) is an entity of the National Department of Transport (NDoT), they are the implementing agents for the national routes. These two key players and various provincial road authorities play an influential role in creating policies and setting standards (Department of Transport, 2018).

Roads represent one of the largest public infrastructure investments in most countries. Focusing more on the provincial road networks of South Africa, these roads are managed, by provincial departments; research shows that there are some roads that has been handed over to SANRAL to maintain due to lack of human capacity and increased traffic on the roads (Department of Transport, 2018). The provincial roads play an extremely vital component to the full network, they are called the connector network and plays a pivotal role in supporting economic activity and providing the required access to social services within the various provinces. Hence, it’s imperative a full understanding of the network is required to make proper maintenance and upgrade decisions in a swift and easy way. The nine provinces of South Africa together manage approximately forty-eight thousand (48000) kilometres paved and one hundred and seventy - four thousand (174 000) unpaved (gravel) roads. The municipalities manage approximately fifty-one thousand, six hundred and ninety (51690) kilometres of paved road and approximately fourteen thousand, five hundred (14500) kilometres of the gravel network. Tabulated in Table 1 is an overview of the network of roads in the country.

Table 2.1: Overview of the South African Road Network

Authority	Road Distance (km)			Network Split
	Paved	Gravel	Total	
SANRAL	22 197	0	22 197	3%
Provinces	48 945	173 732	222 677	30%
Metropolitan municipalities	51 682	14 461	66 143	9%
District Municipalities	40 684	266 416	307 064	41%
Unproclaimed roads	Uncertain	Uncertain	131 919	18%
Total	**163 472**	**454 609**	**750 000**	**100%**

Source: Ross and Townshend,2019:2

2.3 RESPONSIBILITY AND ROLE OF ROAD AUTHORITIES IN SOUTH AFRICA

Various provincial departments have a level of responsibility regarding maintenance and upgrading their roads so there is a constant improvement to the economy. As years progressed due to various reasons which includes, insufficient resources, lack of protocols in policies adopted, invalid information of road conditions and lack of proactive planning, have all calumniated in there being a road maintenance backlog of R197 Billion to R417 Billion (Arnoldi, 2019) and the rising replacement value of these roads holistically equates to R2.0 trillion rands (Department of Transport, 2021, Ross and Townshend, 2019 and National Treasury, 2018).

In South Africa, the provinces are funded through the Provincial Roads Maintenance Grant (PRMG) and as per the Government gazetted Division of Revenues Act (DoRA) the provinces are obligated to collect pavement data of the network and a host of other data annually so they can understand if the network has deteriorated and where are the areas of improvement needed. As funding is made available provincial government have an obligation to strategically plan and understand where the issues lie to ensure policy makers and decision makers receive objective data to make important decisions for the network. According to Gartenstein, (2018), strategic planning is a process used within organisations to provide a sense of direction, helps with the creative ideas to accomplish their goals and internal performance management systems. It is a mechanism to continuously monitor and evaluate progress achieved each year through the operational and management plan created. To strategically plan in an organisation, a clear mission, vision and timelines for strategy implementation and progress monitoring is required which allows for success to be achieved (Gartenstein, 2018).

Radopoulou and Brilakis (2016) indicates that delays in monitoring and implementation of road projects has shown to be problematic as the level of safety on deteriorated roads have further decreased, endangering local commuters. According to Ambe and Weiss, (2012) these delays are severely related to the to lack of efficient procurement processes at government departments due to inadequate planning and linking the demand of activities to the budgets, unethical behaviour, lack of accountability and corruption.

The delays in implementation has also shown to be due to the lack of uniform data collection, data quality control and insufficient protocols for inspections has led to insufficient information of existing roads creating a gap in pertinent information that is given to decision makers. Radopoulou and Brilakis, (2016), stresses that an effective, innovative road asset management system is required for adequate condition assessments, much improvement of the overall identification and monitoring of the South African Provincial Road network is imperative. Although the budgets that are given by the PRMG may be insufficient in certain financial years, with the proper tools in place to obtain adequate data it will assist with creating a prioritization list where all roads will be attended in financial years going forward improving the economy.

2.4 UNDERSTANDING OF PAVEMENT MANAGEMENT SYSTEM

Pavements or roads are a major component of highway infrastructure. This asset is one that is constantly used for transporting goods and people from one point to another. It is the backbone to a country's economy hence requires attention for it to perform and service all amenities. Upgrades, rehabilitation, and maintenance of road infrastructure for the required serviceability is a constant routine problem faced by various organizations and road engineers.

The constant improvement in road management systems provides an end result which is the reduction in costs and time (Zafar, Shah, Memon, Rind and Soomro, (2019)) Pavement Management Systems are an efficient and cost-effective tool to study and address pavement conditions of a road network to assure comfort and safety of all road users (Zafar et al, 2019) and (Rusu, Sitar, and Jecan, (2015)). This system alerts and cautions road managers regarding critical phases in a life cycle of a road network at large. The capacity to deduce the road network current conditions as well as to be able to predict the future condition is one of the significant features of a Pavement Management System (Zafar et al, 2019).

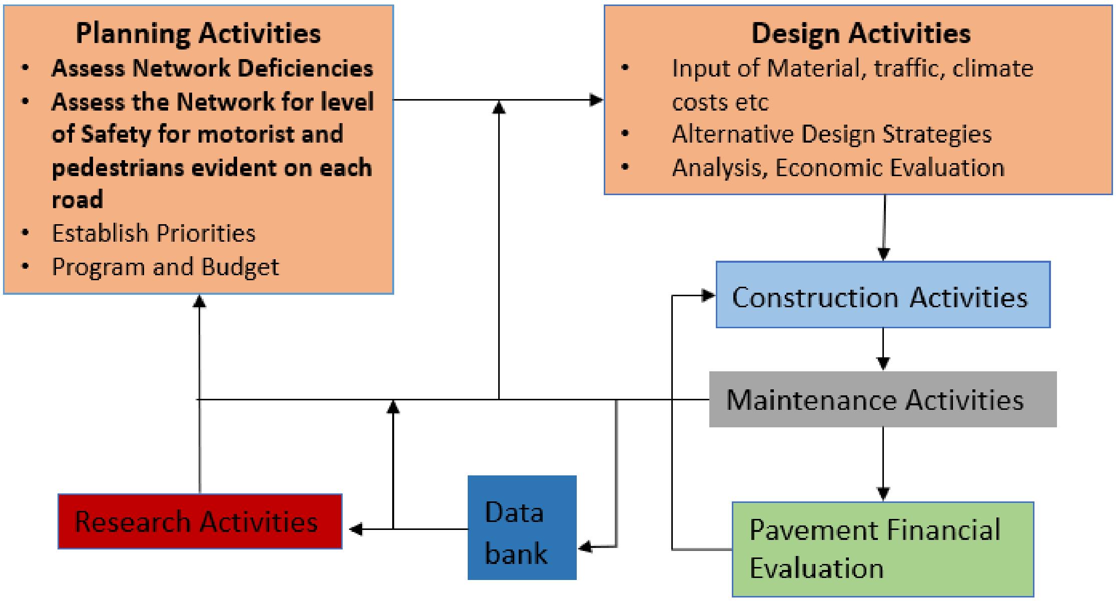

Figure 2.1: Pavement Management System Cycle

Source: Taute and Russell, 2018

Figure 2.1 indicates the Pavement Management System cycle that's has been created to be utilised to assist with strategic and realistic decisions to be made for road infrastructure. The process starts off by the Planning Activities which encompasses data collection to understand the network deficiencies evident on the road, the pavement and geometric design activities, which feeds into construction and maintenance activities. This information helps with road asset evaluations. There are various factors that are intertwined within the Pavement Management System process. When data is collected its stored for usage as this data must be updated on an annual basis as per Department of Transport policies. This data is used continuously for planning and performance tracking from previous years to further evaluate the network. The data bank is a contributing factor to research activities as new improvements can be made for the road infrastructure if adequate, accurate and factual data is produced. The following points will provide a detailed understanding of the cycle.

a) Planning Activities incorporating data collection for condition assessments and Road Safety

There are four components of the Planning Activities for a Pavement Management System of which road condition assessments play a very vital role in the life cycle of the system.

The image below illustrates the process of the pavement management process.

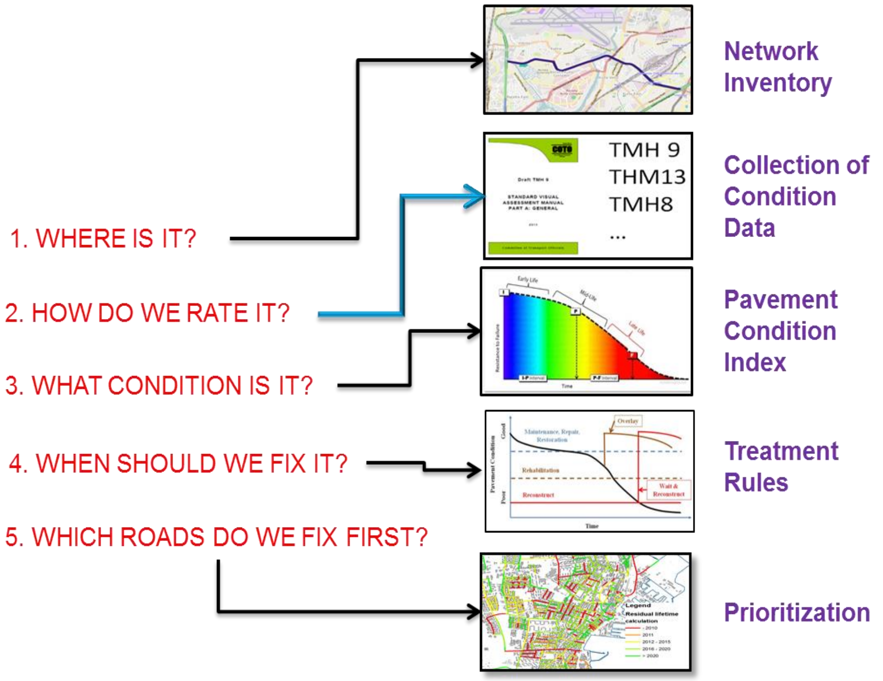

Figure 2.2: Process of the Pavement Management System

(Source: Vitillo, 2017:12)

Recent studies indicate that in order to enhance the road pavement management and continue to guarantee optimal mobility conditions for all vehicle occupants and vulnerable road users a system should be in practice (Ragnoli et al, 2018). Refer to Figure 2.2, here are the steps taken to ensure a productive Pavement Management System. It starts with understanding the status quo of the network for example, obtaining the necessary spatial details of each road in the network. The next step is the data collection process, this is the most important aspect of the planning segment of the holistic Pavement Management System. A road pavement condition affects driver comfort, vehicle occupant safety, traffic and travel times emission levels and finally operating costs, hence it’s imperative to know the status quo of the network. Obtaining the ability to undertake management of a road pavement involves in-depth knowledge of the existing condition and based on the severity of the road condition, when would be the optimal time for maintenance. This methodology of understanding the road network conditions provides an easier platform to prioritise maintenance for the road network. The pavement condition can be determined by two important methods of pavement condition surveys that is manually or automated systems. The first option is undertaking visual assessments manually which is highly labour-intensive, prone to subjectivity of assessors and very time consuming. The latter option of visual assessments provides data collection either via semi-autonomous or fully autonomous methods. Subjectivity is minimized, there is an initial cost involved but the productivity it provides out ways the costs realisation in the long run.

At step three, analysis of the data is undertaken to understand how to improve the design life of each road and the last step is creating a priority schedule of the roads that require the most attention with the necessary costs of treatments.

Road Safety

Worldwide more than 1.35 million people are killed on roads and an additional 50 million people are injured. A large sum of these people dying are from low to middle income countries (World Health Organisation, 2021). In South Africa 26 of every 100 000 people die on the roads. This is much higher that the global average of 18 per 100 000 (Randall, 2021). In the past an approach has been undertaken for evaluating safety in South Africa, this is done by physically assessing each road and evaluating the level of safety evident, this is called Road Safety Audits or Appraisals. Road Safety Audits are undertaken on roads to identify the spots likely to cause an accident. A team of engineers proficient in road safety engineering is required for this process. this method of safety assessments are undertaken for big networks and project level roads. This process is slow as a road a time is safety assessed which introduces various limitations (Road Safety Manuals for Africa, 2014). Along with Road Safety audits, accident investigation is also considered but this is deemed a reactive approach. An investigation is undertaken when an incident or fatal collision has taken place to understand why the incident occurred. According to Hywel, (2018), unsafe conditions and unsafe acts are the result of underling failures and the symptoms of failure of management control is the root cause of majority of accidents.

According to Ragnoli et al, (2018), there has been the traditional reactive approach to road upgrades and maintenance in various authorities where recommendations to conduct road replacement occurs once significant issues arise regarding unsafe condition to commuters. Road condition left unattended over years will deteriorate at a rapid pace creating unforeseen cost not planned for. The interventions for this, lead to expensive road designs and intense road rehabilitation. On the other hand, there is the proactive approach that is orientated around pavement preservation. A systematic strategy is created for implementing moderately small scale and less invasive repairs on the roads prior to any major deterioration or degradation occurring (Ragnoli et al, 2018). This however will limit the necessary full scale road reconstruction. This process calls for roads to be monitored annually and prioritised accordingly. When comparing proactive to reactive approach, the proactive approach will result in long term savings, drastic reduction of traffic congestion, increased and maintained safety conditions (Ragnoli et al, 2018). Data collection and constant analysis phases are vital to undertake a proactive approach, successful and fundamental PMS implementation.

b) Design Activities

The data that is collected under Planning activities are utilised for pavement design. The data of an existing road is analysed to understand the environment the road that to be built is in and decipher ideas on the best possible economic design for the construction of a road. An in-depth understanding of the pavement behaviour is vital prior to starting a pavement design. This will include the pavement behaviour under loading, long term pavement behaviour, load sensitivity and materials. Deflections are obtained when a load is applied to a road and measurements are taken as the pavement deflects (SAPEM, 2014). Deflection data indicating the structural strength of the road is extensively utilised for design to provide an understanding of the integrity of the existing pavement. The deflections are further used within various variable pavements design methods to obtain the most economical design with the best suitable materials taking into consideration factors such as drainage evaluations, type of loads the road will be exposed too, traffic volumes, predicted traffic volumes, needs analysis and costs (SAPEM, 2014). Similarly, a sand patch test is manually used for measurements of macro texture which is undertaken by spreading sand over a section of road with a wooden spoon into a circular patch, filling the depressions in the road and measuring these sections (Bhatti, 2020). To understand level of skid resistance evident on an existing road a wheel is dragged at an angle to its direction of travel. The wheel angle creates a side way force, this is measured and provides a co-efficient of friction (Bhatti, 2020). This method advises on the level of skid that is evident on a road when it is slightly wet.

c) Construction and Maintenance activities

The construction phase includes contracts and specifications, work scheduling, quality control, construction operations, and processing of data (Amin, 2015). Focusing more on quality control for this study, this aspect is very crucial in road building and rehabilitation. Proper quality control is needed so the road will be strong and withstand the traffic that it would be exposed to. Quality control of the methods of construction, construction material and the finished product is important for obtaining improved and uniform standard of road construction. Presently to ensure each layer work of the road structure has passed, density tests are undertaken by various devices after compaction of the layer occurs. This equipment has to be calibrated constantly to ensure the correct readings are given. This process has proven to be time consuming, has a level of subjectivity and can delay processes if this is not undertaken correctly (Bhatti, 2020).

d) Pavement Financial Valuation

Roads Assets must be valued on an annual basis to determine the current replacement value of the asset (COTO, 2013). The main purpose of a valuation is to fully document the financial value of road infrastructure asset owned by a certain roads authority and included in the balance sheets so this can be reported to National Authorities of the country. Valuating places a monetary value on road assets emphasizing its importance and the potential cost to replace such an asset to return to its new workable condition. The cost is determined through the depreciation of the road network which represents the consumption of the applicable asset in delivering services to the road users and other stakeholders (PIARC,2019 and COTO,2013). Continuous monitoring on an annual basis of road assets and its condition assists to indicate if the investment in the road asset is appropriate to maintain and if the applicable funds are being provided for. The feedback received from each province regarding the valuation of road assets help

National Road Authorities and National Treasury understand the improvements conducted per region to uphold safety, access to various amenities and organisations to help boost the economy.

e) Data bank

As data is received from Planning activities inclusive of Road Safety, Design, Construction Activities, Maintenance Activities and Financial Valuation of road assets it is stored as per National Department of Transport DoRA requirements. The PMS framework has separately identified the data bank to highlight its central role as an information base for all activities (Amin, 2015). This data is valid for a period of time as data can be relooked at. According to National Treasury (b), (2018) various Roads Authorities of South Africa do not have valid road data to work with and perform the tasks to undertake the cycle of a Pavement Management System. Lack of the information needed has led to the maintenance and construction backlog that is evident in South Africa (National Treasury, 2018).

f) Research Activities

Research to obtain innovation for Pavement Management Systems is vital, hence it plays a vital role within the PMS life cycle. The data that is stored assists scientist and researchers to view existing issues and create ways to find appropriate intervention programmes to create efficiency (Southern African Bitumen Association, 2018: (Amin, 2015).

A Pavement Management System (PMS) is a highly recommended and a systematic international procedure to assist road authorities and road agencies of South Africa in finding an optimum approach to road routine maintenance of all existing roads in a network particularly the South African road network. It is known as an organised methodology to assist decision makers al various management levels with strategies derived through clearly well-established rational procedures. Improvement to the PMS systems is required as years progress to constant keep data accurate for usage to uplift the road infrastructure (Amin, 2015). Lack of maintenance results in higher costs as more intensive work is required to bring the road back to standards. The correct tools used within a system helps create the efficiency required.

Figure 2.3 illustrates pavement deterioration as lack of maintenance occurs. The less attention a road is given without the needed interventions there is severe deterioration with time. Research shows road failure falls into two major sections for evaluations. Its either functional failure or structural failure. Functional failure is distress in pavement surface theses being depressions, cracks, rutting, and poor riding quality (IRI). As surface failure are not addressed timeously the problem grows into functional failure as well. To easily understand functional failure, the road would not perform its intended function without causing an inconvenience to vehicle occupants and major impacts to the vehicle itself (Zafar et al, 2019). Structural failure involves the intense damage or failure to the underlying layer works of the road structure. This type of failure causes pavements to be unable to withstand axle loads on the surface of the road pavement (Zafar et al, 2019). The cost incurred at the base rehabilitation level is exorbitant, hence its vital for continuous maintenance to be undertake and not let the road surpass its design life. This boils down to constant road condition data collected annually to understand the current issues and strategize for future works.

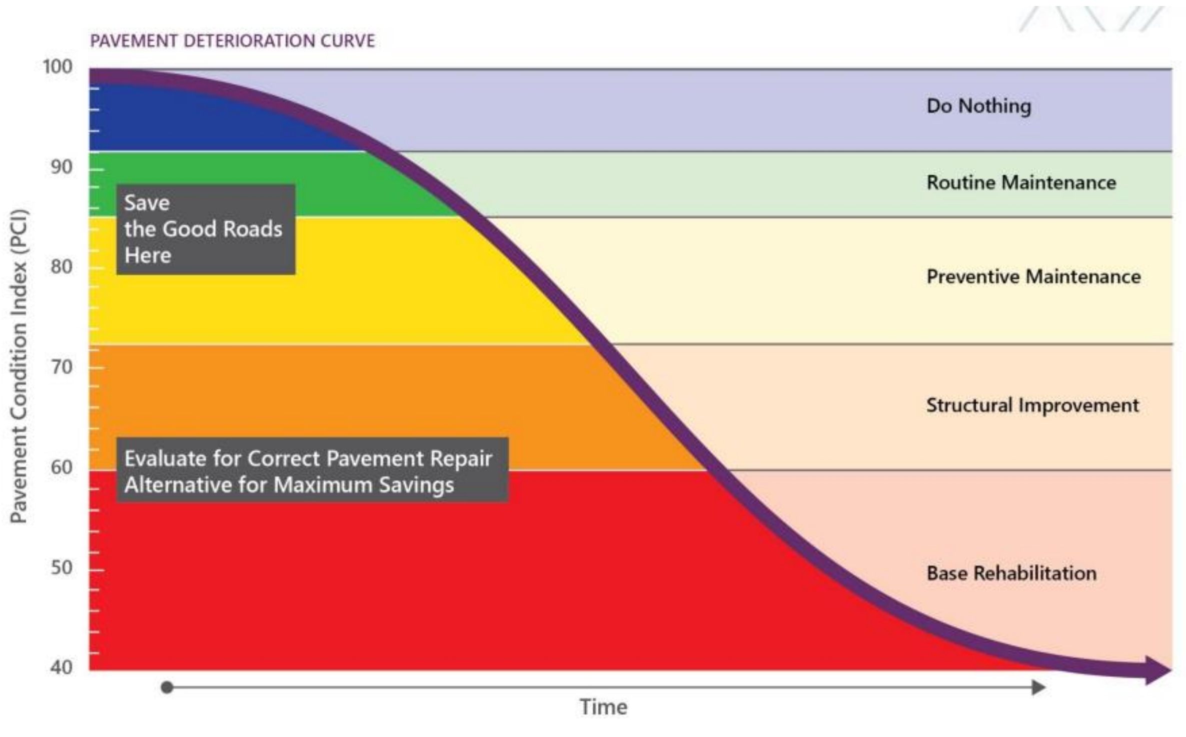

Figure 2.3: Road Deterioration with time

(Source: Southern African Bitumen Association, 2018:2)

2.4.1 USES OF PAVEMENT MANAGEMENT SYSTEMS

The quality of Pavement Condition data supports a variety of decisions, and it impacts directly and indirectly on road authorities processes and procedures. Below are ways in which pavement condition data can be utilised: (Pierce, McGovern, and Zimmerman, 2013)

- Systematically distinguishing current road construction
- Developing models of predicted road deterioration
- Forecasting future conditions
- Creating and preparing treatment recommendations, cost, and timelines
- Developing and focussing on annual and multi-year work programs.
- Assigning resources between regions and/or assets.
- Analysing the effects of various budget and treatment developments.
- Analysing performance of different pavement designs and/or materials.

2.5 CONCEPTUAL FRAMEWORK

To undertake a conceptual framework, it is desired to test for cause and effect via dependant and independent variables. For this subject matter the independent variable is road age and dependant variable is road condition, that is road condition is dependent on time passage. The next step is to identify the other variables influencing the dependant and independent variable. These are called moderators and mediators which is also known as control variables. A moderator alters the effect that an independent variable has on the dependant variable. Therefore, this changes the effect component of the cause-and-effect relationship. For this subject matter the moderator is a Pavement Management System. Adding this component in will have a positive effect on road condition after a period of time increasing life expectancy possibly beyond design life projections. The Pavement Management System as a moderating variable therefore changes the cause-and-effect relationship between the two variables as value increases or decreases. Mediating variables also exist, these link the dependant and independent variable. For this study the mediating variable are the planning activities incorporating safety and road condition assessments, design activities, construction activities, maintenance activities financial evaluation of assets, data bank and research. Being evaluated utilising Rough set theory. These are all control variables which must be held constant, so they don't interfere with data sets which is the calibration of the Network Survey Vehicle and Intelligent Pavement Management Vehicle. These types of equipment will be further studied later in this study.

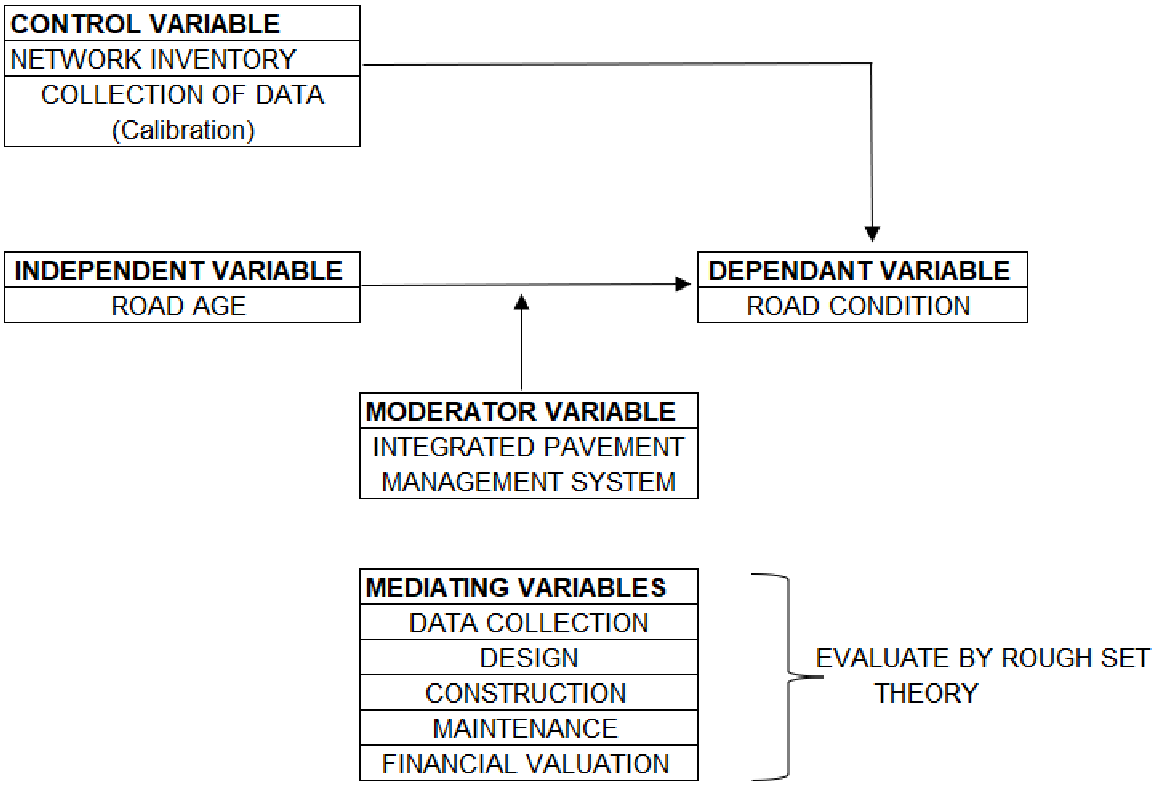

Figure 2.4: Conceptual Framework

Rough Set Theory

Various types of deterioration occur to pavements because of severe dynamic loading, weak foundation, improper mix design change of climates and overweighted trucks. Road distresses survey records the severity and coverage of existing distress types in order to adopt proper maintenance and rehabilitation (M&R) treatments. It is extremely important to utilise proper M&R treatments to be implemented at the correct time for specific distress type (Chang, Kang and Tzeng, 2007). The correct treatments can save long term but will also at the same time keep the pavement above an acceptable serviceability. Currently various M&R strategies are usually undertaken by humans' subjective judgements, hence introducing Rough Set Theory allows data to be used objectively when dealing with large distress data to make appropriate M&R Strategies for eliminating engineering judgement errors and simultaneously improve efficiency in the decision-making process in a Pavement Management System.

2.6 DEFINING PAVEMENT CONDITION SURVEY

As per the Pavement Management Systems cycle, condition surveys are very important for any planning to be undertaken for a road network hence much emphasis is placed on this activity. Pavement Condition Surveys are defined as activities that are undertaken to understand and provide an indication of the serviceability and the current condition of a road pavement over a period of time. The activities of a pavement condition survey have three main aspects which are data collection, the condition rating or assessments and quality management (Adarkwa and Okine, 2013). Pavement condition surveys play a very pivotal role in the management of a road network of any size. Research shows that the most valuable road information is retrieved from a pavement condition survey which analyses pavement performance. Notwithstanding the collected data is further used to forecast the performance of a road structure and determine the level of safety that exists on that carriageway (Timm and McQueen, 2004).

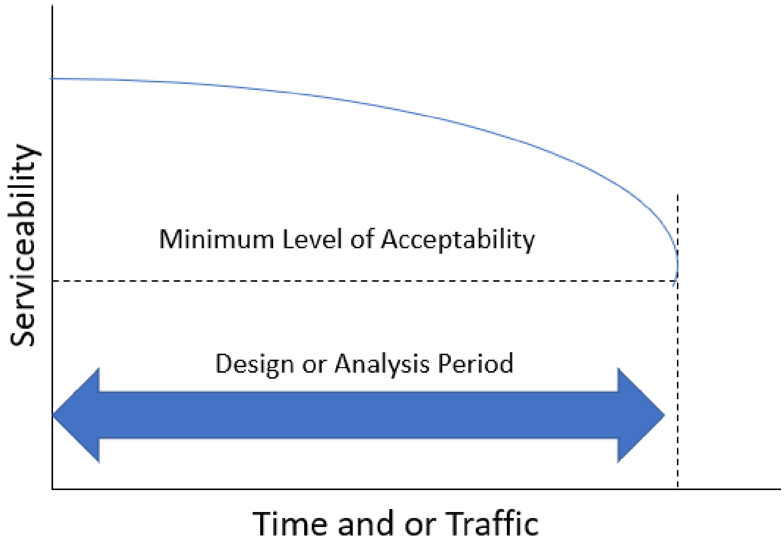

Figure 2.5: Deterioration of Serviceability Over Time

(Source: Timm and McQueen, 2004:7)

Figure 2.5 explains condition surveys accompanied by traffic data history and time over a period of years. This is sufficient information to furnish road authorities with a history or trend pattern of deterioration, serviceability, and performance of the road (Timm and McQueen, 2004).

Monitoring the condition of a road network after construction and comparing the actual with the desired performance levels periodically helps with appraising the extent of damage and identifying the source of the problem. With this information pavement engineers can design the treatments accordingly and adopt an understanding for a prioritization of interventions (Ragnoli et al, 2018). Pavement condition surveys can be conducted in two particular ways either manually or the automated way using sophisticated equipment installed on to vehicles to measure road conditions.

2.6.1 BENEFITS OF PAVEMENT CONDITION SURVEYS

a) Road authority for example, Department of Transport will have comprehensively complete inventory of the paved and unpaved network of the system. The inventory will include information such as road name, length, width, and type of pavement surface, condition index etc; additional roadside furniture data is also captured and stored for use (Sharpe, Southgate, and Deen, 2012), (Timm and McQueen, 2004), (Pierce, McGovern, and Zimmerman, 2013).

b) An objective evaluation of the road condition is obtained from a pavement condition survey. The results from the analysis of the filed data provides the type and number of distresses found, the overall condition rating and the recommendation for maintenance and rehabilitation activities. In addition to this information costs of repairs are deciphered by a program called Highway Development and Maintenance. Management System (HDM4). This vital information is utilised to prioritise roads from worst to good with appropriate costs and treatment plans, hence further plan an implementation strategy for various financial years (Sharpe, Southgate, and Deen, 2012), (Timm and McQueen, 2004), (Pierce, McGovern, and Zimmerman, 2013).

c) The analysis of the pavement condition surveys helps indicate the condition of the road network. This however provides an estimation of budgets required to preserve the infrastructure. These surveys are conducted annually and should be able to indicate if the network is improving or deteriorating. Short term and long-term budgets are dependent on pavement condition surveys (Sharpe, Southgate, and Deen, 2012), (Timm and McQueen, 2004), (Pierce, McGovern, and Zimmerman, 2013).

d) After collection of road data, the road department will have a record of the distresses to be able to base their informed decisions on (Sharpe, Southgate, and Deen, 2012), (Timm and McQueen, 2004), (Pierce, McGovern, and Zimmerman, 2013).

e) As data is collected, this information is stored for usage on a virtual cloud or similar type of medium. The data can be accessed fairly easily by utilising a computer than referring to stored physical files of road data (Sharpe, Southgate, and Deen, 2012), (Timm and McQueen, 2004), (Pierce, McGovern, and Zimmerman, 2013).

2.7 TYPES OF DATA COLLECTED

Traffic volumes, environment, climate, and purpose of the road are taken into consideration when roads are being designed to be built. A road is only designed for a certain design life, as continuous maintenance occurs post construction of a road, the life of the pavement will be prolonged. Due to lack of maintenance the condition of the road begins to deteriorate causing distresses or road failures which are either surface or structural failures. Indicated from figure 2.6 to figure 2.11 are a few types of distresses reducing the quality of the road from good to poor. The information of these distresses are collected manually or by automated equipment. These distresses are measured by type, degree, and extent as per TMH9 (Committee of Transport Officials (COTO), 2016).

a) Crocodile (fatigue) cracks

A sequence of interlinked cracks which are caused by fatigue failure of the surface under continous traffic loading. As loading continous to distress the section of road, it develops a pattern which resembles the back of a crocodile hence the name. These cracks are caused by poor drainage, traffic loading, inadeqaute design of pavement layers etc (Pavement Interaction,(2018), TMH 9 (Committee of Transport Officials (COTO), 2016), (ARRB SYSTEMS, 2018) .

Figure 2.6: Image indicating crocodile cracks

(Source: Pavement Interactive, 2018)

b) Longitudinal Cracks

These are cracks that are found running parallel to the pavements centreline. These cracks form at a joint of the pavement layer (Pavement Interaction,2018), TMH 9 (Committee of Transport Officials (COTO).

Figure 2.7: Image indicating Longitudinal Cracks

(Source: Pavement Interactive, 2018)

c) Transverse Cracks

Transverse cracks are also known as thermal cracks, these are evident cracks formed perpendicual to the pavement (Pavement Interaction,2018) and TMH 9 (Committee of Transport Officials (COTO).

Figure 2.8: Image indicating Transverse Cracks

(Source: Miller and Bellinger, 2014)

d) Block cracking

Block cracking occurs due to structural issues that have arose due to inadequate design of the pavment layers. These interconnected cracks forms rectangular shapes hence the name (Pavement Interaction,2018) and TMH 9 (Committee of Transport Officials (COTO).

Figure 2.9: Image indicating Block Cracks (Source: Pavement Interactive, 2018)

e) Potholes

Potholes are a bowl-shaped depression in the pavement surface. If potholes are left unattended, they can penetrate all through the pavement layer works down to the base course. Potholes can stem from severe cracking of the road and increase in size as vehicles drive over them. Potholes are measured by the category of distress and size (Pavement Interaction,2018) and TMH 9(Committee of Transport Officials (COTO).

Figure 2.10: Image indicating a severe pothole

(Source: Miller and Bellinger, 2014)

f) International Roughness Index (IRI)

Pavement roughness is the measure of how comfortable the ride quality of a vehicle is. The higher the roughness the poorer the quality of comfort when driving over the paved surface, a smoother road have a higher performance life. Roughness not only affects ride comfort but also the vehicle operating costs. IRI is an important attribute to road infrastructure (Pavement Interaction,2018), (TMH 9 (Committee of Transport Officials (COTO) 2016), and ARRB SYSTEMS 2018

g) Rutting

Rutting are depressions developed in the wheel paths of a pavement. When a rut is filled with water it can cause hydroplaning which is unsafe for commuters. Prior to the introduction of road technology Rutting is physically measured manually over distance and depth of depression as seen in the image below. The depth is averaged to obtain a decisive value (Pavement Interaction,2018) and (TMH 9 (Committee of Transport Officials (COTO) 2016), RUTTING 2018

Figure 2.11: Image indicating severe Rutting of road below straight edge

(Source: Pavement Interactive, 2018)

2.8 DATA COLLECTION METHODS

2.8.1 MANUAL METHOD OF PAVEMENT CONDITION SURVEY

The undertaking of road condition assessments, for input to computerized road asset management systems (RAMS), has been systematically undertaken by road authorities in South Africa since the mid 1980's. Considerable advancements in data processing and analysis is evident in this time, but simultaneous development in the actual acquisition of road condition data has not occurred, with this fundamental aspect being predominantly based on manual collection methods i.e., the use of site assessor. (Committee of Transport Officials (COTO), 2016) and (Virginia Department of Transportation, 2012). The methodology used to undertake a network level assessment is the same taken for a project level assessment. Visual assessments undertaken manually have a certain window period when assessments are done which is at the end of a rainy season and in the cooler months. This methodology of data collection is labour intensive, time consuming, consumes substantial human resources and entails a high level of subjectivity (Committee of Transport Officials (COTO), 2016) and Virginia Department of Transportation, 2012)

Traditional methods of determining pavement condition have primarily focused on information obtained from a physical visual assessment of the road surface in accordance with the Draft TMH9 Manual (Committee of Transport Officials (COTO), 2016). Occasionally the visual assessment was augmented with functional data in the form of riding quality using a basic diesel (LDI) vehicle and structural measurements from a falling weight deflectometer (FWD) or similar device. Manual condition assessments have initially been used to assess low volume roads (LVR's) and went on to further assess high volume roads creating limitations (Bogus et al, 2010).

A pavement condition survey is conducted by a small team of two or three people, trained in pavement distress identification and the assessment procedure process (Oregon Department of Transportation,2010). The training first starts when the individual has progressed with an undergraduate degree in Civil Engineering and further trained in depth when in the work environment, in this way there is a foundation of knowledge of pavement engineering. The site team must be led by a senior engineer that is knowledgeable in identifying the various distresses and how to categorise it. The training will include distress identification followed by the Good-Fair-Poor (GFP) condition rating assessment of roads stipulated by the road's authority.

As teams are grouped for the site investigation, the project lead who is a certified assessor will provide sections of roads in the network to commence the data collection. The procedure is in depth to maintain a system which sometimes doesn't go to plan due to various circumstances. Based on the level of experience of the senior assessor and his team, an average of 100 kilometres daily should be achieved (Committee of Transport Officials (COTO), 2016). Tsai, Kaul, and Mersereau, (2010) states manual surveys can gain production of approximately 60 to 80 kilometres per day in a rural environment and up to 20 km's in an urban environment.

The team accomplishes manual condition surveys by physically walking the route or slowly driving the paved road or rather windshield surveying to identify the distress. The accuracy of the assessor's condition rating is highly influenced by frequency of stops made to fully examine the road. When assessments are undertaken the orientation of the sun, any variability of cloud cover and localised moisture on the road is taken into consideration as this will influence the visibility of any distresses (Committee of Transport Officials (COTO), 2016). As the team drives the route to assess, it must be ensured that the vehicle operates in a manner that does not endanger the team or the public. Safety is of utmost priority over the requirements to collect the road condition data (Oregon Department of Transportation,2010).

As the assessment takes place, the trained individuals in the team have separate roles. The entire team observe the road for any distresses, one will note the defects on the TMH9 standardised form, one will capture images and the driver assesses whilst operating the vehicle in a safe and responsible manner. As a start they observe and note the surface type, age, start kilometres distance, end kilometre distance, location, name of road and additional comments that will assist to understand why the distress was caused. The distress is measured, lane width is measured and a GFP rating is assigned which is commonly based on the overall average condition of the section of road. The distresses that are describes by the main characteristics - the attributes of distress namely degree and extend of the occurrence. The level of subjectivity is extremely high, hence quality assurance on site must be conducted prior to compilation of data and analysis. The effects of subjectivity and the resultant validity of data are dependent on numerous factors for example, experience of the assessors, fatigue, traffic, and noise level, etc (Underwood et al, 2011, Tsai et al, 2010, Kock and Brilakis, 2015). According to Virginia Department of Transportation, (2012), it states that due to the high level of subjectivity the data may be inconsistent from year to year and from assessor to assessor. The same team is not always dedicated to the same network cycle of road assessments.

All observations made by the team is recorded in the inspection sheets in accordance with the (Committee of Transport Officials (COTO), 2016). In most cases the conditions vary significantly between lanes, here for manual methods the decision is taken to base the condition of the worst lane. The physical distresses observed and measured on the roads will include the various types of cracking like crocodile cracks, transverse cracking, block cracking and longitudinal cracks. The other distress are potholes, shoving, rutting, and roughness of the road (IRI) (Salama, Chatti, and Lyles, 2006). Once this section of road is assessed, pictures are taken, and they start to locate the next section to be assessed. This process is continued throughout the day. At the end of the day the data is brought back to the office. The information is either captured the same day on a computer at the office or it's done at a later stage for analysis. This provides a disadvantage as data can be misinterpreted and a high degree of human error is experienced if captured at a later stage and not immediately. According to Bogus et al, (2010), road agencies have been concerned about the consistency of data in manual condition assessments as it may include variability because this manual method would involve multiple evaluators.

For years senior engineers in the civil engineering industry mainly in South Africa have always opted for manual condition assessment surveys (Bogus et al, 2010). This method of obtaining data is said to cost-effective but time consuming and there are several factors to take into consideration when executing this methodology of data collection.

2.8.1.1 ADVANTAGES AND DISADVANTAGES OF MANUAL PAVEMENT SURVEYS

According to Schattler, Rietgraf, Wolters and Zimmerman, (2011) and Timm and McQueen, (2004) the following advantages and disadvantages of manual pavement surveys have been noted:

ADVANTAGES

- No capital expenditures required
- Staff can be trained easily to conduct these surveys
- Detailed distress information can be achieved
- Drainage patterns can be seen

DISADVANTAGES

- This method is human resource intensive
- Data collected has a prominent level of subjectivity
- Process is laborious
- High safety risk for the assessors and road users
- Data has to be captured back at the office once site visit is completed creating room for error
- Without comprehensive knowledge and training of the assessment process there is potential of high variability in the datasets and quality assurance.
- Time consuming task
- Reduced kilometres completed in a day

2.8.2 COLLECTION OF DATA THROUGH AUTOMATED TECHNOLOGY

Historically, road agencies in South Africa managing their road assets have fully relied on pavement condition surveys the manual way (Currie,2022). Assessments are undertaken by personnel walking or wind shielding through the road network to identify distresses (Underwood et al, 2011). In recent years various research has been undertaken towards technology of automation which has evolved collecting road data (Radopoulou and Brilakis, 2016). Surveys can now be completed by vehicles fitted with sophisticated instruments traveling at highway speeds, is becoming a practical solution (Underwood et al, 2011). This technique of collecting pertinent road data for road authorities on large networks is completed in short length of time. This is due to innovation continuously evolving the technology used to automate data acquisition and processing effort when compared to other methods (Pierce et al, 2013).

Over the past ten to fifteen years the ideology of fully automating road condition data collection was close to becoming a reality through the various research and major technological advancement. The development and application of ultrasonic, laser sensors, infrared and high-speed computing processing have contributed tremendously for transportation authorities to collect copious amounts of road data efficiently and accurately (Pierce et al, 2013). These technologies that will be discussed going forward allow road authorities to collect and report current condition data to National Departments of Transport frequently as this will have a ripple effect on costs to maintenance and rehabilitation because treatments are undertaken at a rapid pace. The data collected and analysed can be conducted on a network level and project level basis. Due to the intricacies needed for project level data, with the technology this can be undertaken with ease. These highly equipped vehicles are designed to conduct pavement condition surveys collecting geo-referenced images, and profile data such as Texture Depth, International Roughness Index (IRI), Rutting and Crack detection. Surface distresses such as cracks are collected utilising downward facing and forward-facing pavement cameras. As technology in pavement management has evolved data can be collected and post processed using semi automation or full automation methods.

The equipment's technical system are calibrated in accordance with international best practices to obtain data that are as per standards of engineering manuals used nationally. The functional measurements can be exported in various formats for analysis whilst the high-definition images are utilized for post rating techniques. The post rating of surface distress takes place at an office environment where a person in the pavement engineering field is further trained to identify the various distresses utilising the georeferenced images (Pierce and Weitzel, 2019). A certain level of human interaction is required to determine the presence of surface distress. There is a small element of subjectivity as compared to field assessments. Post Rating utilising semi-automated method can be beneficial as roads can be reassessed when necessary, utilizing the georeferenced images in accordance with TMH9 manual (Pierce and Weitzel, 2019).

The fully automated methodology involves zero tolerances of human interaction for identification of any of the surface distress and classification. Software and machine learning has been created to view the georeferenced images and automatically identify the surface distresses, measure the extent of the distress, and classify the findings. This data gets compiled into a database for later use (Pierce and Weitzel, 2019).

As compared to manual condition surveys, the use of these intelligent systems provides a significant increase in production. More than 500 kilometres of data can be collected in a day for its traveling at traffic speeds and more than 100 kilometres of in-house post rated assessments can be completed in a day with quality assurance. This method can be costly at the initiation phase but becomes cost-effective with the increased amount of data collected and assessed per kilometre (Tsai et al, 2010). Less time is consumed, a network of three thousand kilometres can be completely surveyed in four months. Continuous data measurements supply significantly improved data interrogation and more confidence in subsequent analysis. Repeatability of data each year is evident in the information received, decreasing a large extent of subjectivity. Informative objective data can be given to road authorities in a reduced time for their strategic planning. The use of technology is always improving as research is constantly undertaken on a timeously basis to perfect the output received from the equipment.

2.8.2.1 TYPES OF EQUIPMENT UTILISED FOR DATA COLLECTION

2.8.2.1.1 Network Survey Vehicle

The Network Survey Vehicle was designed and developed to provide a very consistent measure of surface condition that is not disruptive to traffic. The Survey Vehicle was based on the latest technology utilising lasers, video image processing tools and Global Positions Systems. The Network Survey vehicle automatically collects road pavement inventory and road condition in conjunction with data required for a Road Asset Management, Road Safety studies and Pavement Maintenance Management Systems. Utilising a network survey vehicle for collection of data enhances the repeatability of data as the vehicle travels in the same wheel path when testing continuously on a variety of roads (Underwood et al, 2011).

The modular design of the equipment fitted on a vehicle of choice allows for modular expansion. This vehicle is custom made for simple adoption of modern technology as innovation evolves for road data collection. It is a safe and efficient method of collecting road data for both urban and rural environment. The network survey vehicle is a fully integrated data collection system with the common data and survey control referencing using a proprietary device called the Heartbeat (ARRB SYSTEMS, 2018).

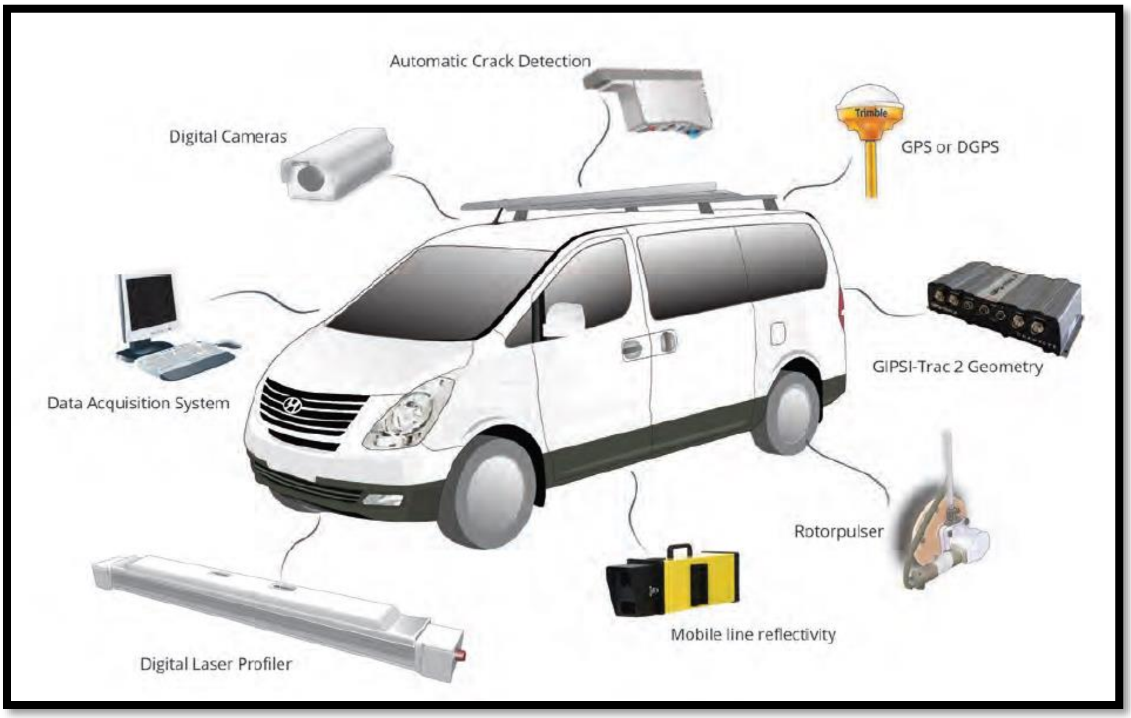

Figure 2.12: Components of the Network Survey Vehicle

(Source: ARRB Systems, 2018:10)

Figure 2.10 illustrates the various components of a Network survey vehicle (NSV) that assist to measure defects of road pavements. The NSV is fitted with high resolution cameras which provides a 360° view of the pavement and roadside, digital laser profilers, GPS to tracks locations, a GYPSI Trac to measure geometry, Automatic Crack Detection device and a data acquisition system to track the data collected. The NSV utilises laser-based methods to assess the texture and shape of the pavement surface at traffic speed. Data can be collected at ease from speeds of 40km/h to 110km/h. The NSV also known as a Digital Laser Profiler can be configured with a variety of sensors to enable collection of data to satisfy all international standards of various road authorities. The data that is collected by the digital laser profiler are as follows:

- Transverse profile, utilising a laser scanner which is used to measure rut depths
- The international Roughness Index (IRI) – Longitudinal profile of both wheel paths utilising the laser measurements from which rideability parameters are measured (3m, 10m and 30m wavelengths)
- Road geometry such as gradient, crossfall and curvature utilising the inertial systems are measured.
- Macro Texture
- Pseudo longitudinal profile, this is undertaken utilising laser scanners from which parameters demonstrating when users would experience an uncomfortable bump-like sensation for example, from shoving or a pothole are measured and calculated.

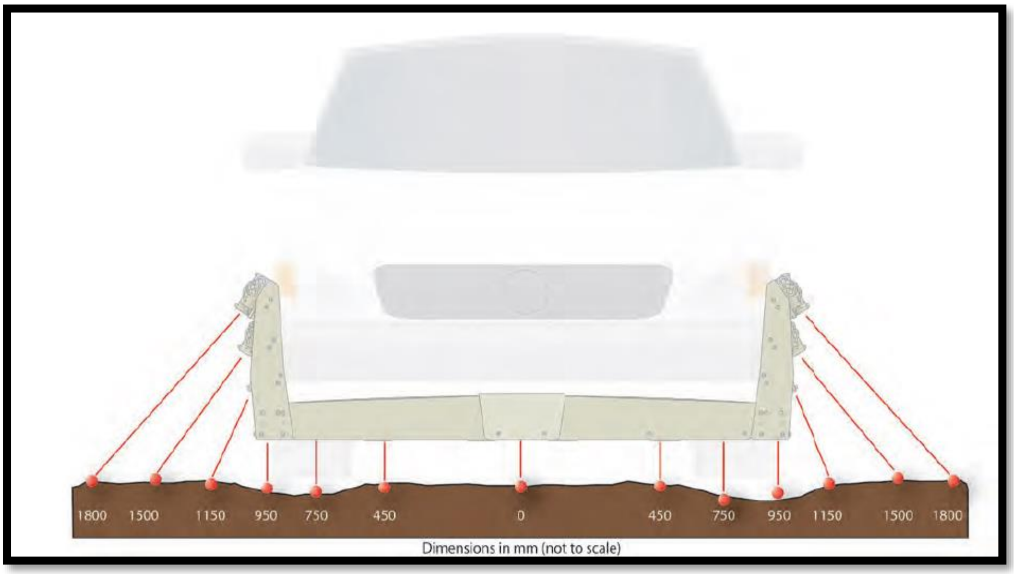

Figure 2.13: Typical laser Layout

(Source: ARRB Systems, 2018:15)

Figure 2.13 illustrates the positioning of the lasers to cover a full width of a lane to capture all data necessary for analysis.

As discussed, the NSV is equipped with high resolution cameras which is an advanced video acquisition system for visually identifying, locating roads and roadside features with precision at highway speeds. The cameras are installed on the hood of the Survey vehicle to get a clear view of all objects in line of sight (refer to Figure 2.12). The images are georeferenced which provides the required co-ordinates and staked kilometre distance of each image processed at various intervals by a registered software where the images can be viewed.

Utilising the georeferenced images from a semi-automated survey, engineers can conduct the post rating technique and assess in terms of the TMH9 manual. This method can be undertaken in the safety and comfort of an office environment. A safer methodology than undertaking spot field surveys and proven to be more productive approximately more than 100 kilometres of visual assessments can be post rated per assessor per day. There is a small level of subjectivity, but this is reduced in comparison to field assessments primarily due to the ability to re-assess the images as often as needed whilst continuously referring to the TMH9 document and the ability to use actual metrics in the assessments of the degree and extent of distress. Quality assurance is via independent "double rating" of random road sections and panel inspection. Exception or validation algorithms are also built into the data capture software. It is prudent to understand that once the baseline data is collected, this can be utilised as a benchmark to monitor the performance of key outputs annually.

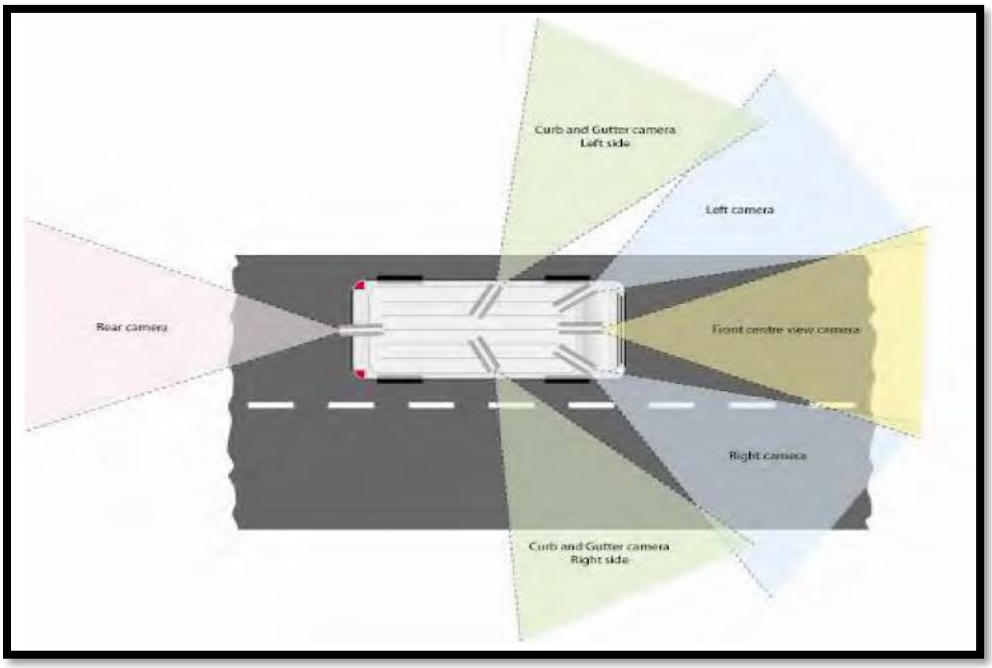

Figure 2.14: Positioning of high-resolution cameras

(Source: ARRB Systems, 2018:13)

The last intricate component of the NSV is the Automatic Crack detection device, this system comprises of two high performance Pavemetrics LCMS 3D lasers which is fitted at the rear of the survey vehicle, vertically above the road pavement. A laser line is projected on the pavement as the vehicle is in motion and an image is taken allowing to measure the transverse profile of the road to a 0.50m height resolution. Once this data is accessed via a proprietary system the functional measurements can be exported in various electronic file formats for subsequent data processing and analysis whilst the high-definition digital images and crack detection enable post rating of the pavement condition to be undertaken (ARRB Systems, 2018). As a final output of the profile data obtained the ability to retrieve numeric data, tables, and graphs is attained for analysis of the cracks and other distresses evident on a road surface.

Profile data obtained from a network survey vehicle assist with providing the baseline understanding of the road network, clients are able to receive accurate quality data,

data is available in various intervals for designs or analysis. The Network survey vehicle provides data at your fingertips, which is objectively collected, reducing survey time and overall cost of the operation (ARRB Systems 2018).
Compared to manual methods the use of the network survey vehicle provides a significant increase in productivity with a data acquisition of up to 500 kilometres per day. Due to vehicles traveling at highways speeds safety is enhanced. The risk of accidents being caused due to road surveys in progress is drastically reduced.

2.8.2.1.2 Traffic Speed Deflectometer (TSD)

The pavement deflection measurements originated and was discovered by Francis Hveem in 1938 and later, in 1952 the Benkelman Beam was developed. This device is used to measure the structural integrity of the pavement. The Benkelman Beam measures the surface deflection by a static vertical wheel impact load utilising the beam in combination of a test vehicle (Manyana, 2021). The next advancement in deflection measurements was the introduction of the first Falling Weight Deflectometer (FWD) in 1968 in Demark. However, in South Africa this device was introduced in the late 1980s utilised for project and network level surveys. For many years, the FWD provided a perfectly accurate view of the structural health of a pavement and most widely utilised (Pantuso et al, 2019).

FWD data is often and primarily used to determine the appropriate pavement overlay thicknesses for flexible existing pavements that requires additional structural support. During the operation of a FWD, the device attempts to simulate a moving wheel of a vehicle by dropping an impulse load on a load plate positioned on the surface of the road. The response of the road to the load creates a deflection bowl which is measured by a series of geophones or sensors. The shape of the deflection bowl provides an understanding of where the problem of the underlying layers of the pavement structure exists (Manyana, 2021). The ultimate requirement for optimum FWD measurements is the test vehicles must remain stationery whilst undertaking the deflection measurements. The FWD can best conduct its testing when a road is closed or there are rolling road closures which will pose a danger. Safety during this operation has to be well planned as there are serious consequences for the team operating the device as well as the local commuters on the road. This methodology of collecting deflection data is very time consuming, submitting information to the client can be delayed as

FWD testing is predominating performed at 50 to 100m intervals per day for project level assessments and at interval spacing of 200m for a full network level basis, for example at 300 tests per day, for project level this will equate to 15 to 30 lane kilometres and 60 lanes. kilometres for network level (Manyana, 2021). That's tremendous time taken to provide road authorities with the information they require to make strategic maintenance decisions.

The falling weight deflectometer is a reliable, effective, and simple tool to determine the structural capacity and properties of existing roads and runaways however there are challenges faced with the methodology of collecting structural pavement data (Oshone, Elshaer, Dave, and Daniel, 2017 and Cambridge Economic Policy Associations Ltd & TRL Ltd, 2018). Hence with technology and integration of the fourth Industrial Revolution the Traffic Speed Deflectometer device (TSDD) was introduced and piloted. The first Traffic Speed Deflectometer device (TSDD) was first introduced in Denmark during the late 1990s. It is proved to be a highly worthwhile substitute to the long-established falling weight deflectometer (FWD) methodology of road pavement measurement response to loading. According to Manyana, (2021) the TSDD technology has subsequently transformed the road asset management system, pavement condition surveys for existing blacktop roads by becoming a global benchmark and creating trends in road assessments. The TSDD system is able to be highly mobile and efficient. This vehicle is equipped with high resolution doppler lasers to calculate pavement deflections in a continuous motion utilising measured vertical surface displacement velocity and horizontal travelling velocity. This is a much more realistic measurement imposed by a rolling tyre motion on a road surface.
Research goes on to note that the TSDD is amazingly effective on network level projects and has the ability to integrate advanced imagining technology to accurately capture and subsequently analyse pavement distresses continuously and seamlessly (Manyana, 2021). As discussed, the TSDD collects continuous data at speeds of 80Km/h, with no disruption to traffic, hence the data can be processed for engineers down to 1 meter to concentrate on where the pavement structure is of concern and make precise design decisions on rehabilitation works. Safety of employees operating the equipment and vehicle occupants utilising the road is enhanced creating an environment where accurate quality data is collected.

With the integration of high-definition imaging technology the TSDD is called the Intelligent Pavement Assessment Vehicle (iPAVe), this vehicle can provide the full spectrum of structural and functional condition data collection such as the International Roughness Index (IRI), Rutting, Texture depth (MPD), crack detection, georeferenced imaging, geometry, and deflections all in one pass on a road surface (ARRB Systems, 2018).

According to Manyana, 2021, this equipment can survey road networks of all sizes and projects level tasks at operating speeds between 20km/h to 80km/h. Due to the continuous data being collected an iPAVe can collect approximately 350 kilometres of data a day which equates to approximately 90 000km's in a year. This is subject to the actual road configuration or traffic congestion. Due to the nature of the methodology to collect data, productivity is enhanced. The usage of this equipment can allow road authorities to receive data at their desired specifications (ARRB Systems, 2018) and providing efficient management of road networks which results in saving millions towards the fiscus by proactively planning the maintenance strategy for the network (Manyana, 2021).

Figure 2.13 illustrates the intricacies of the iPAVe. As discussed, the iPAVe has the capabilities to be fully automated. In one pass of the vehicle deflections, RUT, IRI, mean profile depth (MPD), Crack detection, georeferenced images, and geometry can be collected and analysed.

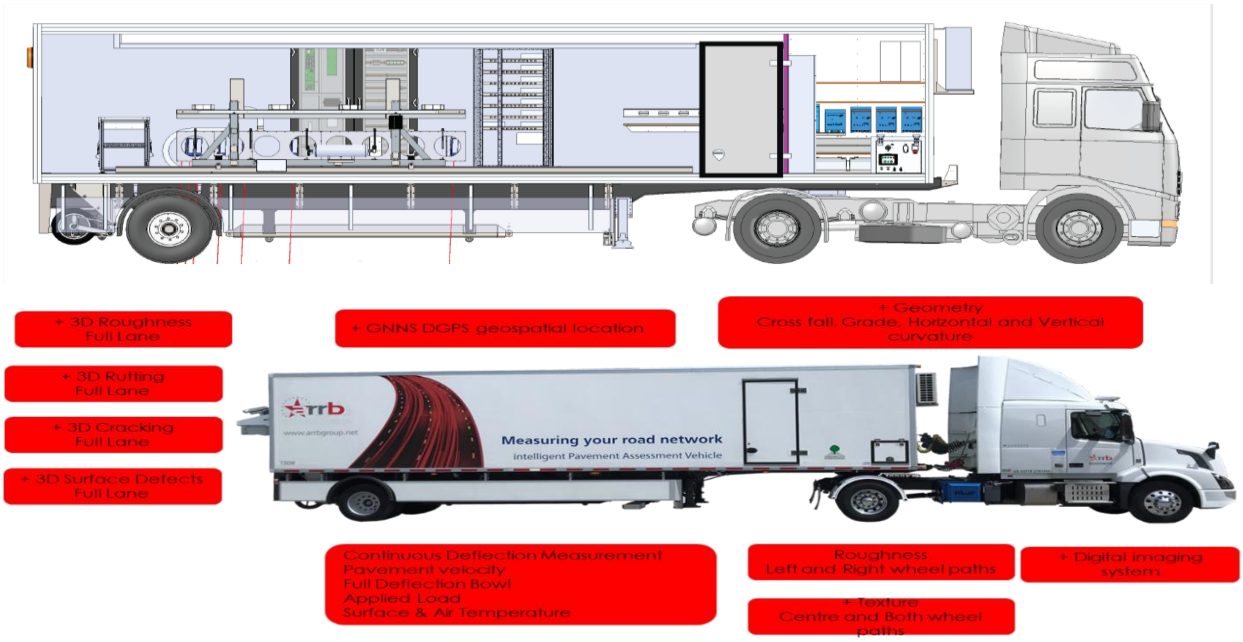

Figure 2.15: Technology within an Intelligent Pavement Assessment Vehicle (iPAVe)

(Source: ARRB Systems, 2018)

2.8.2.1.3 LIGHT DETECTION AND RANGING (LIDAR) MAPPING

Light Detection and Ranging (LiDAR) is a remote sensing type of technology utilises light rays to collect information about objects without making any physically contact with the object. LiDAR data can be collected using an airplane (airborne), collected from satellites (spaceborne), or can be collected from the ground (terrestrial) (Gargoum and Basyouny, 2018). LiDAR can be mounted on to a vehicle called Mobile Laser Scanning (MLS), this equipment can work efficiently under traffic speeds capturing 360 degrees views of the highway. This equipment complements the Network Survey vehicles and its technology as all road features are captured with a very high level of detail.

According Gargoum and Basyouny, (2018), it states a common application of LiDAR in transport engineering is pavement condition assessments and rehabilitation. The images obtained by LiDAR produces closely spaced points with accurate positional details. This enables the creation of meshes and surfaces combined together which represents the roads surface. Abnormalities in the road surface captured are analysed to assess the pavement condition. Research has shown several studies have explored the pavement condition assessments utilising laser data.

A model was developed using LiDAR to perform guided roadway milling. Through this model a digital surface model of the road was created. Cross sections at different intervals was analysed. The accuracy measured was up to 0.004m in height (Grafe, 2008). Other studies showed using LiDAR, the detection of pavement cracks from 3D laser scans is possible. The proposed technique highlighted pavement cracks can be segmented using a dynamic optimized based method. LiDAR can effectively measure the cracks detected and categorise them so these can be assessed utilising algorithms created. The information obtained indicated that cracks with widths of 2mm and thicker can be effectively detected using a 3D laser under a controlled environment (Tsai and Li, 2012)

2.8.2.2 ADVANTAGES AND DISADVANTAGES OF AUTOMATED DATA COLLECTION AND PROCESSING

According to (Currie,2022), (ARRB SYSTEMS, 2018), Schattler, Rietgraf, Wolters and Zimmerman, (2011) and Timm and McQueen, (2004) the following advantages and disadvantages was studied to understand the positive and negatives of the technology to be used in data collection:

ADVANTAGES

- Large volumes of road network data can be collected
- Numerous types of data are collected at the same time for example, IRI, RUT, Cracks, MPD, images, geometry, deflections etc
- Personnel safety out on site is not compromised
- Data is collected at traffic speed hence less interruption to traffic
- Data is collected in short lengths of time
- Repeatability of data is obtained
- Data collected is more consistent
- Data collected for road network and project level
- A small level of subjectivity is gained for post rating assessments, but this can be eliminated when assessments become fully automated
- Pavement Condition Data in conjunction with the georeferenced images can be viewed in an office environment.
- Data collection costs can be reduced by 75% when changing from manual to automation (McGhee, 2004).
- Research shows utilising automated equipment to collect data frees up time of existing staff to undertake other pertinent works for the road infrastructure
- Road authorities do not have to purchase the equipment for data collection, there various companies that are specialist in this fields and have already undertake these operations. Businesses are able to significant cost savings when employing service providers that handle these types of data collections. This method is becoming popular as businesses tend to pay a flat rate to get all data needed to understand the integrity of the road.
- Images and pavement data can be reprocessed when needed for design, research, or processing algorithms
- Quality of data is achieved
- Research is continuously undertaken to perfect the outputs received

DISADVANTAGES

- May be expensive at initial stages
- Automated processing is not fully achievable for some distresses such as, bleeding of the surface layer and ravelling
- If the equipment is not calibrated accordingly data will be compromised.
- Should the vehicle be under speed, inconclusive data is achieved.
- Data cannot be collected in rainy weathers

2.8.3 COST AND TIME FRAME COMPARISON BETWEEN MANUAL METHODS AND AUTOMATED METHODOLOGY

An exercise was conducted by Washington State Department of Transport and Washington University regarding the comparison of time and cost of the manual method versus the automated methods. A state of USA required 13700 kilometres of road to be condition surveyed. A group of four teams of two people driving the routes utilising the manual methods had commenced. Two people per team drove on the shoulder of the roads at slow speeds to ensure they maintain accuracy as far as possible. To conduct 13700 kilometres of pavement condition survey it required 3820 person hours (Sivaneswaran, Pierce, and Mahoney, 2004). There was a Rating form that was utilised during the site assessments and once the team was back in the office the data capturing started. The capturing tasks took place at the end of each tiring day of data collection. A total of 300 person hours was required for the data entry. In totality for the data collection and data entry it took 4120 person hours to complete at price of USD $230 000.00 per year (Sivaneswaran et al, 2004). In addition to the manual method costs, the Pavement Management office was also collecting pavement profiles for quality assurance, this activity required 380 person hours at an annual cost of USD $38000.00 (Sivaneswaran et al, 2004). The final total time and cost equated to 4500 person hours at a cost of USD $268 000.00.

The automated pavement condition survey commenced which simultaneously collected all surface, pavement profile data and georeferenced images by a team of two people. This process required 660 person hours at a cost of USD $100 000.00. once the survey was concluded the data was process and analysed by a team of 4 people in approximately 4.5 months. This process took up to 2600 person hours and the cost to complete this process was USD $140 000.00. To sum up the final time and cost of automated surveys it equated to 3220 person hours at a total cost of USD $240 000.00 (Sivaneswaran et al, 2004).

According to Sivaneswaran et al, (2004), it was concluded by the Washington Department of Transport and Washington University that from the comparison of the time and cost of both methods and the high quality of data of pavement condition surveys, it was found that the automated condition surveys were more cost effective in the long term and improving productivity at a lower overall cost.

Further to the study undertaken by Sivaneswaran et al, a similar study was undertaken in South Africa. According to Visser, Tetley, Lewis, Naidoo, Moolla and Pillay, (2021). There was an emphasis on the most cost-effective way to obtain essential road condition data. Comparisons were taken with the techniques currently undertaken in SA which are mainly based on visual condition assessments with most recently developed techniques which have enabled a more comprehensive and largely automated data collection. Three scenarios were compared, firstly by data collection using visual assessments only. Secondly by utilising the Falling Weight deflectometer (FWD) measuring deflections together with automated roughness, rut depth, high resolution images and texture measurements from a Network Survey Vehicle (NSV). The third scenario is using the Traffic Speed Deflectometer (TSDD) or better known as the Intelligent Pavement Assessment Vehicle (iPAVe) capturing integrated condition data including deflections, automated rut depth, roughness, georeferenced images, crack detection and texture all in one pass at traffic speed (Visser et al, 2021). Sections of five roads were identified for data collection and assessment by manual methods, FWD and iPAVe.

The project commenced with manual methods. Two assessors was assigned to the assessments utilising COTO TMH9 2016 Part B and storing of data. The FWD and NSV commenced with post rating of georeferenced images and finally the iPAVe continued. In scenario one the data was assessed, scenario two inclusive of deflections, visual assessments were post rated with quality assurance and the last scenario is very similar to scenario two but incorporates continuous deflections and crack detection. This data was further economically analysed utilising HDM4 to determine the cost to road authorities when making use of condition assessments methods. Once the analysis was conducted the following results were obtained per kilometre.

Table 2.2: Comparison of savings vs cost for each scenario

Source: (Visser et al, 2021).

Scenario	Overall Cost incl Data Collection for 66.5km's	Discounted Cost per km (ZAR)	Operation cost per km (ZAR)	Total Cost per km (ZAR)	Total Savings per km (ZAR)
1 - Visual Assessment	R 94 086.907	R 1,421,304	R 163	R 1,421,467	-
2 - FWD & NSV	R87 223 788	R 1,316,079	R 1,700	R 1,317,779	R 103,688
3 - iPAVe	R 86 339 794	R 1,300,924	R 3,500	R 1,304,424	R 117,043

Table 2.2 indicates the costs per scenario. Scenario one was conducted with two assessors utilising a vehicle to assess the routes. The all-inclusive operational cost per kilometre equated to R163.00. Scenario two cost includes an operator each for the FWD and NSV vehicles. These specialist vehicles were followed by a safety vehicle. The cost also includes the post rating of visual assessments and processing of the profile data. This cost equated to R2 250.00 per km. Scenario three involves the TSDD iPAVe, one operator and one driver without a safety vehicle behind. The production rate is estimated to be approximately 500 km per day. The operational cost is R 3 500.00 per kilometre (Visser et al, 2021).

According to Visser et al (2021) the study indicates there is a significant saving utilising the TSDD. There is a R 13 355.00 per km saving more than utilising the FWD and NSV even though the cost of the equipment fitted is high. If this same saving is extended to the entire South African paved network there is a saving of R2 Billion (Visser et al, 2021). When compared to the manual visual assessments, utilising the iPAVe provides a massive saving of R 19 Billion. Utilising the iPAVe for data collection not only provides a massive saving it also provides high frequency continuous deflection measurements in combination with imaginary, help locate underground water services and identify roads that are structurally deficient but show signs of no visual distress.

2.9 FUTHER RESEARCH INTO THE ANALYSIS OF AUTOMATED PAVEMENT CONDITION SURVEYS

At present in practice around the world, majority of road distresses are being undertaken through automated data collection by utilising various imaging systems and lasers for example, RUT, IRI, MPD and geometry. However, with this practice post rating assessments are being undertaken which as noted has a small fraction of subjectivity but have the ability to be continuously quality assured as images can be viewed again when needed. This method requires a level of human resources. Researchers had went further in their study and had shown, along with the data that is collected from automated equipment the identification and assessment of potholes, patches and shoving of the pavement surface, from georeferenced images can be undertaken via new methods of viewing the data through machine learning (Huidrom, Das and Sud, 2013). In practice for this method to work, simultaneous identification and assessment of various kinds of distresses are essential and numerous evaluations on large datasets of pavement images are required to analyse accurately each type of distress and validate the results obtained. There hasn't been an official method to undertake this type of automated detection and assessments as various applications have been investigated, but researchers advise that this development of assessing roads by machine learning will save on time and human power of assessing roads (Huidrom et al, 2013). The only human interaction needed will be to oversee the process of assessments and conduct variable checks of the data.

According to Huidrom et al (2013), the paper states that in this proposed method, patching, cracks, and potholes are identified and quantified automatically making use of numerous image processing techniques maintained by heuristically derived decision logic. The procedure to undertake a complete algorithm is broken down in various properties, stages and finally steps to the final product. The thought process behind decision logic is derived on the foundation of three main distinctive visual properties of the distresses. The first property is the visual texture of the distress region given by the Standard deviation, the second property is the shape of the distress region supported by the circularity and the third property is the dimension of the distress supported by the average width.

The methodology of this process is undertaken in two stages. Stage one, the dataset of images processed from the data collection is captured with or without road defects utilising a fast video segmentation algorithm called "Distress Frames Selection (DFS)" algorithm (Huidrom et al, 2013). The next stage of processing is when the dataset of images have evident distresses subject to a particular algorithm called "Critical

Distress Detection Measurement and Classification (CDDMC) algorithm (Huidrom et al, 2013). This stage is purely to decipher a logical algorithm for the distress mentioned in one pass of viewing the images. The research goes further and notes that there are five distinctive steps to this to achieve a product and that is:

1. Image enhancement
2. Segmentation of Image
3. Visual property extraction
4. Identification and Classification by Decision Logic
5. Quantification

After the tests are run it showed that utilising an algorithm for processed automated detection and classification of distresses are achievable. Comparison was taken with manual methods and the algorithm provided a 90% accuracy with 8.5% precision for all distresses (Huidrom et al, 2013). This exercise saved tremendous time than manually recording the defects on site and time was saved by post rating as well after the data is collected by sophisticated technology driven vehicles (Huidrom et al, 2013). This research has provided in depth clarity that swift information to road authorities and engineering consultants to make productive decisions to benefit all road users making roads safer in a quicker time saving millions allowing funds to be used for various other important initiatives. This approach will also increase performance and promote sustainability of businesses as continuous flow of works will be undertaken with precision and accuracy.

2.10 PAVEMENT SURVEY METHODOLOGIES UTILISED AROUND THE WORLD

In various developed countries sophisticated automated equipment are being utilised on a frequent basis as compared to manual pavement surveys. In Japan, the road network equates to 1.208 million kilometres which consists of expressways, national routes, general roads, prefectural road within cities and villages. The national roads are managed by the Ministry of Land, Infrastructure Tourism and Transport and the roads outsides the national routes are managed by the government. Continuous pavement surveys are being undertaken in Japan to understand the status quo to create and operate a Pavement Management and monitoring System (Japan International Cooperation Agency, 2013). The automated route has been chosen, although it has a cost implication but has been the most effective mechanism to obtain for the broad network annually. This thought process has been adopted in UK and USA as well, in UK various governmental bodies manage various areas and utilise a functional Pavement Management System to ensure they meet their budgetary requirements. Semi – Automation pavement survey equipment has been utilised in this country on an annual basis to achieve the information required. Additionally in the UK, a Sideways force Coefficient Routine Investigation Machine (SCRIM) is also utilised every three years to measure Skid resistance at traffic speeds. This type of automated equipment has further evolved with imagining systems and skid resistance sensors called the Intelligent Safety Assessment Vehicle (iSAVe) utilised in Sweden, USA, Australia, and South Africa (ARRB Systems, 2018).

Various states in USA were one of the first countries to explore, research and utilise technology to collect pavement condition data. According to Underwood et al, (2011), the automated survey process has gained national and international popularity in the last decade. In USA, most government road authorities have undertaken these surveys themselves, as time progressed many consulting firms have provided this service to the authorities so they could concentrate on the implementation strategies created from the data collected. USA road networks exceeds 6.6 million kilometres, 4.3 million of these roads are paved, of this value 76.300 kilometres are expressways, and 2.3 million roads are unpaved (Japan International Cooperation Agency, 2013). Various companies and governments have agreed that the profiler system provides an efficient, safer environment and an objective way of collecting consistent pavement evaluation data. Due to the pace the country is revolutionising, maintaining the road network is a prime necessity as this is the one of their main modes used. Informed road data via technology has assisted road authorities achieve their goals set each year with routine maintenance and upgrade.

As time progress emerging countries like Thailand, Malaysia, Brazil, and Chile and developing countries such as Vietnam, Indonesia, Laos, and Philippines had adopted this methodology of automation to understand their road network and work proactively to achieve their strategy set (Japan International Cooperation Agency, 2013). It is evident that countries around the world are gaining from this pavement technology hence their road infrastructure maintains a high level of safety.

2.11 METHODOLOGIES UTILISED IN SOUTH AFRICA

As discussed earlier in the literature, South Africa boasts a network of seven hundred and fifty thousand (750 000) kilometres of which a small percentage of roads are paved, and a substantial percentage are unpaved. The national routes are managed by the South African Roads Agency Limited (SANRAL) and the rest is run by provincial departments. The quality of the roads has deteriorated in South Africa and due to lack of funding there is a backlog in roads maintenance. To be able to comply with the PRMG and as per DoRA, provinces have to ensure they comply with the conditions of the grant (National Treasury (a), 2018). Free State and KZN have adopted the practice of obtaining data utilising automated methods for network level projects, and some companies utilise it only for project level investigations. The two provinces utilising this specialised equipment have the ability to submit status quo standardised information of each road of the network on an annual basis as data is collected swiftly over a short period of time (National Treasury (a), 2018).

According to the National Treasury (a) (2018) many provinces are utilising the manual method of collecting pavement data which have proven to take additional time as ample human resources are required which are very scarce at departments (National Treasury (a), 2018) to identify and assess each distress of each road of the network. Hence this further indicated there is no uniformity in the way road condition data is collected. Undertaking the manual pavement survey method has resulted in provincial road authorities allowing their network to deteriorate at a faster rate as they do not have the quality analysis of roads to make the decisions required to be able to budget accordingly. Many provinces do not send their networks data as the data collection is incomplete for that fiscal year, results of this have led to reduced funding prioritised for the particular provinces (National Treasury (a), 2018). The National Treasury report elaborated on South Africa not adopting a consistent methodology of prioritising their expenditure through a comprehensive Pavement Management System. There is a policy currently in place which is not consistent hence does not provide the guidance required for provinces to set their maintenance schedules and concentrate on issues at hand.

2.12 SUMMARY OF THE CHAPTER

Chapter two has discussed the various components of the Pavement Management Systems producing an efficient system for road authorities to utilise. The study critically discusses the concepts that led up to the types of techniques that are utilised by governmental and private organisations to collect road condition data and how it is collected. The discussion led to the origins of road surveys and why its required, the road network that is being surveyed, and responsible parties for creating and upholding policies and protocols for productive road assessments systems. As the study is focused on the most viable method to collect data to create a fully integrated Pavement Management System, an understanding of the methods are given along with the advantages and drawbacks to these options. A comprehensive discussion is provided on types of distresses that is collected by either manual or automated methods.

The attempt of this paper is drawing the boundary of this operative process focused on distress identification and technological overview aimed for obtaining a proper framework for a Pavement Management System implementation. The literature review indicates an understanding for organisations and road authorities to be productive and remain sustainable in South Africa as in other countries, uniformity is required so adequate data is collected. The next chapter focuses on the research methodology utilised in the investigative research.

CHAPTER 3:
RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter represents the methodology applied by this exploratory study to understand and utilise an integrated solution to Pavement Management and Monitoring Systems for South Africa. This chapter discusses the research methodology utilising a Research Onion. This chapter discusses the philosophies, approach to theory development, methodological choice, strategies, time horizon and techniques and procedures.

3.2 RESEARCH PARADIGM

Research Paradigm is described at a philosophical way of thinking. It is used to describe the researchers understanding and worldview. In this context the worldview is the perspective or standard set of beliefs that will inform the interpretation of the study data (Kivunja and Kuyini, 2017). A research paradigm reflects the basic beliefs system and a theoretical framework with the necessary assumptions. According to Kivunja and Kuyini (2017) it states the paradigm represents the principles at which the researcher views the world, an understanding into how the researcher view the world. It further defined as a theoretical lens through which the researcher identifies the methodological aspects of the study to investigate the research methods that will be utilised and finding methodical ways to analyse the data collected. Lincoln and Guba, (1985) further elaborates that a paradigm consist of four elements which are epistemology, ontology, methodology and axiology.

a) Epistemology of a paradigm

In research epistemology is used to describe how one comes to understand something referred to as knowledge. The truth or reality is found. Epistemology is derived from the Greek language where the word is episteme which means knowledge. Apart from knowledge it goes further into the nature and forms of it and how it can be acquired and communicated to other human beings (Kivunja and Kuyini, 2017).

b) Ontology of the paradigm

As per various research conducted, Ontology is defined as the study of being. It is concerned with the world and surroundings we are investigating, with the structure of reality and the nature of existence. According to Kivunja and Kuyini, (2017) Ontology along with Epistemology are the foundation of a research. They guide and assist with course of action towards research undertaken. Researchers inhabit assumptions when they start a study hence it is the ontological questions that leads the researcher to further enquire the kind of reality that exists with the research area.

c) Methodology of the paradigm

The methodology of a paradigm is informed by the approach taken to collect the necessary data needed. It refers to the investigation and critical analysis of data production techniques. Kivunja and Kuyini, (2017) elucidates the methodology of a paradigm provides the ideas around the strategy, the plan of action and process of design that provides the required information to understand the choice of research methods. The methodological question is what advised the researcher how the world should be studied. Methodology provides the validation for the choice of method of research and the particular form in which research methods are utilized (Al-Ababneh, 2020).

d) Axiology

The fourth element of a research paradigm is Axiology. This deals with ethical issues and the nature of values that are considered when a research study is being planned (Consultores, 2021 and Saunders, Lewis, and Thornhill, 2016).

According to (Saunders et al, 2016), it explains the research process adopted by this study as an onion (Figure 3.1) which includes various important layers. Each layer of the six layers leads into another until the centre of research onion which indicates and includes the choice of data collection methods and analysis of data procedures. The first layer is known as the research philosophy which relates to the development and nature of knowledge. Hence the researcher can undertake various research philosophies such as interpretivism, positivism, pragmatism, and realism (Al-Ababneh, 2020). The second layer is the research approach, which is either deductive or inductive. The third layer is diverse research strategies such as experiment, survey, case study, action research grounded theory ethnography and archival can be applied to assist to answer research questions. The fourth layer in research methods are various approaches to collect data which are mixed methods, mono methods and multi methods. The fifth layer in the research is highly dependent on time. Research can be either collected via cross sectional or longitudinal methods. Cross sectional is where research data can only be collected once in a short amount of time and longitudinal where data can be over several times over a longer period of time. The last layer better known as the centre of the onion, as discussed is the core of the research which includes the techniques of data collection and data analysis procedures (Al-Ababneh, 2020). An understanding of each approach taken per layer will be explained in detail.

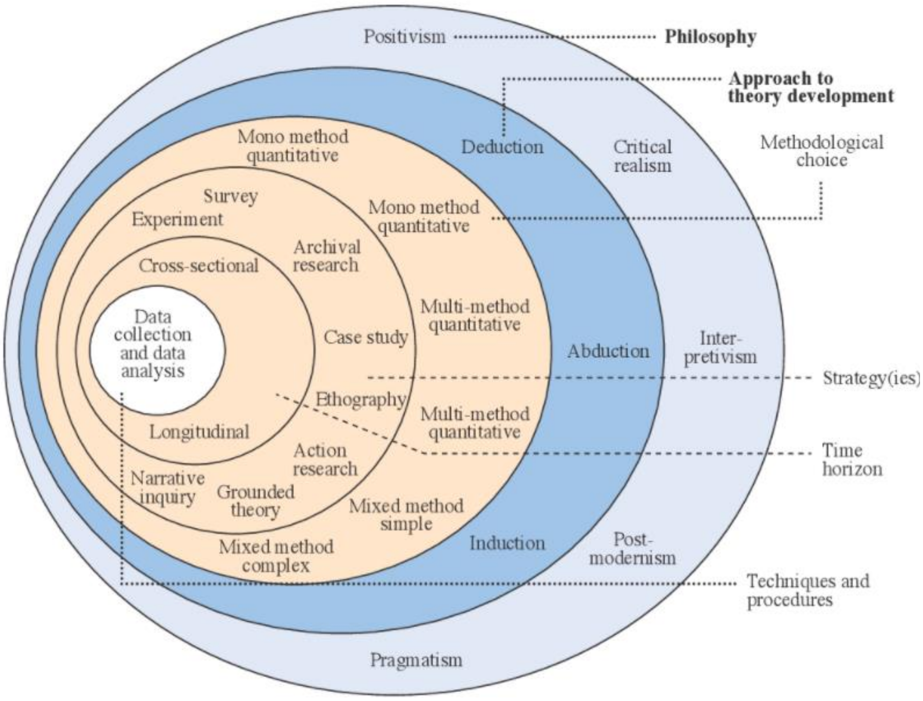

Figure 3.1: Research Onion

(Source: Saunders, Lewis, and Thornhill, 2016)

From the differentiation of the above paradigms, methodology of the paradigm was chosen element. The methodology of the paradigm taken to carry out this study utilised the research onion to help understand the structure needed to collect data, analyse the data and provide reasoning as to the best solution for a Pavement Management System. South Africa requires a system that will incorporate all factors for a functional road infrastructure and the information gained through this study will achieve that.

3.3 RESEARCH PHILOSOPHY

Research Philosophy is known to refer to a system of beliefs and assumptions that guides researchers about the development of knowledge (Saunders et al, 2016). Research shows that this is exactly what's done when undertaking a study, developing a certain type of knowledge in a particular field. As per the research onion, philosophies in research can be classified into Positivism, Realism, interpretivism and pragmatism: (Saunders et al, 2016)

- Positivism – Similar to the philosophical perspective to the natural scientist and works with an observable social reality to produce law like generalisation obtained from experiments and analysis.
- Realism – Reality is the most philosophical consideration for a researcher. This philosophy makes use of post modernisation and positivism to find connections that will assist and guide researchers to solutions of problems that may arise.
- Interpretivism – This philosophy was created as a critique of positivism but from a very subjective perspective. This philosophy explains that human beings are different from the phenomena because they create meaning to events.
- Pragmatism – asserts the concepts and focuses on action than cause and effect.

In this study undertaken, an interpretivism philosophy is followed as the researcher is out to gain in-depth understanding of an integrated system that will support Pavement Management Systems to provide civil engineering organisations and road authorities with comprehensive information required in reducing time and improving efficiency to collect vital pavement data for much needed implementation so as to help boost the economy, provide reasons why investment into SA is a good idea and enviably grow the country. In an interpretivism philosophy the researcher will perform interviews on a small scale to collect data about a phenomenon in the study.

3.4 RESEARCH DESIGN

Saunder et al, (2016) defines research design as a framework of research methods techniques that is chosen by the researcher. The design provides access to researchers to focus on the particular research method that is applicable for the subject matter and set up research for great success. Research design defines a plan for research sites, selecting subjects and procedures for data collection to fully answer the research questions. Jongbo, (2014) added research design is a planned framework for action that will serve as a bridge between questions asked during research and the implementation of the research strategy. Research design reflects the purpose of the study; hence this study was based on a logical qualitative interpretivism approach, which was best suited to obtain in-depth understanding of individuals perspectives on integrated solutions to Pavement Management and Monitoring Systems for SA.

According to Saunders et al, (2016), there are certain characteristics of a design which are: Exploratory, Descriptive, Correlational and Experimental research

- Exploratory – This type of research is aimed at trying to identify the problem. This type of research provides an outcome that is better and allow for a full understanding of the problem. This research will however not provide conclusive results. According to Greener and Martelli (2015), this type of research approach is often qualitative, inductive, and divergent in nature
- Descriptive Research – Descriptive research answers the questions which is factual in nature. It answers the questions of the 4 W's and 1 H. The research design is more structured.
- Correlational Research – This research is an association of variable or searches for relationships between variables.
- Causal or experimental Research – This research tests the hypotheses and was created to understand why a problem occurred, to eventually show the cause-and-effect relationships.

This research design is based on exploratory research. Furthermore, the design brought about superior definitions and comprehension to the industry issues being studied. This study acquired subjective data which is not fully structured from the participants. Nevertheless, this type of design allowed participants to experience openness and flexibility which allowed the researcher to draw conclusion from the patterns formed (Saunders et al, 2016). The following types of data are utilised in a study to make it a success (Saunders et al, 2016):

Types of Data needed

- Primary Data: This is original source of data achieved from interviews, survey, or experiments.
- Secondary Data: Data that is obtained from research sources such as journals, books, records etc.

Qualitative Vs Quantitative

- Qualitative: This choice involves describing and fully understanding the subjective viewpoint and interpretating them.
- Quantitative: This choice of data collection measures variables and goes about finding a relationship between them.

Research Devices

- Interviews: Participants voices their thoughts on a certain topic. Research is conducted as to how participants are chosen and if interviews will be structured or semi structured depending on the environment.
- Surveys: The Significant variables will include numerous participants required and sampling methodology which is (for example, stratified sampling or simple random sampling), designing the questionnaire and method of distributing the surveys.
- Experiments: Experiments that are undertaken in the field or in a laboratory and design technique of the experiments.

Analysis of Data

- Qualitative data Analysis – this approach includes narrative analysis, constant comparative methods, ethnographic analysis, and phenomenological analysis (Kawulich, 2004)
- Quantitative data analysis – This type of analysis involves numerical variables which includes calculations, percentages etc

For this study Qualitative methodology was chosen where interviews will be undertake and a qualitative analysis will be conducted.

3.5 RESEARCH APPROACH

The research approach is a procedure or plan that comprises of the steps of broad assumptions to a detailed method of the collection of data, the analysis, and the interpretation. It is highly based on the research problem being addressed which provides the direction needed to conduct research in a systemically and efficient way (Chetty,2016). There are two types of approaches for data analysis namely, deductive, and inductive.

- Deduction research approach is informally called the “top-down” approach. The deductive reasoning works from the more general to the more specific type of reasoning. The conclusion of the study with this approach follows a more logical approach from available facts (Burney and Saleem, 2008).
- Inductive Reasoning has been seen to work in the opposite way from deductive, moving from the specific understanding to much broader simplification and theories. This is informally known as “bottom up” approach. The conclusions are sometime based on premises. There is a degree of uncertainty (Burney and Saleem, 2008).

The study undertaken adopts an inductive approach as it will seek views and an understanding from various pavement engineers within the Civil Engineering industry. The research undertaken is inductive in nature as it does not have a fully based predetermined theoretical framework, nor does it have a predetermined hypothesis. The study has research questions which will be asked to obtain a variety of views to gain meaning from the data collected.

3.6 RESEARCH METHODOLOGY CHOICE

Qualitative research is to explore and comprehend the meaning of participants experience and how they view a particular case. Subjective experiences and interpreting data is required to gain an understanding and achieve a full description of the information received. Quantitative data is all about the Figures and number. Data for this type of research is utilised to quantify attitudes, opinions, and behavioural patterns with a goal to support or repudiate the hypotheses on a particular phenomenon (Farnsworth, 2019). Mixed methods form a link between both methods and allows the researcher to gain further insight to the data received.

Qualitative research was followed for this study as the researcher was to obtain a detailed and in-depth viewpoint of integrated solutions utilised and can be improved to optimise Pavement Management Systems in South Africa.

3.7 RESEARCH STRATEGIES

Research strategies has been defined by Saunders et al, (2016) as a plan that is diligently followed to address the research questions and/or achieve the objective set for the study. Research have known to be positivism or interpretivist. Experiments and surveys are known as positivist strategies whilst grounded theory and case studies are interpretivist strategies. This research study was phenomenological in nature hence interviews are being utilised. According to Saunders et al, (2016). A research interview is a very purposeful conversation between two people or more. These small meetings allow the interviewer to establish a relationship and ask very unambiguous questions to which the interviewee is willing to respond and to listen attentively. Interviews are used to gather reliable and valid data that is relevant to the research objective and questions furthermore interviews can be used to refine the researchers' ideas when questions and objectives are fully formulated.

There are three types of interviews that can be adopted during a study:

- Structured interviews – this type uses questionnaires based on predetermined and standardised set of questions and researchers refer to them as interviewer – completed questionnaire. Interviews can be conducted face to face and via video calling platforms. Emotion, feeling, and reactions are best seen in a face-to-face interview (Saunders et al,2016).
- Semi-structured interview – for this type of interview, the researcher has a theme to be followed and key questions to be asked, the sessions between interviews may vary in a semi structured interview. The interview may be captured by audio – recording or notes will be taken. The aim for this approach is to remove any restrictions and to go deeper in the questions and answers to obtain an understanding and learn more from the interviewee (Saunders et al,2016).
- Unstructured Interview – this is a very informal interview. Researchers would use these types of interviews to explore in depth a general area in which the researcher is interested in. These are known as in-depth interviews. Research

shows there is no predetermined list of questions, and the interviewer is given the opportunity to speak freely on aspects of behaviours, events, and beliefs on the topic area.

The interview process for this study will be taking a semi-structured approach to be able to obtain the objectives and answer the research questions. The participants would be able to interact more if the interview was more like a discussion than a fully-fledged interview process. The purpose of an interview process was to understand the participants viewpoints to ab able to achieve the objectives of this study.

3.7.1 OBSERVATION

Observation research is a qualitative research method where researchers observe participants' ongoing behaviour in a natural situation (Fox,1998). Field work was conducted to enhance the viewpoints achieved from the interviews. The observation will be undertaken on paved roads, here road condition assessments will be conducted via manual and automated methods to understand the efficiency and accuracy achieved from these methods first hand. For the manual assessments method five (5) assessors were chosen to conduct visual assessments on five (5) kilometres of four (4) roads each. All distresses and parameters were collected by both manual and automation but for this exercise only the International Roughness Index and Rutting will be evaluated and analysed for discussion. The resultant of this exercise will further help decipher the methods that will support an integrated system for a Pavement Management System.

3.8 TIME HORIZON

According to Saunders, Lewis, Thornhill, (2009), research articulates that it is the time taken to research the phenomena which is independent of the research methodology that has been chosen. There are two options for time horizon which is Cross Section studies and Longitudinal Studies. Cross Sectional studies are conducted when there are major constraints of resources and time. The data is collected only once, over a noticeably short period of time before analysis and interpretation. The Longitudinal study on the other hand is research taken place over time of a group or variable of subjects. This type of study is undertaken by investigating the same individuals or situation several times or continuously over the time in which the issue runs its course. The observation are repeated to fully understand the relative stability of the phenomena. A study of a cross sectional nature was utilised for this research, the time to conduct the research was very limited.

3.9 TARGET POPULATION

The target population for this study was pavement engineers, managers, and directors from Nankhoo Consulting Engineers, ARRB Systems South Africa, Endocon Consulting, VNA Consulting, Gibb Engineering and the Free State Department of Police, Roads, and Transport. The target population equates to approximately seventy (70) pavement Engineers in KZN and Free State Province. The above-mentioned organisations were chosen for this study due to their extensive work they have undertaken in Road Asset Management for government departments. Pavement engineers of the Civil engineering industry has been chosen for concise understanding of the research topic hence a non-probability sampling was selected.

3.10 SAMPLING

Sampling is known as the selection of a population in a research study. In various research endeavours, the involvement of people of an entire population is not possible so a smaller group is relied upon for undertaking the data collection (Turner, 2020). Research is much more accurate and economical when utilising a sampling method. Sampling has proven to be more practical and is able to allow data to be collected quicker and at a reasonable cost than having a bold ambition of reaching the entire population. Sampling plays an important role in data collection as it makes inference about the population, understanding the methods of how data arrived in the database is a very crucial aspect of analysing and concluding from the data (Turner, 2020).

Sampling can be divided into probability sampling and non-probability sampling. In probability sampling each sample in the research has an equal likelihood of being chosen hence it’s an element of the population that has a non-zero probability of selection (Showkat and Parveen, 2017). Non-probability sampling techniques on the other hand utilises non-randomised methods to create a sample. Non-probability sampling is mostly associated with judgement. Participants are selected instead of randomisation for easy access. This method is very convenient, less expensive, less complicated, and an appropriate method which is available in most cases. Through this type of sample, researchers can study a particular phenomenon with a possibility to generate valuable insights. Below are a few non-probability methods of sampling that are qualitative in nature:

- Convenient Sampling – This is the type of sampling utilised where researchers prefer participants as per their convenience. In this type of sampling participants who are readily available are the ones that are selected (Showkat and Parveen, 2017).
- Purposive Sampling – Judgement of the researcher is used when choosing participants. Purposive sampling is used in exploratory research or field observation. This type of sampling addresses problems with a specific plan in mind, hence most of the sampling methods may be considered purposive in nature. Research shows that this sampling is much more convenient, cheaper, has the ability to select the certain individuals that is relevant to the research design (Showkat and Parveen, 2017).
- Quota Sampling – For this type of sampling, researchers pre-plan the number of participants to be involved in a study. Quota sampling is executed by leading structured interviews as part of a survey that is not random (Showkat and Parveen, 2017).
- Snowballing - This sampling method is also referred to as “chain referral sampling”. This type of sampling is when participants are willing to offer to take part in a research study especially when it is difficult to find participants for the chosen target population. On invitation current volunteers recommend additional volunteers and the course repeats itself (Saunders et al, 2016).

For this study, a non-probability sampling was adopted for the exploratory study and to be more specific a stratified purposive sampling was undertaken. It focuses on a specific stratum of pavement engineers within the civil engineering industry. The selection criteria for this research study were:

1. The participants needed to be pavement engineers, people in management roles making decisions or experienced individuals working with various methodologies that plays a huge role towards an integrated solution to a Pavement Management System.

2. The participants must be willing to talk and engage openly about their view on an integrated solution towards a functional and effective Pavement Management System, the challenges currently faced with the backlog of road maintenance and solutions to help improve the problem that will positively impact the economy. A sample size of thirty-four (34) people were selected for the study. A total of twenty – one (21) participant agreed to undertake the study. Thirteen (13) participants didn’t respond to the request to part take in the interview process, it is presumed there was a rise in work commitments. Of the twenty-one respondents, fifteen (15) were pavement engineers working with monitoring systems and the latter six (6) were part of management and road authorities’ personnel that make strategic decision regarding Pavement Management Systems for roads of South Africa.

3.11 DATA COLLECTION

The data collection had started late October 2021. This process ran for approximately four weeks from 20th October 2021 to 08 December 2021. The data collection was conducted during the COVID -19 pandemic but by this time many individuals had been vaccinated against the virus. Nevertheless, all protocols was still observed when interacting with colleagues where face to face interviews occurred. Most interviews took place via online platforms such as Microsoft Teams and Zoom. The participants of the interviews were pavement engineers working directly with Pavement Management Systems and senior managers that have been making pavement engineering decisions to ensure design, performance tracking and maintenance construction are conducted in a timely manner. The data collection process was followed as per below:

- The researcher identified civil engineers from various engineering consulting companies and road authorities who are well experienced in the pavement engineering field.
- As the interview process started, the topic was introduced along with the purpose of the study, the aim and objective was explained so the participant can agree to part take in the interview and sign the consent form before the questionnaire commenced. Within the consent form the participants are asked if the interview can be audio recorded or not. Refer to appendices for the template of the Consent form.

- The researcher had to ensure the participants where available for approximately 30 to 40 minutes. Meeting requests was sent in advance to engineers to set aside time so this process can be uninterrupted.
- The participants were notified at the introduction of the meeting that their names will not be documented in the interviews, and they will be referred to as a numeric number such as Respondent 3 (R3). The participants were also advised that participants are undertaking this process on a volunteer basis and can withdraw at any given time.
- Details of the researcher was given to each participant if they wanted to get in contact and obtain any more information needed.
- To ensure data accuracy the responses were recorded when given permission and accordingly when notes were taken it was repeated to the participants where needed to ensure no errors occurred.

3.12 ANALYSIS OF DATA

Data analysis is important and crucial in describing and explaining the data collected from the participants being interviewed and observation. According to research, data analysis involves searching for themes or patterns that occur in the data set collected (Saunders et al, 2016). Therefore, for this study, Thematic Analysis was utilised. This type of analysis is a foundational method for qualitative analysis. Thematic analysis presents a systematic yet flexible and accessible approach to understand and interpret qualitative data. This method enabled the finding of the research to be established from the dominant, common, or vitally important themes within the raw data (Maguire and Delahunt, 2017).

The thematic data analysis process begins by transcribing the data, re-reading and double checking the transcripts, then codification commenced in a systematic way. Searching of themes commences. The coded data was analysed and grouped into similar patterns or themes. Themes are collated and checked against each other. The themes are internally distinctive, coherent, and consistent which was further verified and defined. Once the themes are derived the analysis goes deeper into interpretation.

For the Field work undertaken, analysis of the manual data as well as the interpretation of the automated data collection was undertaken via guidance of the COTO TMH9. The manual visual assessment data was inputted into a spreadsheet determining the degree of each distress. This was further correlated to the COTO TMH 9. The automated data was also characterised as per the TMH 9 manual and compared to understand the level of accuracy achieved from both pavement data collection methods. The field data was undertaken to enhance the information received from interviews. The interviews are views of people and their perspective on the topic, the field data has the ability to objectively provide further insight to the problems faced and once analysed find the solutions needed. Data is understood such that the data makes sense. By analysing the data, it tells a well organised story and advises if the research questions and objective of the study has been achieved. The last step is the written report of the analysis.

3.13 LIMITATION OF THE STUDY

Undertaking a study comes with various challenges along the way. This segment could not be viewed as a confession of the researcher's shortcomings or the compromise to credibility, but as a mature expression of the extent of which the researcher findings and conclusions can be said to be 'truths' (Saunders et al, 2016). The following factor noted a challenge experienced through the study prior to submission:

1. It was envisaged to have a total of thirty-four (34) respondents for this study to obtain increased diverse feedback to the interview process, but this was not achieved as thirteen participants was not responsive towards the invitation to participate.

3.14 ELIMINATION OF BIAS

Bias has the inclination or prejudice for or against one person or group, especially in a way considered to be unfair; a concentration on an interest in one area or subject; a systematic distortion of statistical results due to a factor not allowed for in their derivation (Saunders et al., 2016). Bias is a major issue to the credibility of the research study and may invalidate it. Hence, to minimize bias, the researcher performed interviews at the most suitable time for the participants so that they were not in a rush to finish the interview. Furthermore, the researcher circumvented his own subjective perspective or persona to manipulate a rational and precise interpretation of 22 the participants' responses. Researcher bias was therefore avoided since it could affect the responses of the participants through influence of the researcher

3.15 ETHICAL CONSIDERATION

Amidst the research study, it was imperative and important that the researcher treats all participants with the utmost respect and abide by their time of convenience when undertaking the interviews (Walliman, 2011). The general opinions, professed rules, and regulations which are basic to conduct a research project in a sample of the target population remained confidential. The data obtained from the research will be kept confidential and stored for a certain period of which the supervisor and researcher will have access to.

3.15.1 Ensuring no harm comes across the participants during the study

Due to COVID-19 being amidst us globally, the interviews was conducted only via platforms such a Zoom and Microsoft Teams as participants felt more at ease. This methodology of virtually chatting with the participant ensured no harm comes to the interviewee as there was no need for masks or social distancing over a Zoom call. The participants was either interviewed from their offices or from their homes as some was still working on a hybrid basis.

A per Denscombe, (2012), no actual harm to interviewees includes cognitive impairment such as the emotional and feelings or condescending of self – confidence which could be caused by the questions asked, this harm also extends to being physical which may be at a result of the situation in which the questions are delivered. Questions or comments regarding gender was avoided to refrain from emotional harm.

3.15.2 Gatekeeper permission is obtained

Prior to the study, Gatekeeper letters are obtained to gain access into the organisation. Organisations can accept or decline approval for a researcher to conduct a study within their company, management of the various companies are not obligated to part take in a research study. For this research, an introduction emails followed by a telephone call was sent to management of each of the six companies. This was later followed by a request for a permission letter from the organisations and resulting in all companies granting access to conduct the study.

3.15.3 Participants providing informed consent prior to questionnaire

Prior to the interview process the researcher had furnished the participants with sufficient relevant information about the study and the reason for the study so participation can continue at ease. An agreement letter with reference number: HSSREC/00003400/2021 was approved by the Ethics committee of University of KwaZulu Natal. This document was utilised and distributed to participants proposing the reason for the study, it advised that their participation is on a voluntary basis, the interviewees responsibility and the time required for them to answer the interview. As the participant approves to consent to the interview, they would voluntarily sign to undertake the interview process.

3.15.4 Confirming anonymity and confidentiality with the study

The name of each interviewee was deliberately kept private and was always referred to as participants. This ensured the privacy and anonymity of each participant was guaranteed. The participants was further referred to as Respondence and a number followed for example, R3. The data obtained from the participants will be kept confidential and protected as to not share the data with any individual.

3.16 SUMMARY OF THE CHAPTER

In this chapter, the research discussed the paradigm approaches utilising the Research Onion that were employed to obtain valuable data for the study. The various concepts and elements of the research methodology as illustrated in the research onion, have shown the interrelationships between each item and how researchers use research projects to develop a consistent research process. The choice of research design strategies and ethical consideration was explained and noted how applicable it was when understanding a most appropriate integrated solution to Pavement Management and Monitoring Systems utilised in South Africa. The next chapter will fully discuss the results of the study.

CHAPTER 4:
RESEARCH FINDINGS AND INTERPRETATION OF DATA

4.1 INTRODUCTION

This chapter presents the findings from the study. The study did evaluate the most integrated solution for a Pavement Management and Monitoring System. An interview process and field assessments were undertaken to collect data. An interview schedule was utilised to gather information from pavement engineers working at private and governmental organisations. The themes were generated from the responses that were obtained from the interviews held and based on the objectives of the study. The results of interviews were analysed through a thematic analysis and further discussions with the literature review. The data collection was further collected by field assessments, here an objective comparison was undertaken, and a full understanding of the accuracy obtained between manual and automated methods was provided.

The utilisation of qualitative research enabled the researcher to explore the various methodologies out in industry to collect road pavement data for a Pavement Management System which will play a vital role in making strategic decisions for the life of road infrastructure in South Africa. The following research questions were answered:

1. How important is road condition assessment for strategic planning at government level in South Africa?
2. How does Pavement Management Systems influence road maintenance strategies?
3. What are the accepted methods of conducting road condition assessments by pavement engineers in South Africa?
4. What are the key road-testing technologies pavement engineers can utilise and adopt to conduct road condition surveys on various types of road networks of South Africa?
5. What impact will an integrated solution to Pavement Management and Monitoring Systems have on the South African economy?

The next section presents the results. This starts off with the qualification of the participants, years of experience and followed by a discussion of the identified themes.

4.2 DEMOGRAPHICS

Due to the Protection of Personal Information Act, 2013 (Act No.4 of 2013) which took effect on 1 July 2021, companies were not able to divulge more information about their staff than the following academic knowledge hence the questionnaire compiled have minimal information about the demographics about their staff members.

4.2.1 Educational qualifications of participants

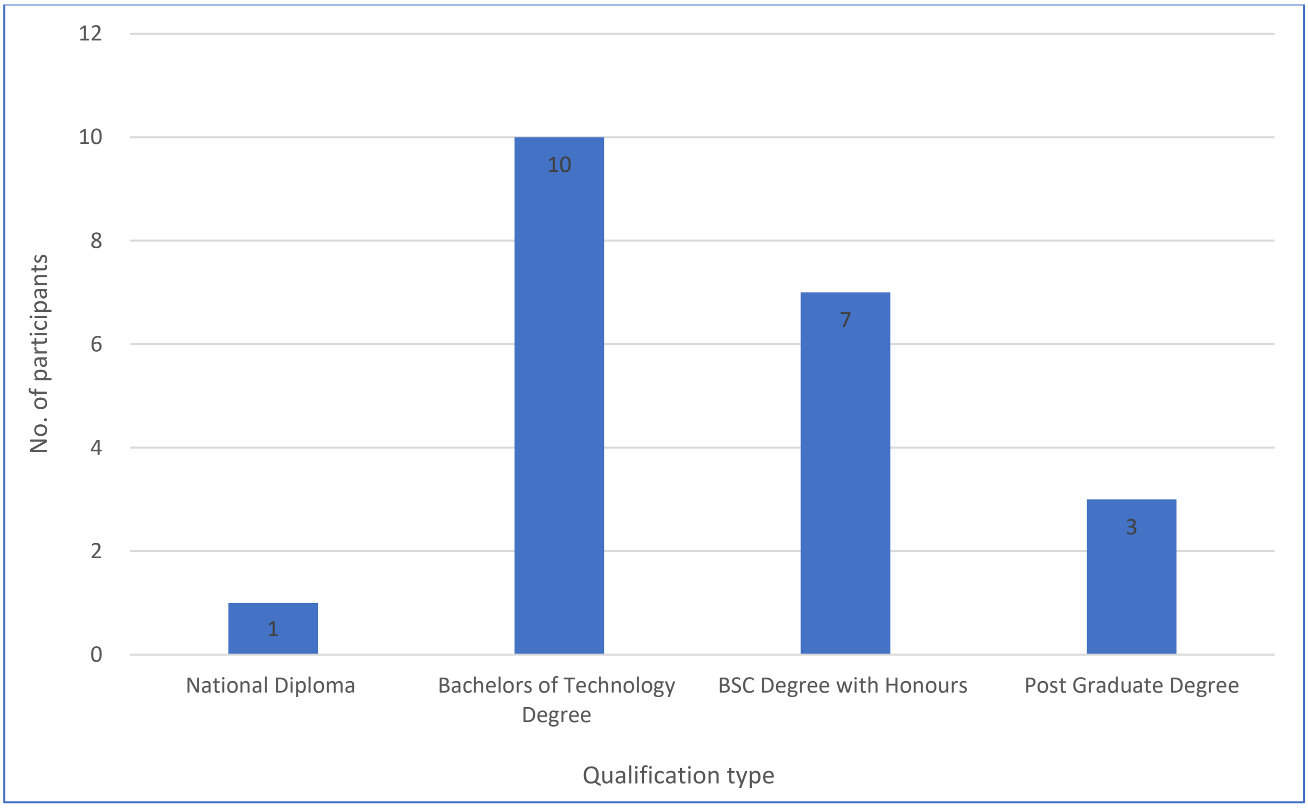

Figure 4.1: Qualification of participants in the study

The results in Figure 4.1 above summarises the outcomes of the educational qualification of the participants. Since the focus of the study was on the best integrated solution for an effective Pavement Management System in the Civil Engineering industry it was crucial to have participants who clearly understand the interview questions and have worked within pavement engineering departments of their organisations to be able to make relevant contribution to the study. The participants that contributed to the study were from a road authority and private engineering companies on behalf of the road agency making strategic decisions for road infrastructures.

4.2.2 Years of experience in the Civil Engineering Industry

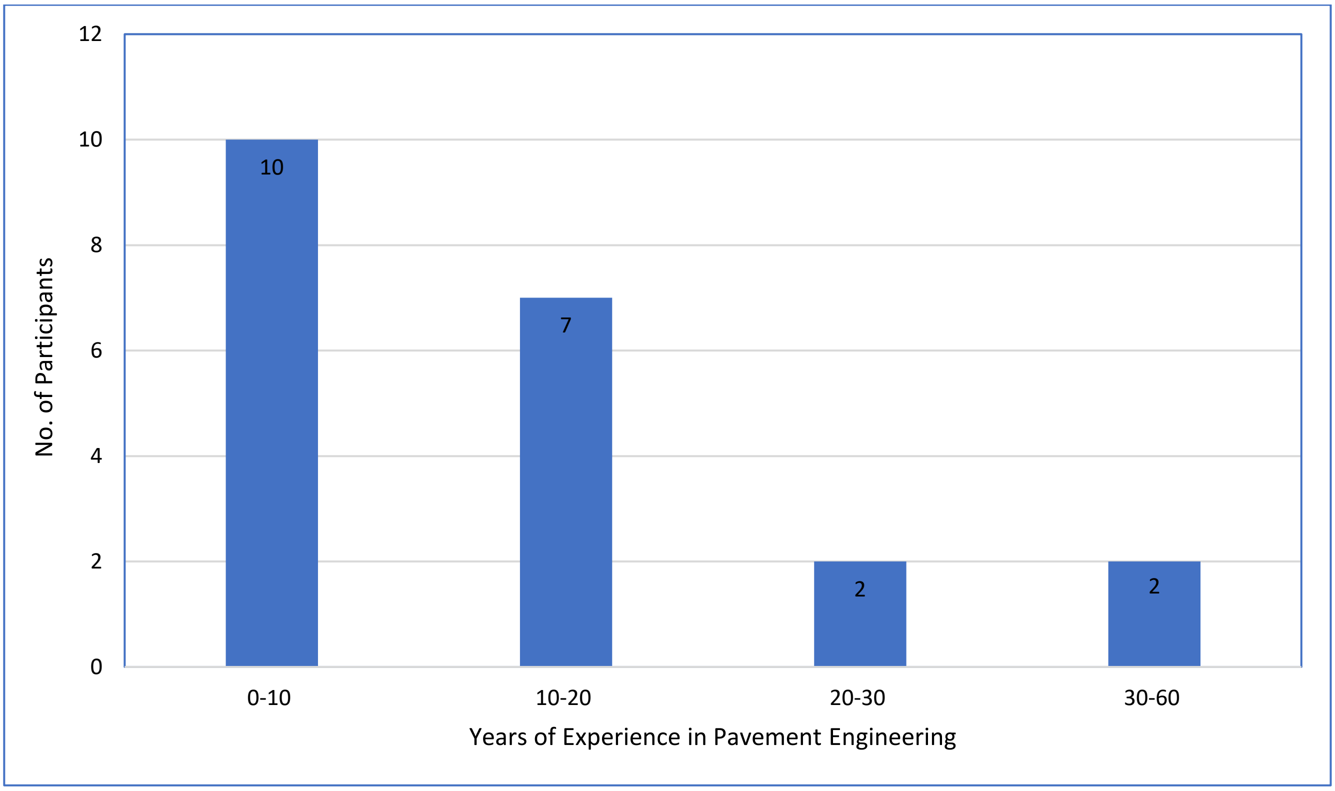

Figure 4.2: Years of Experience of participants

The results in Figure 4.2 indicates the individuals that were interviewed have grasped substantial knowledge and work experience in the pavement engineering department in their organisations. The majority (10) of participants have gained experience between 0 to 10 years, 7 participants gained between 10 to 20 years' experience. Two participants have gained 20 to 30 years of experience in pavement engineering's and the final two participants have gained a wealth of experience in pavement engineering exceeding 30 years. The participants that were chosen as the sample had experience and knowledge on the topic of this study. For the purpose of this study, the working experience of the participants were considered adequate as they have vast knowledge and understanding of Pavement Management Systems and the future of the methodologies utilised to create efficiency in South Africa.

4.3 ANALYSIS OF THE DATA COLLECTED

This section presents the results obtained from the data that relates to the themes that were obtained from the interviews undertaken in accordance with the objectives of the study.

4.3.1 Themes about the perception of the importance of road condition assessments for strategic planning at government level for road infrastructure

This study reveals three sub-themes reflecting the various perspectives of strategic planning in the Civil Engineering Industry. The list of these themes includes: 1) Requirement for suitable systematic strategic planning, 2) Procurement process at road authorities, 3) Limited budgets/ funding at governmental level for road infrastructure

Table 4.1: Themes focusing on the perception of the importance of strategic planning at governmental level at Provincial level.

Theme focusing on the importance of road condition assessments for strategic planning at governmental level	**Frequency**
1. Requirement for suitable systematic strategic planning	15
2. Procurement process at road authorities	8
3. Limited budgets/ funding at governmental level for road infrastructure	5

4.3.1.1 Requirement for Suitable Systematic Strategic Planning

Of the twenty–one participant interviewed in this study fifteen participants had explored the fact to understand the road network, they have stated road assessments are a necessity to be undertaken to understand how to plan effectively, resulting in less room for a maintenance backlog. R2 and R6 has similar sentiments regarding strategic planning with the following statement:

> "…*Assessments has a high level of importance in planning; the assessments provide consultants and road authorities the understanding of future implementation plans. It provides short-, medium- and long-term goals based on the severity of maintenance measures of existing roads."*

Participant R6 went on to note how Strategic planning has an overarching effect on the holistic life of the road infrastructure:

"*Strategic Planning plays an integral role in the cost effective and efficient means of properly prioritising the need for road maintenance. A proper updated road asset management system which considers road categories as a means of prioritising will allow for funding to be spent wisely due to managed road condition data."*

Road assessments are a vital component of Strategic planning as one can gain sufficient knowledge of the network to make decisions in the planning that will benefit the road infrastructure. Participant R2 had stated:

"*it's extremely important, you have informed knowledge of the status quo of the road network or on a project level. Road authorities can prioritise where the problem areas are and concentrate on the worst roads, hence plan appropriately".*

Strategic planning is a key component when outlaying road infrastructure projects. Foresight for road infrastructure is required and this is achieved by proactively planning. According to Hall, (2013) strategic planning is a management technique, an art of creating specific business strategies that assist organisations prepare for the future with appropriate goals and objectives for predictable and stable growth. Strategic planning is further defined as an instrument that allows making the long-term plans in full consideration of risks and opportunities experienced by the road authority or organisation (Hall, 2013).

4.3.1.2 Procurement process at Road Authorities for maintenance projects

From the interview responses it was inferred that road authority's procurement process lack full understanding of what is required or the end goal of outlaying projects to maintain the road network swiftly for the betterment of everyone utilising it. The procedures taken to implement projects for road assessments or for implementation after road assessments and designs are concluded are not conducted in the best objective sense. Timelines are crucial when introducing and procuring road maintenance projects in industry. Some of the respondents subjectively have alluded politics has been a catalyst in not achieving the strategic goals set for implementation of projects.

According to three of the participants they stated the following:

Participant R1 stated:

"…*Streamlining procurement process is also critical as currently this is resulting in delayed commencement of work and increased costs due to interferences."*

Participant R8 stated:

"…. *we need commitment from the top. Defined maintenance budgets allocated based on needs and not on politics*."

Participant R15 Stated:

"Due to a political nature of the way roads are maintained in our country, it seems as if this backlog will never be reduced to a considerable amount. Various interferences have delayed construction processes over the last few years causing roads to severely suffer as they go beyond their pavement age resulting in distresses that deteriorates from surface failure to structural failures very easily. I personally believe that roads should be prioritised on the number of vehicles on a route and the movement of traffic for that route, thereafter roads that are in a fair condition is maintained to bring it to good condition."

The responses show that interferences in the procurement process of outlaying maintenance and construction projects has led to serious issues which causes the road infrastructure to further deteriorate. According to Beke and Mendeita, (2018), Political interferences in public procurement can affect economic performances such as maintaining the road infrastructure and state functioning. The author goes on to note that political influence over public procurement can be direct with various politicians interfering in the actual process to secure their party or personnel interest (Beke and Mendeita,2018). According to the Southern African Development Community, (2012), The costing of maintenance of roads remains a distinct issue as funding for roads gets diverted to other sections due to political interference. Likewise, some funding has been allocated to road infrastructure but have been poorly and inefficiently managed by government (Southern African Development Community, 2012). The traditional top-down approaches to the funding of maintenance and construction has proven to be highly ineffective (Southern African Development Community, 2012).

4.3.1.3 Limited budgets/ funding at governmental level for road infrastructure

The interview process has boldly indicated that at governmental level there are huge budgetary issues, this is due to the lack of planning and poor management of the funds which focuses on prioritisation of roads and officials being more reactive than proactive (Rensburg and Krygsman, 2019). The limited funding resulting from reduced lack of planning has resorted to a backlog of road maintenance that has reached a high of R478 billion from R197 billion. This value is more than double the amount set out the South African National Roads Agency Committee of Transport of Officials (COTO), Condition and Budgets Needs Report. A report is created and distributed to make National Departments aware of the issues on the ground and come up with strategic decisions for implementation (Arnoldi, 2019). Respondents stated that there is a pure need for a functional plan of action:

Participant R4 stated:

> *"The backlog is created by poor planning and the lack of funding. The South African government needs to priorities these backlogs as it is creating a problem for the user. The road agencies need to take a plan of action to the South African government and give the government different alternatives of fixing these issues of maintenance. Infrastructure is an important part of our economy, and this will need to be realised quicker by the different road agencies. The road agencies need to evaluate and measure the cost of South Africa's Road maintenance backlog, they will need to evaluate the skills development as well as the investment in these roads in order to better understand the backlogs".*

Participant R*12 stated:*

> *"The most important aspect is to know the condition of your network (assets) and develop a model with triggers to use for maintenance activities, in this way you are able to identify and prioritize where most budget should be spent, also, the roads that are still in good condition to be allocated budgets for maintenance to preserve than and extend serviceability to avoid focusing only on poor roads whilst the rate*

of deterioration is increasing on the neglected roads therefore putting more pressure and imbalance to the network. Keep the condition of the good in good so that the backlog is addressed on poor-to-poor roads."

In the study a total of eight (8) respondents have alluded the lack of budgets have been caused over the years due to an outdated or unreliable Pavement Management System feeding into a Road Asset Management System. Two of the participants explained this statement:

Participant R1 stated:

"Limited funding will always be an issue as the need for infrastructure spend demand is weighed up between the various demands. Timely preventative maintenance on the existing infrastructure is critical so that the backlog does not increase exponentially. This in conjunction with a reliable Pavement Management System will best utilise available funding…"

Participant R10 stated:

"Road Agencies should have an updated Road Asset Management System and Pavement Management System in place. These systems must be regularly updated so that it can be utilised to prioritise their assets which require urgent attention in respect to maintenance to ensure no additional costs are incurred when conducting maintenance activities."

According to Southern African Development Community, (2012), in numerous governmental levels, funds are diverted to other sectors of government decreasing the allocation to road infrastructure which poses a disturbance in outlaying of projects. On the other hand, budgets play an integral part for any upliftment of Departmental assets, hence it should be spend wisely and based on information that is correct and true so that the assets are maintained in the best way and continuously monitored. Arnoldi (2019) added that various municipalities and the provincial governments have frequently had disparities in their road assessment report collected in various financial years which resulted in obtaining inaccurate data. The author has pointed out an example where cost of maintenance to full upgrade have elevated from being R347 000 per kilometre to a high of R11.4 million per kilometre due to inaccurate data supplied to and collected by government. Hence, it's imperative that government work with accurate road data to price accordingly and allocate the appropriate funding given to then from National Treasury (Arnoldi, 2019).

4.3.2 Themes relating to the effectiveness of Pavement Management Systems on Maintenance Strategies

This study revealed two different themes regarding the influence Pavement Management Systems have on maintenance strategies. To be precise, these themes are 1) Obtaining objective big data to develop a beneficial financial and engineered solution and 2) Knowledge of pavement behaviour.

Table 4.2: Theme focusing on the influential factors of Pavement Management Systems on Maintenance Strategies

Themes relating to the influence of Pavement Management Systems on Maintenance Strategies	Frequency
1. Obtaining objective big data to develop a beneficial financial and engineered solution	5
2. Lack of knowledge of pavement behaviour	15

4.3.2.1 Obtaining objective big data to develop a beneficial financial and engineered solution

During the research, a total of five participants mentioned and believed that data collection must be objective and obtaining big comprehensive statistics apart from detailed impartial road condition information plays a vital role in understanding the network and obtaining a cost benefit to further strategize the end goal for road maintenance. The respondents said the following:

Participant R2 stated:

> *"Maintenance decisions needs to be objective. Some factor that need to be considered include existing road asset condition, asset usage in terms of traffic volumes, socio economic factors such as strategic routes (for example, tourism, timber haulage etc) available funding and which maintenance options will result in the biggest benefit to road uses. In other words, a cost benefit analysis. This is often reliant on big data and a system*

with a sort of relational database is required to mathematically model a cost beneficial solution."

Research shows a proper and fully functional Pavement Management System is the only mechanism that can be utilised to efficiently provide the guidance needed for road maintenance. According to the Technical Recommendations for Highways Draft TRH 22 (Department of Transport, 1995 and Mfinanga, 2007) on Pavement Management Systems, it states a Pavement Management System provides consistent, objective, and justifiable measures that can effectively address the requirements of road maintenance. There are a number of essential components structured to assist in the decision-making responsibilities at various corporate hierarchical levels which include, objectively collected pavement condition survey which also relates to serviceability and a database of vital pavement related information for example, traffic, socio economic factors of the route. Additional information included in a Pavement Management System provides a basis for a decision criterion, analysis schemes, implementation procedures and available funding.

The Pavement Management System helps to prioritise the roads that requires road maintenance by using maintenance options that will result in the largest cost benefit to road users. As a cost benefit is created from objectively accurate data, using a tool like the Highway Development and Maintenance Management System (HDM4), organisations are able to establish rehabilitation programmes that fits the budgets that's allocated and will be able to notify the authorities the future budgets required for subsequent financial years (Department of Transport, 1995).

4.3.2.2 Lack of knowledge of pavement behaviour

When road condition assessments are undertaken a comprehensive understanding is required of the road and surroundings so accurate decisions are being adequately made when the stage of implementation occurs. According to fifteen participants that participated in the interviews concurred on the view that lack of knowledge of understanding the pavement behaviour has contributed to further deterioration of the road network. Pavement behaviour includes understanding the life cycle of the road, the frequency of road maintenance works, and the correct remedial measures needed to extend the life of the road. It was also highlighted that budgets are being spent on inaccurate visual diagnosis of the differences between a functional failure and a structural failure of the road.

Participant R6 and R8 stated the following:

> *"Road distresses are categorised into structural and functional defects. The lack of knowledge to enable differentiation between the two types means that problem areas in road pavements are not properly addressed which may lead to premature failure. Structural defects usually indicate that a road has reached the end of its structural life and will no longer be able to cater for the current traffic loading while functional defects typically indicate aging/deterioration rather than structural damage. What is indicated visually does not always represent structural adequacy and can in fact look worse than it actually is. Understanding pavement behaviour is the focal point to effectively address prioritisation for road maintenance and also assists in determining the extent of repair measure along with associated costs which if based solely on functional condition can be exorbitant."*

Participant R4 stated:

> *"The functional aspect is an issue due to the road not being monitored correctly. The data that is collected are either non or little to make a decisive decision. Maintenance is required regularly, and this is an issue because we are more reactive than being proactive in South Africa. Honestly, this is a problem because we end up spending more money trying to fix issues that could have easily been maintained with a much lower cost."*

Roads are essentially the lifeline to various industries of the economy; it transports passengers and goods hence analysing the road network correctly is fundamental for roads to be safer for all road users. As indicated in the interview's, knowledge plays a vital role for success. This statement above agrees with Okine and Adarkwa (2013), when manual assessments are conducted experiential, and skills knowledge is pertinent to evaluate the correct measures needed for a road. Knowledge is gained from continuous research conducted on the activity, knowledge sharing in the workplace and constant practice on the task.

A distinction between structural conditions versus functional characteristics is required. According to literature, structural condition evaluations are determined by the performance of damage on one or more pavement components (layer works below the blacktop) causing the road to no longer restrain the traffic load. It further explains that functional evaluation is information that is gathered to decipher the characteristics of that pavement that directly affects the safety and comfort of road users (the blacktop surface layer). Without adequate knowledge and extended experience these two components are mistaken causing a ripple effect on the underlying costs hence affecting the ideas on strategies implemented for a successful maintenance outcome (Rusmanto, Syafi and Handayani, 2018).

4.3.3 Themes pertaining to the acceptable methodology chosen to conduct road condition assessments in organisations

To concentrate further into the study to decipher an integrated solution for future Pavement Management System, this study has identified three themes on the acceptable methodologies chosen to conduct road condition assessments, to be more precise the themes are as follows: 1) Physical Visual Assessments, 2) Post Rating Condition Assessments in engineering practice, 3) Insight into the perspectives of the challenges and positives of the accepted choice.

Table 4.3: Themes focusing on the acceptable methodology chosen to conduct road condition assessments

Themes pertaining to the acceptable methodology chosen to conduct road condition assessments in organisations	Frequency
1. Physical Visual Assessments	9
2. Post Rating Condition Assessments in engineering practice	12
3. Insight into the perspectives of the challenges and positives of manual methods.	21

4.3.3.1 Physical Visual Assessments

A total of nine participants stated the best practice undertaken to obtain road data is the Manual method of road condition assessments. Participants have stated that this method was utilised for the last few decades as it’s the first principal methodology of doing assessments in accordance with the TMH9 manual. Participants have noted this technique has been chosen as various road agencies support this.

Participant R1, R4, R7, R10, R11, R13, R18, and R20 all relayed the same sentiments:

> *"Manual Methods - The company currently uses the TMH 9: 1992 – Pavement Management Systems: Standard Visual Assessment Manual for Flexible Pavements. My company has adopted the physical visual assessments method primarily because as it allows the engineer to walk the road by foot recording distresses encountered in each direction of travel against kilometre staked distances and its relevant position within the road width i.e., shoulder, left or right wheel path etc. We have gained much knowledge on the manual methods hence we fully utilise it."*

It was further noted by Participant R4 that during physical visual assessments more properties of the road can be seen.

Participant R4 stated the following:

> *"Manual methods are the best option of road assessments that we use for provincial and municipal roads. The physical visual assessments make you understand the road and layout. One can visually see the types of deterioration that has occurred and being on site you identify the types of vehicles that are travelling the route capturing traffic data. Site inspections provide a sense of what road users are doing, the pattern of travel."*

According to Timm and McQueen (2004), manual methods of collection road condition data has been practiced for decades as this is what most road authorities have chosen for other methodologies had not been fully understood or researched adequately, hence keeping to the conventional methods of wind shielding or physically walking the route was the most practical option. However, the accuracy of the assessments is fully dependant on the experience of the assessor undertaking the field work (Timm and McQueen, 2004).

4.3.3.2 Post Rating Condition Assessments in engineering practice

Since the manual methods of condition assessing roads took off and utilised for decades, innovation was henceforth introduced to the market and boomed in various countries. Interestingly twelve participants expressed that they would fully embrace the semi-automated to fully automated system to further undertake post rating condition assessments in their organisation. Respondents advise that utilising the automation is within full compliance to the TMH 9 manual series and are in line with the Division of Revenue Act, PRMG Grant conditions following National Departments mandate hence been fully utilising this system than the manual methods.

Participant R2 stated the following:

> *"Visual assessments undertaken via post rating methods are within compliance to the TMH 9 manual series and in line with DoRA PRMG Grant requirements. The major difference in the method of visual assessments undertaken, is that survey of the road networks is done using highly specialised vehicles equipped with laser profilers to accurately measure surface conditions, high-definition cameras used by visual assessors to perform post ratings on the road condition based on TMH9, and traffic speed deflectometers that measure the deflections of the road, and automatic crack detection which also aids in a non-subjective visual assessment. "*

Research shows the most important aspect of an automated pavement condition survey is the data collection. This process is fully undertaken by technological complex vehicles traversing on road networks at highway speeds collecting and storing vital surface and structural data. Surface distress data are collected automatically utilising downward facing cameras aimed at the pavement surface and forward-facing cameras viewing the surrounding to capture the full environment. The images are then uploaded to a cloud-based storage facility, so data is not lost and finally post rated back at the office to determine the type, extent and severity of any surface distress that is present (Timm and McQueen, 2004). This methodology reduces the level of subjectivity that is present with the manual method, it's convenient and quality assurance of data is conducted with ease. Large networks are surveyed within a prescribed time, data is accessible when needed, no revisits to site needed each time an issue arises, and data is processed at various intervals for design purposes etc.

According to Department of Transport, (1995) and noted by the participant all methodologies undertaken for data collection of pavements are in compliance with the criteria's prescribed in the TMH9 manual series and in line with the Division of Revenue Act.

Moolla and Tetley, (2021) provides the understanding that of the nine provinces in South Africa only two provinces, one municipality and the South African Roads Agency Limited (SANRAL) have adopted and are in compliance with the National Departmental regulations of utilising the automation for pavement condition assessments in order to promote efficiency and improve sustainability for all.

4.3.3.3 Insight into the perspectives of the challenges and positives of manual methods.

All twenty-one participants expressed their perspectives of the manual methods and is noteworthy the disadvantage out ways the advantages from the responses. The participants went on to further share their outlook on the advantages which stated its cheaper, opportunity to obtain a broader understanding of the inspected road but what stood out was defined, intricate drainage patterns are seen during manual methods which play a role in the distresses evident on the road, this is sometimes not fully seen on automated images:

Participant R1, R3, R4 and R7 shared similar sentiments and stated the following:

> *"The advantage comes with assessment of roadside furniture especially drainage as you can stop and inspect stormwater crossing to check condition and functionality that is, if they are blocked and requires cleaning."*

Participant R6 and R8 added a variant to the advantages and noted that this methodology helps with employment of people of an organisation. This type of skill undertaken for road assessments can help alleviate the unemployment rate that is experienced in South Africa.

Participant R6 stated the following:

> *"Another advantage could be increased skills development as it's generally easier to understand and interpret when you are physically viewing something in different scenarios as appose to learning from a manual where your visual aids are limited."*

According to Timm and McQueen, (2004), there is an agreement with the advantages of the manual pavement condition assessment but notes they are extremely limited. Studies goes on to show this method provide a deep perspective of the physical site condition. An assessor get to physically measure the depth of an undulation, understand the roughness of the road, determine drainage and road user patterns, but this is extremely time consuming, and deadlines cannot be met accordingly undertaking this method.

Employment is generated through this methodology, but this is also enhanced at the post rating process as well after data is collecting autonomously. A degree of human interaction and skills transfer is required for the post rating and quality assurance.

All participants have expressed their view on the disadvantages of the process even though as previously noted nine participants prefer using this technique. All participants agree that there is a high degree of subjectively in the data, this process is time consuming, it causes fatigue of the assessor, less data is collected in a day than anticipated, if lack of knowledge is evident in the assessor inaccurate data will be collected and this methodology inhabits unsafe conditions for field assessors.

Underwood et al., (2011), Tsai et al, (2010), Kock and Brilakis, (2015) agree with the sentiments of the participants. Literature notes that the drawbacks out ways the advantages of this process. Road Authorities require systematic information for their Pavement Management System and data collection play a vital role to make strategic decisions on the future of the road network to make it safer to continue keeping the wheels turning of the economy as the road network is part of the backbone to a sustainable South African.

4.3.4 Themes relating to pavement technologies engineers can adopt to conduct road assessments

This study discovered three different themes regarding the introduction of intelligent pavement technology to conduct road assessments in the civil engineering industry. There are 1) Awareness of pavement technology in industry, 2) Prioritization of maintenance projects backed up by scientific data to make informed strategic decisions for implementation on South African roads, 3) Resistance to change to pavement intelligent technology. 4) Safety during field assessments.

Table 4.4: Themes relating to pavement technologies engineers can adopt to conduct road assessments

Themes relating to pavement technologies engineers can adopt to conduct road assessments	**Frequency**
1. Awareness of pavement technology in industry	20
2. Prioritization of maintenance projects backed up by scientific, accurate data to make informed strategic decisions for implementation on South African roads	12
3. Acceptance to pavement intelligent technology	9
4. Safety during field assessments.	20

4.3.4.1 Awareness of pavement technology in industry

Figure 4.3 illustrates 95% of the participants interviewed whom conduct visual assessments on a daily basis know that road pavement technology exist to help feed vital information into a Pavement Management System to undertake future maintenance projects. Data collected reveal that there are a host of sophisticated equipment that collects road data and additional pertinent data that is not seen by the eye of the assessor such as structural integrity of the pavement.

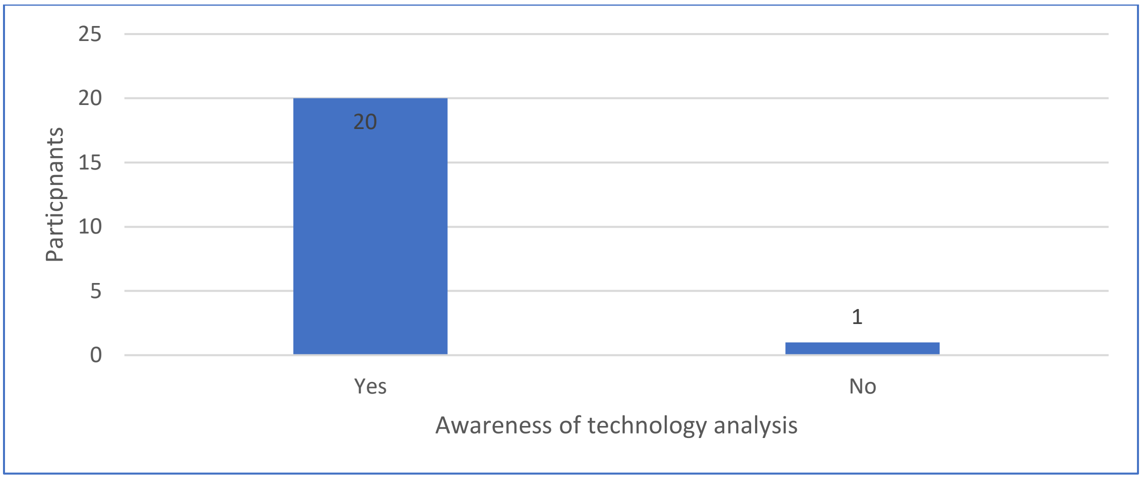

Figure 4.3: Graph illustrating participants that are aware of intelligent pavement technology

The interview process reveal that participants are aware of road technologies but not in full detail, below are the responses:

1. Network Survey Vehicle, which is used to collect IRI, RUT, Crack Detection, Texture Depth and Georeferenced images of a road network.
2. Intelligent Pavement Assessment Vehicle (iPAVe) – this system has a spatially geo referenced integrated laser crack detection, digital imagining, and a Class 1 laser profilometer inclusive of a traffic speed deflectometer for structural measurements. This integrated system simultaneously provides structural and functional condition data.
3. LiDAR – Light Detection and Ranging technology are closely spaced points that are used for road surveys to capture all images for road assessments. this will also include safety road assessments.

Participant R6 stated similar sentiment of the 95% that are aware of the technology as follows:

> "*Yes, I am aware of various technologies in industry. Currently there are a number of survey vehicles capable of obtaining various condition data in a fraction of the time of manual methods. Such a device is the Traffic Speed Deflectometer Device (TSDD) which is capable of continuously measuring deflection, rutting, roughness, and texture simultaneously. All measurements are geographically recorded with GPS coordinates for ease of reference. The device is also equipped with high resolution cameras for a 360° view of the road and surrounding environment. It is also equipped with ACD lasers which are capable of identifying and effectively categorising cracks on site to enable post rated visual assessments.*"

According to Underwood et al, (2011), automated surveys have gained popularity in various countries in the last decade, and many private vendors provide this data collection service. These services utilise sophisticated and common technologies such as inertial navigation (INS), global positioning (GPS), laser, radar, imaging, and infrared to gather, store and process pertinent road asset data. The data that is collected is roughness, rutting, patching, potholes, drainage, cracks, and georeferenced images to view and measure the distress whilst post rating in the comfort of an office environment.

4.3.4.2 Prioritization of maintenance projects backed up by scientific, accurate data to make informed strategic decisions for implementation on South African roads

A total of sixteen participants shared the view, they would consider adopting the approach of utilising intelligent pavement technology for condition assessments taking into account six of the participants who were very apprehensive at first as they only use the first principal methodology in their practice. Various participants elaborated whilst costs may be higher at the initial stage compared to manual methods, utilising advancement in technology for road assessments helps maintain repeatability of data, accuracy and objective data that is confidently used for research, designs and provide a comprehensive foundation for informed decision making.

Participant R12 stated:

> *"Yes, I would consider adopting the automation approach, whilst the initial cost might seem to be exorbitant, the value of the data always substantiate the cost as it can be used for the prioritization of maintenance projects backed by scientific data to make well informed decisions on specifying the correct treatments. The data can used as part of producing accurate asset valuation report as the condition of assets will be readily available. Data can also be utilised for producing design reports as well as for future demand analysis based on current pavement conditions against forecasted future traffic and developments. Most importantly, having the data on hand also assist with predicting network deterioration trends which assists on planning for future needs."*

Data that eliminates subjectivity is regarded as reliable data for all types of usage obtained from semi automation and fully automated techniques. The initial costs of obtaining the technology is marginally higher but cannot be compared to the magnitude of the proficient data that is collected. Data collected from sophisticated equipment guarantees repeatability and high-quality data, the data is consistent and in full compliance to the government policies on Asset Management. Due to data collected at a faster rate than manual methods road authorities are able to strategize the funding for road networks which comes from a foundation of quality data to make informed decisions to budget accordingly. Data collected for a particular year helps with planning for implementation of the same year or following fiscal year. In this way maintenance of roads are always kept updated resulting is reducing the backlog that is experienced.

Research shows that accuracy of automated pavement condition data have been of great interest recently to agencies, researchers etc as they have come to be aware physically assessing roads have led to poor data quality which have significantly impacted pavement performance analyses and modelling (Ong, Noureldin, and Sinha, 2010). According to Ong et al (2010), high quality data collected from pavement technology should be utilised which broadly assists and guides with setting preservation, prioritization of roads to be maintained, determining trends in the road network, and allocating suitable funding for the projects.

4.3.4.3 Acceptance to pavement intelligent technology

Of the twenty-one participants twelve have expressed the need to change to more innovative methods of collecting road condition data. The participants relayed a view of trust towards the semi-automated and fully automated methods. The perspective expressed is, reliability of the data, the efficiency of analysed results are world class and authorities can effectively utilise the data as a portfolio of evidence for audit purposes should there be any arising issues of clarity needed.

Participant R12 stated:

> *"The automated assessments are the way to go, portfolio of evidence for the assessed roads can be audited at any given time should uncertainties exists. It also eliminates the subjectivity as one assessor can rate differently to the other in terms of degree and extent. Data can be easily accessed if automated data is collected than manual methods should an error occurs with the assessments. Also, since the automated assessments are conducted in a controlled environment, efficiency and productivity levels are increased as more kilometres can be assessed per day than the conventional method."*

According to research, data collected from automated systems illustrates data that can be defendable and ensures repeatability. Objective data captured have gained an elevated level of confidence in its overall effectiveness (Underwood et al, 2011).

On the other side of the spectrum, while a large number of the participants believe automation systems are the new leaders in industry, the minority believe that manual methods are the more trusted for it has been the most widely used technique. Notably, participants reveal a sense of resistance. It has been indicated confidence in utilising the new innovative systems have not been achieved. Evidence of lack of added knowledge of the automated systems and its capabilities have protruded from the interview process.

Participant R17 stated the following:

> *"… Unfortunately, the legacy approach is most trusted because of the "the way it was always done" mentality that is strong in the engineering society coupled with the power structure, resistance to change/adoption of "unnecessary" risk."*

According to Heathfiled, (2021), resistance to change is defined as the unwillingness to try to adapt to a unique environment or to an altered circumstance. This type of resistance can be organised, convert or overt and individual. Employees tend to feel uncomfortable with novel changes made in their current task. This mostly occurs when the changes have not been fully introduced to them or the employees are not fully educated on the technique which results from lack of knowledge of the new concept to be utilised. Resistance to change can intensify more when leaders of organisations do not accept change in their business environment hence the mentality then gets filtered to the employees resulting in a vast disadvantage to the organisations who are reaping for excellence (Heathfield, 2011).

4.3.4.4 Improved Safety of Employees during field assessments

Nineteen participants inclusive of the respondents that are very keen to continue utilising manual methods agree that condition assessments undertaken via automated technology are safer in the long run for all during an assessment, i.e., the assessor/operator is safe during the data collection, the local commuter and pedestrian utilising the route is also free from danger. The vehicle mounted with the equipment drives the route collecting IRI, RUT, Texture, cracks, and images data at various intervals at highway speed resulting in a safer option as the risks are reduced. Participant R1 indicated that as lanes on a route increases the safety risks are extremely higher for physical visual assessors as traffic volumes will increase causing data collection to be difficult.

Participant R1 stated the following:

> *"The automated road condition assessment is definitely safer, both for the assessors and also for the road users. Increase in lanes will result in increase in traffic making it more risker for assessors on site walking to collect distresses."*

Safety of people is paramount on the road infrastructure, the risk of fatalities whilst undertaking an assessment is high as it will add to the fatalities rate of road accidents in South African. According to the Roux and Labuschagne, 2016 on behalf of the Road Traffic Management Corporation the cost of road accidents is estimated to equate to 3.5% of the GDP of South Africa. The cause of accidents apart from pedestrians on the road include, reckless driving, drunk driving, jaywalkers, inclement weather etc This is a substantial dent to the economy which can be prevented and the funds that's pays for road accidents could be utilised for road maintenance or other top priority projects in the country improving the state of South Africa's economy.

Since the evolution of automating data collection safety of staff members undertaking site evaluation of distresses has reduces substantially. Safety is of great concern on site as various parties are involved and poses a danger to everyone using the route. According to Sivaneswaran, et al, (2004), safety is enhanced whilst data is collected via automated techniques, the vehicle is travelling at sign posted speeds and an array of data is collected in one pass. Assessors are much safer as the post rating of the data is conducted back at the office and there is much improvement in accuracy as data can be revisited when needed for quality assurance than revisiting the site to verify.

4.3.5 Themes relating to perspectives of the impact of an integrated solution to Pavement Management and Monitoring Systems in South Africa

The study concentrated on two different themes regarding the effectiveness, efficiency, and performance of advanced techniques to conduct data collection which can in the future uplift the economy. The themes are as follows: 1) Project deliverables are achieved much faster and issues arising are address timeously 2) Organisations adopting a long-term approach utilising technology for road infrastructure.

Table 4.5: Theme relating to the perspectives of the impact of an integrated solution to Pavement Management and Monitoring Systems

Themes relating to perspectives of the impact of an integrated solution to Pavement Management and Monitoring Systems in South Africa	Frequency
1. Project deliverables are achieved much faster and issues arising are address timeously	20
2. Organisations adopting a long-term approach utilising technology for road infrastructure	18

4.3.5.1 Project deliverables are achieved much faster and issues arising are address timeously

Information gathered from the participants indicate automations bring about elevated levels of efficiency and effectiveness into an organisation either public or private sector.

Participant R5 stated:

> *"… If technology is implemented correctly, it can meet the objectives of the Department which is to create a safe road network, which stimulates economic growth and reduce poverty by providing employment for our people. Furthermore, in a provincial Department decision needs to be made on regular basis, whether be political or technical challenge, and therefore objective data serves as base where these decisions emanate."*

Participant R6 stated:

> *"…. Advances in technology are the way forward to achieve cost effective means of reaching one's goals with the least snags. The use of advanced technology coupled with the ability to work and communicate online significantly reduces turnaround time to a fraction of what it usually is. Deliverable are achieved much faster and problem areas are addressed in a timely manner reducing outcome delays."*

Participant R12 stated the following which describes automated data usage to guide with the needs analysis pertinent to the Pavement Management System for roads authorities.

> *"…The agencies will have scientific data that backs the rationale behind prioritization of maintenance and rehabilitation project and the type of treatments they specify so that they can make informed decisions and also conduct needs analysis of current network for proper budget allocations. In addition, demand for future needs can also be derived from the data presented that will influence future developments and capacity improvements based on traffic demands."*

Participant R5, R6 and R12 have similar understanding that automation provides the integrated solution for a Pavement Management Solution. The plethora of data from the TSDD and NSV can be used for an understanding of the road condition, calculate the level of safety evident on each road of a network at any given time by using the International Road Assessment Program, utilise continuous deflection data for in-depth pavement designs than utilising FWD which is not comprehensive data, undertake quality assurance on rehabilitation and construction projects by measuring the Roughness (IRI) of the roads. As accurate data is collected and analysed its assists with the road asset valuation process. Roads can be evaluated in a systematic manner as the correct costs are associated with the correct treatment for a road. Roads are prioritised; accordingly, issues are addressed in a timely manner. As expenditure on maintenance and construction works is shown in each financial year the level of poor roads are decreasing. Government will be able to provide the adequate budget needed for the road network which results in the maintenance backlog slowly decreasing as roads come back to their drivable safe condition. The road condition data such as the images, profile data and deflections filters to the next step of the Pavement Management System and stored in a data bank as per DoRA and continuously used each year for research and development. Figure 4.4 indicates the integrated solution technology can provide for a Pavement Management System.

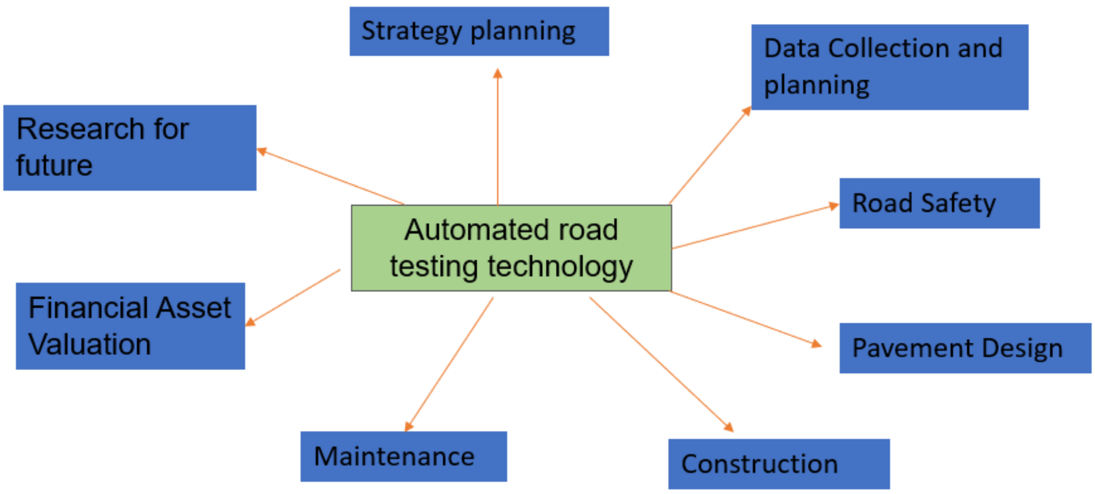

Figure 4.4: Integration for a Pavement Management and Monitoring System

4.3.5.2 Organisations adopting a long-term approach utilising technology for road infrastructure

Eighteen participants agree that organisations should adopt and embrace technology in their practices as this will enhance their objectives set for the business and their way of working. As road maintenance and rehabilitation projects are obtained from road authorities the operations of the business will be more streamlined providing the department with pertinent information in limited time resulting in providing the necessary tools for a fully integrated Pavement Management System with the innovation it requires.

Maintenance of roads are continuously required, and technology can help to achieve that. Roads are known to be the backbone of the economy as businesses of all industries rely on the transportation system to enhance productivity resulting in sustainability and a boost to the economy (Southern African Development Community, 2012).

Participant R2 stated:

> *"Yes, technology will definitely help businesses in the long term. Roads are essential in that they in a way facilitate movement of the economy. Technological advancements in road condition determination allow for effective management of the road networks and appropriate maintenance strategic and professionally managed road networks allow for lower user costs which has a direct impact on the improvement of the economy."*

Participant R12 stated:

> *"Yes, there will be a positive boost to the economy, this will ensure that money is spent where it is needed in practices that is economical feasible as decisions are made it will be based on scientifically proven facts on the data provided. Long term plans and budgets can be derived from the data sets as well. Technology is the way to go as it improves efficiency and reliability of the results produced, real time data can be accessed at any time anywhere in the world. It also produced proven audit trails and compliance to regulating bodies."*

According to Schwab, (2016), the fourth industrial revolution (4IR) is described as a technological evolution that have altered the way each individual live, work and relate to each other. It is characterised by a combination of technologies for all industries in the world that is blurring the lines between digital, physical, and biological spheres. 4IR is disrupting every industry to move from a common ground to a more innovative ground creating easier ways of streamlining activities which in turn creates productivity (Schwab, 2016). With the evolution of 4IR, it is widely recognised that technology of all types especially for improvement of road infrastructure is one of the key drivers of economic growth for the country, region, or city. As technology progresses it allows for more efficient production of more and better goods and services. Utilisation of technology has the potential for long term gains in efficiency and effectiveness resulting in higher performance of businesses which boosts the economy (Kvochko, 2013).

Technology for pavement engineering has evolved since the manual methods providing companies and road agencies the efficiency that's required. The technology will create and open more doors for emerging markets where companies requiring road surveys can get access to qualified specialists with the equipment which will drastically reduce the costs of purchasing the equipment required for pavement survey (Kvochko, 2013), (Ong, Noureldin, and Sinha, 2010). According to Tim and McQueen, (2004) with the innovation that is introduced into the semi-automated and fully automated road devices reliable repeatable data is obtained, this is amazingly effective as budgets are spend accordingly with the corrected data due to the correct maintenance measures are derived for the appropriate roads.

Participant R15 fully agrees with adopting of technology for condition assessments within businesses and alluded that advocating for the 4th Industrial Revolution to conduct the data collection can help free up adequate time of the professions to concentrate on more strategic tasks which can further boost the organisations as innovative ideas are being developed, humans will have more valuable time at hand.

> *"Yes, it is important we embrace the fourth industrial revolution so that life is made simpler and easier. This will allow for humans to focus their expertise and time on things that will make a difference and we need to allow "computers" to do remedial things that occupy our time. Due to the time saved on these "small" activities and time being spend by humans on more complexed things with accurate data, will in turn save money."*

Respondents went on to express that there are great advantages to embracing technology to undertake road condition assessments but have noted that there will be skills change of personals in the organisation this may seem to be a drawback at initial stages but with overall benefits in the long run as personnel is trained to conduct more highly skilled work when working with the equipment.

Participant R6 stated the following:

"I personally think improvements in sustainability and profitability are a definite advantage for a particular business that adopts automated means of assessment however this will likely have a negative effect initially on the overall economy of South Africa. Introducing automation results in a reduction in the need for skills training and overall skilled persons. In turn this reduces the rate of employment resulting in a negative economic impact. However, when one weighs the pros and cons, automation is generally favoured from a business perspective especially when one can motivate for skilled people to carry out quality assurance on the automated data output."

Schwab, (2016), agrees with the views of participant R6, the evolution of technology for road infrastructure has the potential to disrupt the labour market, the automation may substitute the labour across the entire economy but here is room for creativity and innovative ideas on how to upskill the labour force from their current workstream tasks to more skilled opportunities in the organisation. Humans can take a more intricate role in quality evaluation of the data and analysis on cost effective trends before it goes to the client for further discussions on implementation strategies.

4.3.6 Analysis of the field assessments between the two methods to collect pavement data

In addition to the interviews that was undertaken an observation exercise was conducted which assisted to evaluate the accuracy of visual assessments undertaken manually versus the data collected by a Profilometer or better known as a Network Survey Vehicle. The interviews provided a subjective view of the data collection methods that can be best used to create an integrated system. The field assessments were able to provide the objective view in the results obtained from the two methods to indicate the most efficient technique that can be used for South Africa.

Four paved roads, five kilometres each were chosen for the visual condition assessments based in KZN, the names are as follows: P454, P461, P551 and P85. These roads that were chosen are provincial roads exhibiting various types of distresses and had low to medium traffic in order to safeguard the assessors. Five assessors were chosen to undertake these assessments. This selection was chosen after a full calibration and knowledge sharing of the TMH9 (COTO, 2016) was undertaken between the assessors and operators of the profiler. The assessors were asked to assess the same five kilometres of each of the above-mentioned roads to compare the integrity of the data.

Manual data collection commenced on December 1st to December 7th, 2021. As data was collected manually the NSV had commenced with the automated data collection of the same roads. The network survey vehicle utilised has the capabilities of collecting RUT, IRI, Texture, Images and Crack detection. The NSV is managed by an operator during data collection whilst the driver travels the route at 60km/h. Data was collected in 2-kilometre sections of each 5-kilometre stretch. The manual data collection took five days to complete whilst the NSV collected five kilometres of all mentioned roads in one day with processing of data took approximately (three) 3 hours. The climate on all days of data collection was hot and humid with temperatures in upper twenties. All distresses and parameters was collected by both manual and automation but for this exercise only the International Roughness Index and Rutting will be evaluated.

4.3.6.1 International Roughness Index (IRI) Comparison

Riding quality (IRI) is an intrinsic parameter in understanding the condition of the road because it is a collective measure of most pavement distresses (potholes, corrugations, erosion, and surface deformation). The evaluation compares each assessor’s data with the profile data that was collected for those sections of road. The results are represented in table 4.7 and is further indicated as the X-Y scatter chart which inhibits a direct comparison between automated data collected and of the manual visual assessments undertaken.

Table 4.6: Description of degree and roughness of a road

(COTO, 2016: 42)

Degree	Description
1	The ride is very smooth and very comfortable
2	The ride is smooth and comfortable
3	The ride is fairly smooth and slightly comfortable
4	The ride qulaity is poor and uncomfortable
5	The ride quality is very poor

Referring to Table 4.7 are the degrees for each road that was assessed by each assessor as well as the profile data retrieved from the Network Survey Vehicle.

Table 4.7: Data collected from Assessors and Network Survey Vehicle – IRI

Road	From	To	Profiler Degree	Assessor 1 Degree	Assessor 2 Degree	Assessor 3 Degree	Assessor 4 Degree	Assessor 5 Degree
P454	0	2	3	4	4	3	3	3
P454	2	4	3	5	4	3	4	4
P454	4	5	3	5	3	3	4	4
P461	0	2	4	3	3	3	3	4
P461	2	4	3	3	3	3	3	3
P461	4	5	4	5	3	3	3	3
P551	0	2	5	5	4	4	5	4
P551	2	4	5	4	3	3	4	4
P551	4	5	5	4	3	3	4	4
P85	0	2	3	2	3	3	3	4
P85	2	4	2	2	3	3	2	3
P85	4	5	2	2	2	2	2	3

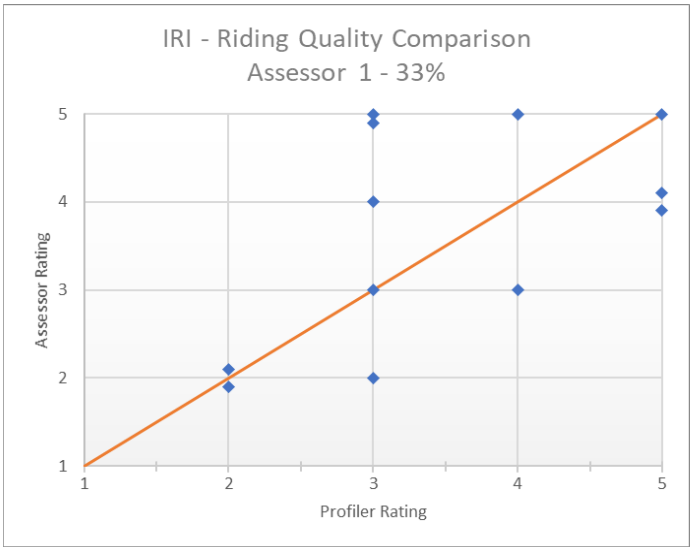

Figure 4.5: Comparison of data for Assessor 1

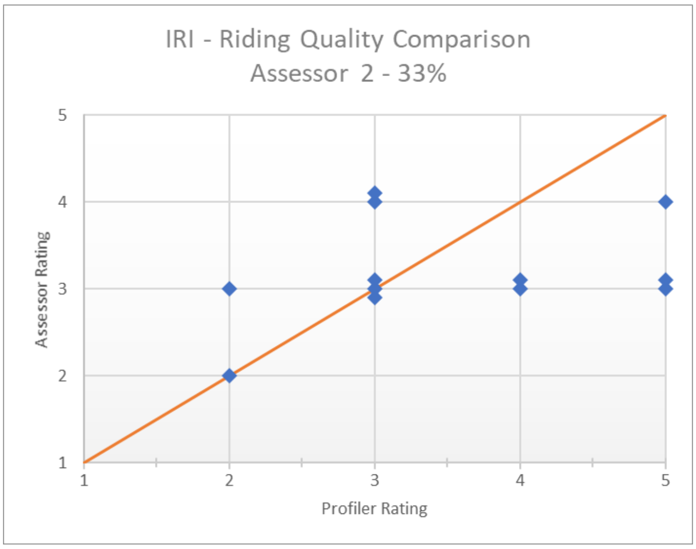

Figure 4.6: Comparison of data for Assessor 2

Figure 4.7 Comparison of data for Assessor 3

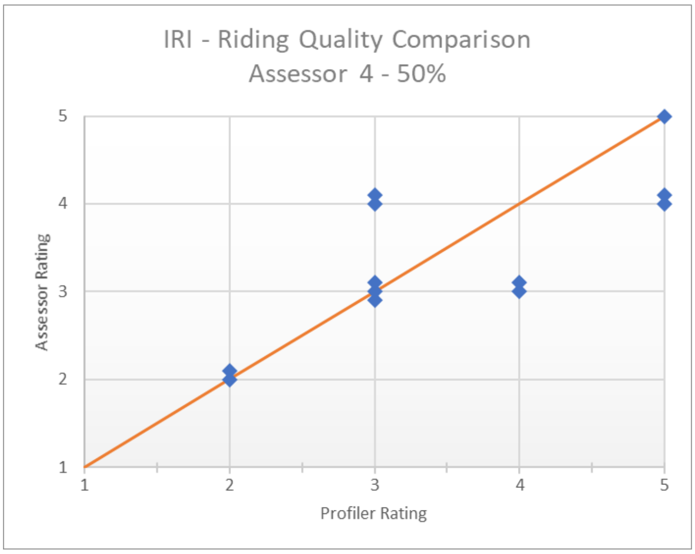

Figure 4.8: Comparison of data for Assessor 4

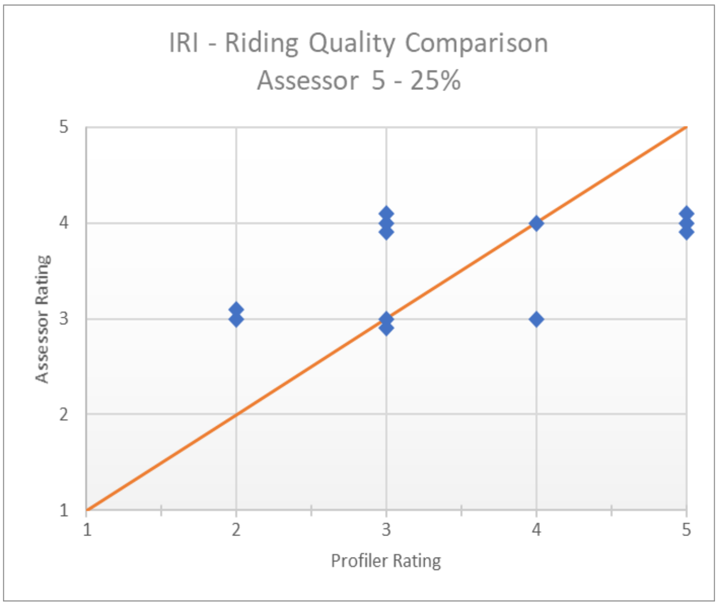

Figure 4.9: Comparison of data for Assessor 5

The solid line in Figures 4.5 to 4.9 signifies a perfect correlation between automated and manual assessments. The blocks represents the various condition categories for IRI limits. The data was collected in accordance with the TMH9 (COTO, 2016) where degrees were recorded ranging from 1 being very good up to 5 which is very poor. As can be seen for assessor 1 and 2 there has been a 33% correlation to the automated data, assessor 3 and 4 has a 50% correlation to the automated data and assessor 5 has a 25% correlation to the automated data. There is noticeable variance between the five manual assessments done on the same road sections.

4.3.6.2 Rutting of the Surface Comparison

The same evaluation was undertaken for Rutting. The results are represented in table 4.9 below and is further indicated as the X-Y scatter chart inhibits a direct comparison between automated data collected and of the manual visual assessments undertaken. The red line in Figures 4.10 to 4.14 signifies a perfect correlation between automated and manual assessments. The data was collected in accordance with the TMH9 (COTO, 2016) where degrees were recorded ranging from 1 being very good up to 5 which is very poor.

Table 4.8: Description of degree and rutting of an assessed road

Source: (COTO, 2016: 33)

Degree	Description
1	Rut Depth between 0 - 5mm - difficult to discern unaided
2	Rut Depth between 5 - 10mm - Slightly discernible
3	Rut Depth between 10mm - 15mm - Easily discernible
4	Rut Depth between 15-20mm - Obvoiusly discernible
5	Rut Depth > 20mm - Severe and dangerous

Table 4.9 shows the degrees for each road that was assessed by each assessor as well as the data retrieved from the Network Survey Vehicle.

Table 4.9: Data collected from Assessors and Network Survey Vehicle – Rutting

Road	From	To	Profiler	Assessor 1	Assessor 2	Assessor 3	Assessor 4	Assessor 5
			Degree	Degree	Degree	Degree	Degree	Degree
P454	0	2	2	2	3	1	3	1
P454	2	4	2	3	3	3	3	2
P454	4	5	1	2	3	2	3	2
P461	0	2	1	2	3	2	3	2
P461	2	4	1	1	2	1	2	1
P461	4	5	1	1	2	1	3	2
P551	0	2	2	3	4	3	4	4
P551	2	4	3	1	3	3	3	2
P551	4	5	3	2	3	1	2	2
P85	0	2	3	2	4	4	4	3
P85	2	4	2	2	3	3	3	1
P85	4	5	2	1	2	1	2	2

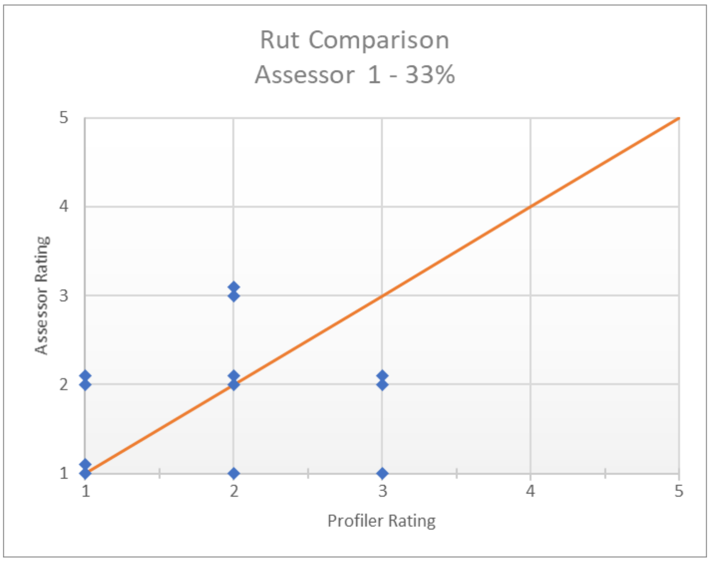

Figure 4.10: Comparison of data for Assessor 1 – RUT

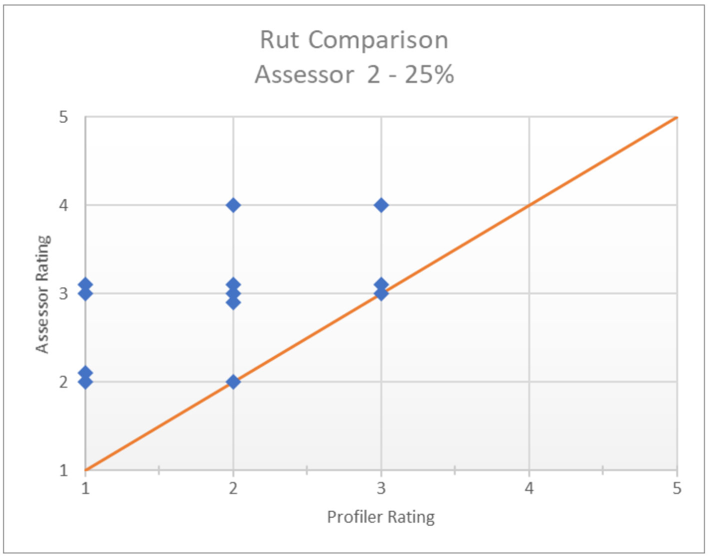

Figure 4.11: Comparison of data for Assessor 2 – RUT

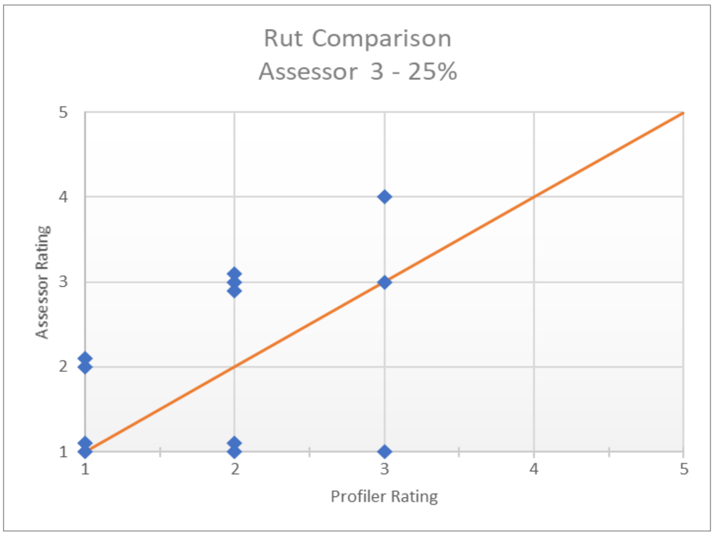

Figure 4.12: Comparison of data for Assessor 3 – RUT

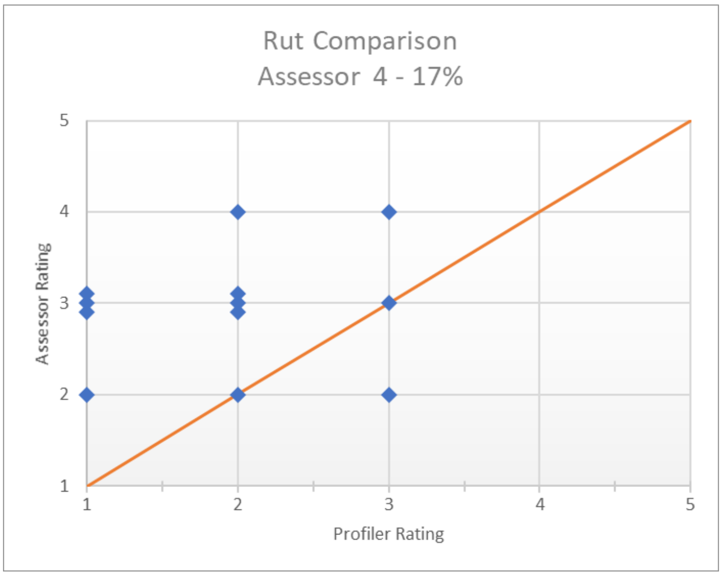

Figure 4.13: Comparison of data for Assessor 4 – RUT

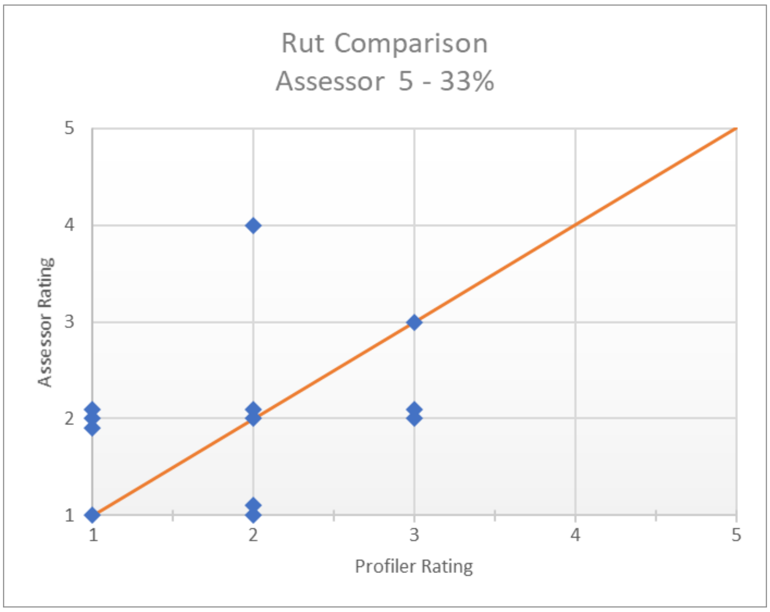

Figure 4.14: Comparison of data for Assessor 5 – RUT

The tests for RUT were conducted illustrating a great variance between the assessors and the data collected from the Network Survey Vehicle. Assessors 1 and 5 showed a 33% correlation whilst assessors 2 and 3 shows a 25% correlation and assessor 4 illustrated discerning 17% correlation to the automated data collected. The data collected by manual methods did not reach acceptable correlations which enhances the disadvantages of manual methods.

These results for IRI and RUT highlights what has been previously discussed as the main issue of manual methods which is the prominent level of subjectivity when conducting assessments with people. From this assessment it shows that should further tests be conducted for quality assurance of this same data using manual methods, additional time will be taken, and the costs will be higher compared to data collected by the automated methodology.

4.4 DISCUSSION OF THE STUDY

4.4.1 Finding on the perception of the importance of road condition assessments for strategic planning at government level for road infrastructure.

This study had found three different themes focussing on the importance of road condition assessments for strategic planning at government level by making use of thematic analysis. Participants have revealed that there is a lack of planning at government level for road networks which has a ripple effect on budget allocations. Roads that requires maintenance measures are not completed in the period needed delaying prescribed periodic maintenance.

Notably road assessments are a vital component in planning for the future of the roads in a network. It provides intricate knowledge of the network which assists with focussing on the sections of roads that requires attention in the short, medium, or long term.

The knowledge that is gained from road assessments can be used proficiently as road authorities have insight of the roads that have extensively deteriorated and can cause harm to the road user. This further feeds into planning, decisions can be made when efficient data is received to be able to make informed decisions which justifies why various lengths of the road infrastructure requires remedial actions now than later reducing the increasing backlog that is causing a ripple effect to the economy.

The study also concludes there a major interference in the procurement processes of outlaying maintenance projects which has further led to the deterioration of the road infrastructure. Projects that requires the immediate attention have not been prioritised as there are politics that have disrupted the procedures of the procurement process. Roads that do not need attention now are being prioritised due to political issues on the rise reducing the funding that is allocated for roads that are highly distressed.

4.4.2 Findings on the effectiveness of Pavement Management Systems

In this exploratory study it notable that a Pavement Management System is a particularly crucial tool to be used when undertaking road maintenance strategies, it guides companies with decisions to be made hence objective data collected is pertinent when implementing projects for construction. Utilising an updated functional Pavement Management System can effectively address the requirements of the road infrastructure with the actual costs needed for financial years to come which is important in strategic planning for the country which also help reduce the interferences discussed as all roads will get the attention desired.

Condition assessments is an intricate component in the planning activities of the Pavement Management System. Data captured on site must be undertaken by people that fully understand road conditions, lack of knowledge of pavement behaviour can be detrimental in the analysis of the data and can have a recurring effect on the future of roads especially when frequent road surveys are required to measure deterioration.

Along with the condition assessments, performance modelling is undertaken to predict the future condition and performance of the road which is important as this helps select the proper treatment needed. Apart from the Pavement Management System serving as an analysis tool it serves as a reporting tool. With information from the condition assessments and needs analysis with costs it helps with the decisions that's required for the future of the road network of South Africa. A Pavement Management System is a tool to determine maintenance strategies as it guides how funds are spent and how much is needed for future works which concludes that it's imperative a functional system is utilised as its highly efficacious.

4.4.3 Findings on the acceptable methodology chosen to conduct road condition assessments in organisations

In this study, its notable the minority of engineers prefer to use the manual methods of collecting data. It was advised that it is the method that was used since 1980 and has been tried and tested but will remain to be the technique of choice. It was defended that with this method more aspects of the road can be viewed in depth like drainage paths etc. It was also said that employment can be increased with this methodology helping the unemployment rate. Overall, the participants concluded that although this method has been utilised for decades the disadvantages outweighs the advantages. Only up to 60 to 80 kilometres of data can be collected in a day. The level of subjectivity is extremely high, as data is captured at the end of the day fatigue sets in resulting in incorrect data recorded for analysis, lack of knowledge of the distress types and severity can lead to incorrect data collection, this method is time-consuming and as verification of data is required a trip to site maybe required delaying the analysis of data to be submitted to road authorities, increasing costs.

Remarkably, attention was drawn to the automation of data collection. As time progressed innovation for road infrastructure had set in. A range of data can be collected at highway speeds by sophisticated road technology. With this technology majority of the parameters can be collected like geo-referenced images, roughness, rutting, crack detection, and structural integrity. During a survey up to 500 kilometres of data can be collected and processed at various intervals for designs. As the images are collected, it provides comprehensive information like staked kilometre distances, date of survey, temperature of day etc to conduct post rating for condition assessments in the comfort of an office environment. Here data can be assessed and checked viewing the images and further quality assured utilising the images surveyed. Time is saved and data accuracy is maintained as the TMH manuals can be constantly used for clarity. The study concluded that as technology for roads are in our midst there will not be a decrease of employment as constant research into the technology is always needed and new improved skills will be required for quality assurance of the data collected creating uniform data for decision making and guiding the road authority in the direction where efficiency is reached.

The site observation concludes and authenticates the study taken with the participants. Data collected by a human element increases the level of subjectivity and substantially reduces the level of accuracy needed for pertinent distresses illustrated on a road network.

4.4.4 Findings on pavement technology that engineers can adopt to conduct road assessments

The study concludes to state engineers in the industry have come to understand there is sophisticated technology like the Network Survey Vehicles and the fully integrated Intelligent Pavement Assessment Vehicle that has the ability to survey roads and provide information at an advanced level than the manual methods in the least amount of time. The minority of the participants advised although they aware of the technology available they would not adopt this automated technology in their works, as the manual methods is more trusted and its widely used since the 1980's. A gap that has been found was that there is resistance to change from the normal way of working and producing outputs. This study noted that mindset of people will not be changed as the value in the automation is not fully seen and discussed further. This revealed lack of knowledge of the technology and its capabilities in industry that can help businesses perform.

Consequently, the majority of participants that undertake assessments noted they would adopt this approach to provide information for a functional and effective Pavement Management System. With this information obtained from technology there is reliability and repeatability of data which helps with prioritization of maintenance projects. As data collection is automated road authorities can obtain systematic, objective, accurate and uniform data on an annual basis which helps them be compliant with government policies put in place by National Treasury to continue securing ample funding. Along with the concluding points, data is collected at traffic speed that further enhances the safety of assessors, road users and pedestrians on a road.

4.4.5 Findings of the impact of an integrated solution to Pavement Management and Monitoring Systems in South Africa

The outcome of the exploratory study was, changing from manual systems to automation will have a tremendous impact creating an integrated solution for a Pavement Management System. Data collected via automated methods will enhance productivity as objective data is collected to understand the serviceability the road can provide; safety is thoroughly analysed via an innovated international assessment tool. Data for designs are more conclusive as in-depth structural data is provided than data collected missing weak spots of roads. Design life can be evaluated accurately with precise known variables and no assumptions. This leads to the construction; road swill be passed with tangible quality assurance undertaken. Maintenance can be undertaken efficiently as road authorities can monitor their roads at frequent intervals annually which helped with the holistic road asset evaluation solving the current issues experienced at government level.

There will be elevated levels of efficiency and effectiveness in public and private organisations. Large road networks can be assessed in shortened time frames allowing more time for analysis and brainstorming ideas for strategic planning to decrease the large backlog experienced.

4.5 SUMMARY OF CHAPTER

In this chapter, the research findings were presented. The study evaluated the best possible solution for an effective and functional Pavement Management and Monitoring System for South Africa. An interview schedule was used to obtain information from various pavement engineers working in the Civil Engineering industry. Themes was generated from the participants responses that have been obtained from the interviews. Results was analysed through a thematic analysis and compared to literature. For further analysis and contribution to the views of the participants, tests were conducted through site observation evaluating and comparing the two methods of data collection for a Pavement Management System. In this chapter the objectives of this study was fully discussed as per the views of the participants, literature on the topic and site observation. The next chapter discusses the conclusions and recommendations for this study.

CHAPTER 5:
CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

The concluding chapter of this dissertation provides a summary of the study in relation to the objectives of the research, which is then followed by recommendations ascending from the study.

5.2 OVERVIEW OF THE STUDY AND FINDINGS

The aim of this study is to explore and understand the methodologies utilised in the Pavement Management System for collection of road condition data, the approach taken towards these methodologies and its extended use beyond pavement condition data to synergise components such as design, road safety, construction, and financial evaluation for South Africa. The objectives of the study are as follows:

1. To understand the importance of road condition assessments for strategic planning at government level.
2. To explore the value of Pavement Management Systems in identifying maintenance and rehabilitation requirements of the countries road infrastructure.
3. To observe the perceptions of the accepted methods of conducting road condition assessments by pavement engineers in South Africa.
4. Identify the key road-testing technologies pavement engineers can use and adopt to conduct road condition surveys in South Africa.
5. To understand the impact an integrated solution to Pavement Management and Monitoring Systems have on the South African economy.

The study undertaken adopted an interpretivism philosophy which assisted to guide the research. A qualitative exploratory research methodology was followed to gain an in-depth understanding of the various perceptions and views of pavement engineers on the techniques used in industry for road condition assessments to help create a functional and efficient Pavement Management System. To explore the value of a Pavement Management System in understanding the requirements of maintenance for

South African Roads. A good understanding was needed to observe the perceptions of the accepted methods of collecting road data. This further assisted to understand the gaps and challenges in relation to continuously maintaining South African roads and providing recommendations to improve the efficiency of data collection to create an integrated solution for a functional Pavement Management System.

In this study, a purposive sampling technique was used to select twenty-one (21) pavement engineers working the Civil Engineering Industry as the research participants. Qualitative data was obtained by undertaking semi structured interviews utilising Microsoft Teams and Zoom. An interview guide was employed in this study to collect qualitative data. The researcher had used Thematic Analysis to develop main themes reflecting:

- Perception of the importance of road condition assessments for strategic planning at government level for road infrastructure.
- The effectiveness of Pavement Management Systems on Maintenance Strategies
- Acceptable methodology chosen to conduct road condition assessments in organisations.
- Pavement technologies engineers can adopt to conduct road assessments in South Africa.
- Perspectives of the impact of an integrated solution to Pavement Management and Monitoring Systems in South Africa

The interview process provided comprehensive views of engineers working with the various practices and understanding the issues that requires the resolutions for a system to be effective to take the country to new heights. The observation provided an objective understanding of the participants views that was evident in the interview process. the site investigation helped analyse reasons why integration and innovation is required for a developing country.

The limitation of this qualitative study comprises of the following:
Sample Size - The sample size could have been much larger, but due to COVID-19 engineers were not available for the interviews as they worked on a hybrid basis with added responsibilities of working from home.

Sample profile – The study conducted was undertaken by only consultants and one road authority in South Africa. It would have been beneficial to obtain the view of various other road authorities in each province. This would have provided more clarity on the methods of obtaining data, how they plan for their maintenance projects, the challenges faced and the time it takes to obtain the data to make precise decisions. The perspectives of various National and Provincial Transport Departments would have been crucial to the study.

5.3 CONCLUSION OF THE STUDY

5.3.1 Objective 1 - To understand the importance of road condition assessments for strategic planning at government level.

The study indicated with a road network of approximately 750 000 kilometres effective strategic planning is deficient, this has elevated to a maintenance backlog that can't be rectified with interim measures. The study further alluded to budget constrains as this caused a ripple effect to any production to road infrastructure. The lack of funding has led to delays in maintenance works causing roads to service communities passed their design life, resulting in road accidents, increased fatality, and serious injury rate. All these issues has boiled down to the lack of knowledge of understanding the road condition and the requirements of it. Understanding the road condition provides the information needed to make strategic operational decision. Hence helps government authorities plan according and prioritise roads to be bult so funds can continue to be available. The more expenditure is shown in development of communities, National Treasury continues to support the plans put forward for road networks. The study proved that road condition is a pivotal aspect, if collected in the correct manner it can be the foundation to all improvements of existing road infrastructure.

5.3.2 Objective 2 - To explore the value of Pavement Management Systems in identifying maintenance and rehabilitation requirements of the countries road infrastructure.

The study found along with the research undertaken a Pavement Management System is an integral tool utilised to guide road authorities in their planning for each financial year. It provides the solution for an objective understanding of a road network. The participants noted that various political interference is evident in government hence with this system decisions with informed road data can be made and executed rather than to improve a certain route due to political influence. the common trend brought about from the study was to see the value a Pavement Management system and its components bring to the industry, correctly interpretating the pavement behaviour of a road is crucial when assessing roads. Data collected by manual methods must have a high level of accuracy but due to human error this is not possible with the current system of collecting data. Pavement Management Systems for strategic planning help predict the funding needed, provides a safer platform for road users, the rehabilitation and maintenance works decreases the elevated level of road failures, so roads are attended to, to extend their design life and not live beyond the life expectancy.

5.3.3 Objective 3 - To observe the perceptions of the accepted methods of conducting road condition assessments by pavement engineers in South Africa.

Road condition is a major component of the Pavement management System hence much emphasis is placed on this aspect for this study. For decades, manually assessing roads have been the end solution to obtaining integral data for road conditions. This has been the technique of choice as organisations have instilled the notion that manually assessing a road is the preferred option because it got the task completed. Time was not a factor previously hence data could be collected like this. As per the study as time went on engineers got to fully evaluate the outputs achieved by this method. Data had a high level of subjectivity, if fatigue or a mood of an assessor on the day conducting site assessments is bad then the assessment is compromised. Manually assessing a road only provided data for surface failure and assumptions was made for the structural failures which mislead designs hence road repairs are carried out after a year of construction. A large fraction of the participants conveyed those

manual methods had perceived to be best, but the drawbacks outweighs the advantages.
Lack of knowledge had played an integral role, from the conclusions a certain mindset was drawn towards automated technology for roads, hence technology was not accepted for various years and questions arose with the integrity of the data. There was a resistance to change which was evident with the engineers in the study. Tests have shown that automation provides a safer solution for collecting data. Automated technology like the iPAVe, NSV, LiDAR etc can provide a range of surface and structural data at traffic speed. Information that is not picked up by manual assessments is easily noted with automated at intervals stipulated. Road technology has shown various advantages one being employment of people, this can increase as more quality assurers are needed as the equipment collects the necessary data. naturally it was perceived that the cost of manual methods will out way the cost of undertaking an automated survey. This study and research undertaken further indicated

The study indicated that the various participants that initially said they mostly use manual methods to conduct assessments conveyed they would shift to utilising technology as there are much more benefits in the long run.

5.3.4 Objective 4 - Pavement technologies engineers can adopt to conduct road assessments in South Africa.

The study have shown with the sophistication of science and innovation, specialist road technology is available in South Africa. Specialist companies globally have created the Network Survey Vehicle which collects rut depths, roughness data, macro texture data, Global Positioning System (GPS) data and georeferenced images to help post rate and conduct assessments in the comfort of an office, data is collected with accuracy at intervals stipulated by the client. Repeatability of data of a road network is guaranteed providing assurance when utilising it for strategic planning. With time the integrated Intelligent Pavement Assessment Vehicle (iPAVe) was developed. This vehicle provides an integration of FWD and the Network Survey Vehicle collecting surface and structural defects in one pass at traffic speed. The data collected with the iPAVe allows engineers to obtain continuous deflections, rutting depth, roughness, macro texture depth, images, and automated crack detection. LiDAR was also introduced in the study providing the necessary variable to make data collection easier for all pavement engineers and road authorities for decision making. Studies have shown that a mind shift from manual to automation for a Pavement Management System improves the efficiency of obtained informed data. data collection is so pertinent to PMS, without this the concepts within the system and interconnecting to the Pavement Management System would be able to function effectively.

5.3.5 Objective 5 - To understand the impact an integrated solution to Pavement Management and Monitoring Systems have on the South African economy.

Introducing automated road technology with the correct mindset to the road infrastructure fraternity enhances the industry as road technology will provide comprehensive data to be utilised for every aspect of the holistic Pavement Management System life cycle. Technology will change the current operations of a PMS. As discussed, the technology can be extensively used to collect all data objectively. Road can be prioritised efficiently without any interference in a short space of time, the level of subjectively is drastically reduced providing confidence in the data. Within the system road safety is managed well. The automated data of each road can be used in a programme called the International Road Assessment Programme (iRAP). Level of safety is deciphered per road of an entire network by Star Rating. Road Agencies will use this data and implement measures saving lives.
Utilising the SAPEM manual mechanistic design are required for an existing road with the aid of continuous deflections from the iPAVe, weak spots are easily identified whilst if using the FWD data collection is discrete, data is collected at certain intervals missing the weak spots which is detrimental to the design causing irregular treatments for roads. Similar to this, technology is used for construction, previously densities were taken and parameters for quality assurance was not conducted with precision. The road technology such as the NSV and iPAVe can conduct quality controls on roads so it can be passed in accordance with standards in industry. This feeds into the maintenance, upkeep of continuous maintenance works are undertaken with continuous annual surveys indicting the areas of concern. All of this information from road technology is used for financial evaluation of assets of SA. Investors interested in financially supporting the country will have annually updated figures of the road assets

which will help the economy. The introduction of road-testing technology uplifts the existing operation of a Pavement Management System into a system that synergises all components creating results for a high-class road infrastructure system. This integration of technology to the Asset Management System enhances the economy as roads are and can remain in a good standard. The swift action of collection of data and integrating it will all PMS components can help reduce the road backlog experienced. The result of that will reduce accidents, decrease fatalities and serious injuries, reducing elevated costs of road furniture and rehabilitation as the technology will help the country work in a proactive way than reactive.

5.4 SUMMARY OF THE CHAPTER

Utilising a qualitative and exploratory research methodology, the study had explored an integrated solution for a Pavement Management and Monitoring System in South Africa. The study had five research objectives pertaining to the topic which assisted in obtaining conclusions to the study. The research also concludes with recommendations drawn from the key finding to help organisations make systematic decisions to improve the countries roads now and in the future. It is hoped that this study is valuable to pavement engineers in their works and Departmental organisations in the driver's seat of decision making for the future integrity of our road infrastructure

5.5 RECOMMENDATIONS FOR THE FUTURE

The study had proposed the following recommendations:

1 Whilst the initial equipment costs are higher than manual methods there is substantial savings in prioritizing maintenance strategies according to accurate and scientific data verses subjective data. National Department of Transport should mandate that all road agencies undertake automated road condition assessments. Furthermore, the data can be standardised into a uniform format and uploaded to a central data base which can be made accessible to multiple parties including the National Treasury. This will allow for transparent allocation of funding and road network maintenance prioritization. Road agencies should also prioritize means of data collection as the benefits of having historic dataset which can influence future funding requirements.

2 It’s recommended for companies and individuals currently researching, working on improving pavement technology and hold extensive knowledge of the data collection equipment to host conferences, knowledge sharing events and talks about the equipment, educating the industry on a frequent basis about the technology and its capabilities which could in turn change the mind set of many people that resist this innovation.

3 Data supplied at a network level must be closely considered with deterioration models that use pavement condition indices as a control variable. This will enable an informed investment strategy for road construction and maintenance.

4 South Africa has the tenth (10^{th}) longest road network in the world, it is imperative to take care of the network as this is one of the lifelines of our economy. Influential people with proficient business and engineering background should be employed at government level to understand and fully analyse the needs of road infrastructure as this will eliminate poor procurement processes, funds will be managed correctly, corruption will be lessened, and intelligent decisions will be made to uplift this country’s assets.

REFERENCES

Adarkwa O and Okine NA, June 2013. Project Report for Pavement Condition Survey – Overview of Current Practices, Delaware Centre for Transportation

Al-Ababneh M., July 2020. Linking Ontology, Epistemology and Research Methodology. *ResearchGate*, 8(1), pp. 75-91.

Amin MS, 2015. Pavement Management Systems: Integration of Transportation modelling, land use, economy and indictors of development, Thesis, Concordia University, Quebec, Canada

ARRB Systems, March 2018. Hawkeye 2000 Series General Specification, URL available at www.arrbsystems.com , Accessed date: 15 September 2021

Arnoldi M, July 2019. South Africa's roads maintenance backlog, University of Cape Town, URL address: https://www.news.uct.ac.za/article/-2019-07-10-south-africas-road-maintenance-backlog ,Accessed date: 21 December 2021

Beke M. and Mendieta M., 2018. *Political influence in public procurement: balancing between legality and illegality*. Ph.D. Universidad Complutense De Madrid Facultad De Ciencias Políticas Y Sociología.

Bhatti M, August 2020. Quality control in Road Construction and a few important tests, Linkedin, URL available at: https://www.linkedin.com/pulse/quality-control-road-construction-few-important-tests-muhammad-bhatti/ , Accessed 17 June 2022

Bogus SM, Giovanni C., Migliaccio and Cordova AA, Jan 2010. Assessment of Data Quality for Evaluations of Manual Pavement Distress, Transportation Research Record, Vol 2170 (1): 8, Access date: 12 September 2021

Burney, S.M.A; Saleem, H., March 2008. Inductive & Deductive Research Approach, Lecture delivered on 06-03-2008 at Auditorium of Faculty of Arts and Science, University of Karachi, Karachi, Pakistan.

Cafiso S, D’Agostino C, Delfino E, Montella A, 2017. From manual to automatic pavement distress detection and classification, URL available at : https://www.iris.unina.it/retrieve/handle/11588/710586/179983/MT-ITS%20From%20manual%20to%20automatic%20pavement%20distress%20detection%20and%20classification.pdf , Accessed date: 21 November 2020

Cambridge Economics Policy Associations Ltd & TRL Ltd, May 2018. Measuring Pavement Conditions – Office of Rail and Road Final Report, Accessed date 15 November 2021

Chang CM, Rodriguez E, Yapp M and Pierce L, July 2018.Consequences of delayed maintenance of pavement networks, 37th Annual Southern African Transport Conference (SATC 2018).

Chang JR, Kang SCJ and Tzeng GH, January 2007, Using Roughness Set Theory to induce Pavement Management Strategy, Department of Civil Engineering, MingHsin University of Science and Technology, ResearchGate

Chetty, P., 2016. Importance of research approach in research. [online] Project Guru. Available at: https://www.projectguru.in/selecting-research-approach-business-studies/, Accessed date: 24 October 2021.

Committee of Transport Officials (COTO), May 2016, Draft TMH9, Manual for Visual Assessments of roads pavements Part B: Flexible Pavements, Technical Methods for Highways

Consultores B., May 2021. Axiology in Research. [online] Online Tesis. Available at: <https://online-tesis.com/en/axiology-in-research/> [Accessed 16 October 2021].

Currie A, February 2022.Economic benefit of automated road condition data collection, Infrastructure news, URL found at: https://infrastructurenews.co.za/2022/02/09/economic-benefit-of-automated-road-condition-data-collection/ , Accessed date: 18 June 2022

Department of Transport, 1995. Technical Recommendations for Highways Draft TRH 22. Pretoria, pp.3-15.

Department of Transport, March 2018, Government Gazzette Staatskoerant – Publication of Draft Roads Policy for South Africa, Vol 633m issue No. 41488

Department of Transport, 2021, Welcome to Roads Branch – Overview: South African Road Network, URL available at https://www.transport.gov.za/roads , Access date: 12 September 2021

Decscombe M, 2012. Research Proposal – A practical guide, McGraw Hill Open University Press,
Division of Revenue Act, 2013 (Act No. 2 of 2013): Government Gazette, Vol 567 URL available at: https://www.gov.za/sites/default/files/gcis_document/201409/36555act2of2013.pdf , Accessed 21 November 2020

Farnsworth, Ph. D, B., 2019. Qualitative vs Quantitative Research – What Is the difference? [online] Imotions Publish. Available at: <https://imotions.com/blog/qualitative-vs-quantitative-research/#quantitative> [Accessed 24 October 2021].

Fox N, 1998. How to use Observations in a Research Project, Trend Focus for Research and Development in Primary Health Care,

Gargoum S and Basyouny KE, December 2018.Transportation Infrastructure Asset Management using LiDAR Remote Sensing Technology, International Journal of Trend in Research and Development, ISSN 2394-9333, pg. 143 - 250

Gartenstein D., 2018. Why Is Strategic Planning Important to an Organization? [online] Yourbusiness.azcentral.com. URL available at: <https://yourbusiness.azcentral.com/strategic-planning-important-organization-4103.html> [Accessed date: 30 December 2021].

Gräfe G, 2008. Kinematic 3D laser scanning for road or railway construction surveys, Proceedings of the International Conference on Machine Control & Guidance, pp. 24-26.

Greene S. and Martelli J., 2015. *An Introduction to Business Research Methods*. 2nd ed. Bookboon, pp.46-49.

Growing Global and Regional Interdependencies", IECS 2015, Procedia Economics and Finance 27 (2015) 14-21.

Hall F, June 2013.The Importance of Strategic planning, ResearchGate, URL available at: https://www.researchgate.net/publication/241688503_The_Importance_of_Strategic_Planning , accessed date: 19 December 2021

Heathfield SM, March 2021. What is Resistance to change, The balanced Careers, URL available at: https://www.thebalancecareers.com/what-is-resistance-to-change-1918240 , accessed date: 26 December 2021

Huidrom L, Das LK and Sud SK, 2013. Methods for automated assessments of potholes, cracks and patches for road surface video clips, Procedia - Social and Behavioural Sciences 104 (2013) pg. 312 – 321, Elsevier

Hywel T, 2018, Accident and Incident Root Cause Analysis.

Japan International Cooperation Agency, January 2013. Information Collection and Confirmation Survey on Road and Bridge Maintenance Management, Mitsubishi Research Institute, Inc, pages 2 – 63

Jongbo, O., 2014. The Role Of Research Design In A Purpose Driven Enquiry. Review of Public Administration and Management Vol. 3, No. 6, December 2014. Department of Business Administration, Lagos State University, Ojo.

Kawulich B., 2004. Qualitative Data Analysis Techniques in Qualitative Research. ResearchGate, pp.96-98.

Kivunja C. and Kuyini A., 2017. Understanding and Applying Research Paradigms in Educational Contexts. *International Journal of Higher Education*, 6(5), p.26. URL available at: https://doi.org/10.5430/ijhe.v6n5p26, Accessed date 16 October 2021

Kvochko E., 2013. Five ways technology can help the economy. [online] World Economic Forum. URL at: https://www.weforum.org/agenda/2013/04/five-ways-technology-can-help-the-economy/ [Accessed date: 27 December 2021].

Lincoln, Y. S. & Guba, E. G. (Eds. 1985). Naturalistic Inquiry. Thousand Oaks: Sage.

Maguire M and Brid Delahunt, 2017. Doing a Thematic Analysis: A Practical Step-by-Step Guide for Learning and Teaching Scholars, Dundalk Institute of Technology, Volume 8, Number 3 pages 3352 – 3356.

Manyana N, June 2021. iPAVe saves billions by redefining live deflection measurements, Infrastructure news, Construction, IMIESA Cover Story, URL available at: https://infrastructurenews.co.za/2021/06/30/ipave-saves-billions-by-redefining-live-deflection-measurement/ , Accessed date: 23 September 2021

Masarova J, August 2013. Importance of Road Instructure in the Economic Development and Competitiveness, Economics and Management: 2013, 18(2) pg. 263 - 267 , URL available at: https://www.researchgate.net/publication/272702914_IMPORTANCE_OF_ROAD_INFRASTRUCTURE_IN_THE_ECONOMIC_DEVELOPMENT_AND_COMPETITIVENESS/link/5ccc902792851c4eab80fb62/download , accessed date: 12 September 2021

McGhee KH, 2004. Automated Pavement Distress Collection Techniques: A Synthesis of Highway Practice, National Cooperative Highway Research Program (NCHRP Synthesis 334), The National Academies of Science Engineering Medicine, URL available at: http://nap.edu/23348, Accessed date: 27 September 2021

Mfinanga DA, 2007.Sampling procedure for pavement condition evaluation of local collectors and access roads, Tanzania Journal of Engineering and Technology (TIJET) Vol ,1 (No.2)

Miller JS and Bellinger WY, 2014. Distress Identification Manual for the Long-term Pavement Performance Program, Federal Highway Administration, pages 4 – 45
National Treasury, February 2018, Performance, and expenditure Review – Provincial Roads Final Report, Cornerstone Economic Research

Moolla T and Tetley S, 2021. The Journey Towards Autonomous Full Spectrum Pavement Condition Data Acquisition And Evaluation In South Africa: A Road Less Travelled.

National Treasury (a), February 2018, Performance and Expenditure Review, Provincial Roads

National Treasury (b), March 2018, Roads and Transport, Chapter 7, pg. 128-139

Ong GPR, Noureldin S, Sinha KC, 2010. Automated Pavement Condition Data Collection Quality Control, Quality Assurance And Reliability, Technical Summary INDOT Research – Technology transfer and Project Implementation information, URL available at: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2636&context=jtrp , accessed date: 24 December 2021

Oshone M, Elshaer M, Dave EV and Daniel JS, June 2017. Evolution of Asphalt Modulus from Falling Weight Deflectometer Tests and Challenges Associated with its Interpretation and Applications: A Case Study using LTPP Data, ResearchGate, available at : https://www.researchgate.net/publication/318855663_Evolution_of_asphalt_modulus_from_falling_weight_deflectometer_tests_and_challenges_associated_with_its_interpretation_and_applications_A_case_study_using_LTPP_data/link/59b1d7310f7e9b37434ac904/download , accessed date 22 December 2021

Pantuso A., Loprencipe, G., Bonin, G. and Teltayev, B., 2019. Analysis of Pavement Condition Survey Data for Effective Implementation of a Network Level Pavement Management Program for Kazakhstan. Sustainability, [online] 11(3), p.901. Available at: <https://www.researchgate.net/publication/331042238_Analysis_of_Pavement_Condition_Survey_Data_for_Effective_Implementation_of_a_Network_Level_Pavement_Management_Program_for_Kazakhstan> [Accessed 24 September 2021].

Protection of Personal Information Act, 2013, Act 4 of 2013. Government Gazette, Vol 581

Okine NA, Adarkwa O, June 2013.Pavement Condition Surveys – Overview of Current Practices, Delaware Centre for Transportation,

Pavement Interactive, Pavement Distresses, March 2018, URL available at: https://pavementinteractive.org/reference-desk/pavement-management/pavement-distresses/ , Accessed date: 03 October 2021

Pierce LM, McGovern G, Zimmerman KA, February 2013. Practical Guide for Quality Management of Pavement Condition Data Collection, U.S. Department of Transportation Federal Highway Administration, Form DoT F1700.7 pg. (8-72)

Pierce LM and Weitzel ND, 2019. Automated Pavement Condition Surveys, NCHRP Synthesis 531, National Academies of Science, Engineering and Medicine,

Radopoulou SC, Brilakis I, April 2016. Improving Road asset condition monitoring, Elsevier, ScienceDirect, Transportation Research Procedia 14 (2016) pg. 3004 - 3012

Underwood BS, Kim TR, Corley-Lay J, 2011, Assessments of use of Automated Distress survey methods for network level Pavement Management, *American Society of Civil Engineers*, URL available at https://ascelibrary.org/doi/pdf/10.1061/(ASCE)CF.1943-5509.0000158?casa_token=IcPdW1Sp1qEAAAAA:hMB5r6Mt75IWx-ZJsj-Y64LjkICvP4ihMmp7eGvunBT9UHm7MId0jftYYxrrFQOybdhQL5GmRuo , Accessed date: 21 November 2020

Ragnoli A, Blasiis MRD, Benedetto AD, December 2018, Pavement Distress Detection Methods: A Review, Infrastructures,

Randall L, April 2021, South Africa bottom of the class for road safety? Here’s why this isn’t true, University of Witwatersrand, Johannesburg, URL available at: https://www.wits.ac.za/news/latest-news/opinion/2021/2021-04/south-africa-bottom-of-the-class-for-road-safety-heres-why-this-isnt-true.html#:~:text=In%20an%20average%20year%2C%201.35,in%20the%20road%20death%20pandemic., accessed date: 12 June 2022

Rensburg JA van, Krygsman SC, September 2019, Funding for roads: Understanding the South African road funding framework, JTSCM – *Journal of Transport and Supply Chain Management*, URL available at: https://jtscm.co.za/index.php/jtscm/article/view/453/827 , Accessed 19 December 2021

Ross and Townshend, 2019, The road Maintenance backlog in South Africa, University of Pretoria, 38th International Southern African Transport Conference, URL available at: http://hdl.handle.net/2263/74310, accessed date 25 September 2021

Roux D and Labuschagne FJJ, August 2016. Development of a Methodology for the calculations of the Costs of Crashes in South Africa, Project Report Phase 2, Road Traffic Management Corporation, Version 1.1

Rusmanto U, I Syafi and Handayani D, 2018. Structural and Functional Prediction of Pavement Condition (A case study of South Arterial Road, Yogyaakarta), AIP Conference Proceedings, Vol 1977 Issue 1, URL available at: https://aip.scitation.org/doi/abs/10.1063/1.5042984 , Access date: 22 December 2021

Rusu L, Sitar DA, Jecan S, 2015. An integrated Solution for Pavement Management and Monitoring Systems, Procedia Economics and Finance, Elsevier, ScienceDirect, Volume 27, pages 14-21, URL available at:

https://www.sciencedirect.com/science/article/pii/S2212567115009661 , Accessed date: 10 October 2021

Saeed N, Dougherty M, Nyberg RG, Rebreyend P and Jomaa D,2020. A review of Intelligent methods for unpaved road condition assessment, ResearchGate, URL available at : https://www.researchgate.net/publication/341568052_A_Review_of_Intelligent_Methods_for_Unpaved_Roads_Condition_Assessment/link/5ed6646a4585152945286796/download , accessed date 07 September 2021

Salama HK, Chatti K, and Lyles RW, October 2006. Effects of heavy multiple axle trucks on flexible pavement damage using in-service data, *Journal of Transportation Engineering*, Vol 132 Issue 10, URL available at: ascelibrary.org/doi/full/10.1061/%28ASCE%290733-947X%282006%29132%3A10%28763%29?casa_token=HAtrLr5-XLcAAAAA%3Avwoj6pDYSl-I6mgNjfPo6m9IMKEFPh_2mM5BWwZNoBBjpNW2NYAbESCbufrbCcY7hDfdhXZJ_N4, Access date: 21 September 2021

SAPEM. 2014. South African Design Manual (SAPEM) Chapter 10, Second Edition. March 2014. South African National Roads Agency SOC Ltd (SANRAL), Pretoria, South Africa

Saunders M., Lewis P., and Thornhill A., 2016. Research Methods for Business Students. 7th ed. England: Pitman Publishing - Pearson, pp.122 -130.

Saunders, M., Lewis, P., Thornhill, A, 2009. Research Methods for Business Students, 5th edition, Prentice Hall

Schattler K, Rietgraf A, Wolters A and Zimmerman K, December 2011. Implementing Pavment Management Systems for Local Agencies, Implementation Guide, Illinois Centre for Transportation, Series No, 11-094-1

Sharpe GW, Southgate HF and Deen RC, 2012. Users Guide for Pavement Condition Surveys, Research Report, U KTRP-87 -12

Showkat N and Parveen H, July 2017. Non-Probability and Probability Sampling, Aligarh Muslim University, ResearchGate, URL available at https://apps.apple.com/us/app/researchgate/id1208163937?ls=1 , Accessed date: 30 October 2021

Sivaneswaran N., Pierce L., and Mahoney J., 2004. Transition from Manual to Automated Pavement Condition Surveys: Washington States Experience, in 6th International Conference on Managing Pavements. Washington: TRB Committee AFD10 on Pavement Management Systems, pp.1-13.

South Africa Yearbook 2015/16 Transport, 2015. South African Government, URL available at https://www.gcis.gov.za/sites/default/files/docs/resourcecentre/yearbook/Transport-SAYB1516.pdf, Accessed date: 21 November 2020

Southern African Development Community, 2012. Towards a common future, URL available at: https://www.sadc.int/themes/infrastructure/transport/roads-road-transport/ , accessed date: 27 December 2021

Shwab K., 2016. The Fourth Industrial Revolution: what it means and how to respond. [online] World Economic Forum. URL Available at: https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/ [Accessed date: 27 December 2021].

S.M.A; Saleem, H., March 2008. "Inductive & Deductive Research Approach", Lecture delivered on 06-03-2008 at Auditorium of Faculty of Arts and Science, University of Karachi, Karachi, Pakistan. Accessed URL 24 October 2021

Timm DH and McQueen JM, April 2004.A study of Manual vs. Automated Pavement Condition Surveys, Alabama Department of Transportation Mongomery, AL,

Tsai Y, Kaul V, Mersereau RM, January 22010. Critical assessment of pavement distress segmentation methods, *Journal of Transportation Engineering*, Vol 136 Issue 1, ASCE Library, URL available at : https://ascelibrary.org/doi/full/10.1061/%28ASCE%29TE.1943-

5436.0000051?casa_token=ezddcWI9MScAAAAA%3AM8gSLZaHDANC52Yq9aFRv6gAEIPwRnkLCkjIfvnymePw8Rkp87Hfl47HTJhW58FkpVFsXyFG2H4 : Accessed date : 03 September 2021

Tsai, F. Li, 2012. Critical assessment of detecting asphalt pavement cracks under different lighting and low intensity contrast conditions using emerging 3D laser technology, *Journal of Transportation Engineering* 138 (5), 649-656.

Turner DP, January 2020. Sampling Methods in Research Design, Headache, The Journal of Head and Face pain, Wiley Periodicals Inc, URL available at: https://headachejournal.onlinelibrary.wiley.com/doi/epdf/10.1111/head.13707, Accessed date: 30 October 2021

Transport and ICT Department, 2014. Road Safety Manual for Africa, Existing Roads: Reactive Approaches,

TRL, Cambridge Economics Policy Association, May 2018. Measuring Pavement Condition – Office of Rail and Road Final Report

Underwood BS, Kim TR, Corley-Lay J, 2011. Assessments of use of Automated Distress survey methods for network level Pavement Management, *American Society of Civil Engineers*, *Journal of performance of constructed facilities*, pgs. – 250 – 258 URL available at https://ascelibrary.org/doi/pdf/10.1061/(ASCE)CF.1943-5509.0000158?casa_token=IcPdW1Sp1qEAAAAA:hMB5r6Mt75IWx-ZJsj-Y64LjkICvP4ihMmp7eGvunBT9UHm7MId0jftYYxrrFQOybdhQL5GmRuo , Accessed date: 21 September 2021

Visser H., Tetley S., Lewis T., Naidoo K., Moolla T., Pillay J. (2022). A Study into the Benefit and Cost-Effectiveness of Using State-of-the-Art Technology for Road Network Level Condition Assessment. In: et al. Advances in Road Infrastructure and Mobility. IRF 2021. Sustainable Civil Infrastructures. Springer, Cham. https://doi.org/10.1007/978-3-030-79801-7_2

Vitillo, N Dr, 2017. Pavement Management Systems Overview.

Walliman, N. 2011. *Research methods: The basics.* New York: Routledge

World Health Organisation, June 2021. Road Traffic injuries, URL available at: https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries, Accessed date: 12 June 2022

Virginia Department of Transportation, 2012. A Guide To Evaluating Pavement Distress Through The Use Of Digital Images, Version 2.60, Maintenance Division

Zafar MS, Shah SNR, Memon MJ, Rind TA and Soomro MA, June 2019.Condition Survey of Evaluation of Pavement Condition Index of a Highway, Department of Civil Engineering, Mehran University of Engineering and Technology, Shaheed Zulfiqar Ali Bhutto Campus, Khairpur Mirs', Sindh, Pakistan, *Civil Engineering Journal*, Vol. 5, No. 6, URL accessed at : https://www.researchgate.net/publication/334032695_Condition_Survey_for_Evaluation_of_Pavement_Condition_Index_of_a_Highway , accessed date 11 September 2021

Appendix A1 - Gatekeepers Permission Letters – Nankhoo Engineers

XARIBA ENTERPRISES cc t/a
NANKHOO
Consulting Engineers
CIVIL · STRUCTURAL · PROJECT MANAGEMENT

Tel: 031 536 8310
Fax: 086 516 2332
Email: nankhoo@nadbn.co.za
VAT No.: 4470182397

Gateway Office Park, Block 1
1 Sugar Close, Umhlanga, 4021
P.O Box 2135, Umhlanga Manors, 4021
Level 1 B-BBEE Contributor

22 July 2021

To: Research Ethics Committee
University of KwaZulu Natal
University Road
Westville
Private Bag X 54001
Durban
4000

To whom it may concern,

The purpose of this letter is to inform you that Nankhoo Consulting Engineers, hereby grants permission to Verushka Balaram, student number 219052894, to conduct research titled "ENHANCING THE QUALITY AND SAFETY OF ROAD INFRASTRUCTURE BY INTRODUCING AUTOMATED DATA COLLECTION TO ENABLE SUSTAINABILITY OF ORGANISATIONS WITHIN THE BUILT ENVIRONMENT"." by collecting data through an interview process with the highly skilled Civil Engineers at Nankhoo Consulting Engineers.

Yours sincerely,

[redacted]

Duly Authorised Signatory
On Behalf of
NANKHOO CONSULTING ENGINEERS
A-N SUKURAM (Pr. Tech Eng)
031 536 8310

www.nankhoo.co.za
QUALITY · INTEGRITY · INNOVATION

Appendix A2 – Gatekeepers Permission Letters – ARRB SYSYEMS

ARRB Systems
Reg. No. 2018/103893/07
VAT No. 4550284063

10 Kyalami Road, Westmead, 3610
KwaZulu-Natal, South Africa

P: +27 31 700 2500
E: info@arrbsa.com

To: Research Ethics Committee 09 July 2021

University of KwaZulu Natal
University Road
Westville

Private Bag X 54001
Durban
4000

To whom it may concern,

The purpose of this letter is to inform you that ARRB SYSTEMS AFRICA, hereby grants permission to Verushka Balaram, student number 219052894, to conduct research titled "ENHANCING THE QUALITY AND SAFETY OF ROAD INFRASTRUCTURE BY INTRODUCING AUTOMATED DATA COLLECTION TO ENABLE SUSTAINABILITY OF ORGANISATIONS WITHIN THE BUILT ENVIRONMENT"." by collecting data through an interview process with the highly skilled Civil Engineers at ARRB SYSTEMS AFRICA.

Your Sincerely,

[redacted]

Yeshveer Balaram

General Manager: ARRB SYSTEMS AFRICA

arrbsystems.com

Appendix A3 - Gatekeepers Permission Letters – VNA Consulting

REALISING
CONTINENTAL
POTENTIAL

To: Research Ethics Committee 08 July 2021

University of KwaZulu Natal
University Road
Westville

Private Bag X 54001
Durban
4000

To whom it may concern,

The purpose of this letter is to inform you that VNA Consulting, hereby grants permission to Verushka Balaram, student number 219052894, to conduct research titled "ENHANCING THE QUALITY AND SAFETY OF ROAD INFRASTRUCTURE BY INTRODUCING AUTOMATED DATA COLLECTION TO ENABLE SUSTAINABILITY OF ORGANISATIONS WITHIN THE BUILT ENVIRONMENT"." by collecting data through an interview process with Civil Engineers at VNA Consulting.

Your Sincerely,

[redacted]

Preven Naicker (Pr CPM, Pr Snr Arch Tech, AAArb)

Director

CORPORATE OFFICE
596 Peter Mokaba Ridge, Berea, Durban,
KwaZulu-Natal, South Africa, 4001
PO Box 70803, Overport, Durban, KwaZulu-Natal, South Africa, 4067

Tel: +27 31 207 8121 I Fax: +27 31 207 8722
Email: info@vnac.co.za I Web: www.vnac.co.za

HEAD OFFICE
10 Kyalami Road, Park 2000 Westmead,
Pinetown, KwaZulu-Natal, South Africa, 3610

Tel: +27 31 700 2500 I Fax: +27 31 940 4243

OTHER OFFICES
BLOEMFONTEIN
CAPE TOWN
JOHANNESBURG
PIETERMARITZBURG

AFFILIATIONS
AUSTRALIA
DENMARK
INDIA
MAURITIUS
SWEDEN

www.vnac.co.za

NEXOR 312 (PTY) LTD TRADING AS VNA CONSULTING (REG. NO.: 2013/093275/07)

\0000-TL01

Appendix A4 - Gatekeepers Permission Letters – Endecon Consulting Engineers

ENDECON
UBUNTU (PTY) LTD
ENGINEERING CONSULTANTS
REG NO. 1998/17844/07

MBOMBELA
P.O. BOX 10345
MBOMBELA, 1200

9 EHMKE STREET
MBOMBELA, 1200
MPUMALANGA
SOUTH AFRICA

Tel: +27 (13) 755-1190
Fax: +27 (13) 755-4904

website: www.endeconubuntu.co.za
e-mail: ubuntu@endecon.co.za

OUR REF: **DATE:** Tuesday, July 20, 2021

YOUR REF: **ENQUIRIES:**

To: Research Ethics Committee
University of KwaZulu Natal
University Road
Westville
Private Bag X 54001
Durban
4000

To whom it may concern,

The purpose of this letter is to inform you that Endecon Ubuntu, hereby grants permission to Verushka Balaram, student number 219052894, to conduct research titled "*Enhancing the quality and safety of road infrastructure by introducing automated data collection to enable sustainability of organisations within the built environment*"." By collecting data through an interview process with the highly skilled civil engineers at Endecon Ubuntu.

Your Sincerely,

[redacted]

P. Bouwer – PR.ENG, C.ENG, MICE
pp Endecon Ubuntu (Pty) Ltd

Appendix A5 - Gatekeepers Permission Letters – GIBB Engineering

Our Ref:

09 June 2021

University of KwaZulu Natal
University Road
Westville

Private Bag X 54001
Durban
4000

GIBB
ENGINEERING & ARCHITECTURE

Cape Town

8th Floor
The Link
19 DF Malan Street
Cape Town 8001

Tel: +27 21 469 9100
Fax: +27 21 424 5571
Web: www.gibb.co.za

To whom it may concern,

The purpose of this letter is to inform you that GIBB Engineers, hereby grants permission to Verushka Balaram, student number 219052894, to conduct research titled "ENHANCING THE QUALITY AND SAFETY OF ROAD INFRASTRUCTURE BY INTRODUCING AUTOMATED DATA COLLECTION TO ENABLE SUSTAINABILITY OF ORGANISATIONS WITHIN THE BUILT ENVIRONMENT"." by collecting data through an interview process with the highly skilled Civil Engineers at GIBB Engineers.

Yours faithfully
for GIBB (Pty) Ltd

[redacted]

Alan Moffett
TECHNICAL EXECUTIVE

Appendix A6 - Gatekeepers Permission Letters – Department of Police, Roads and Transport, Free State

police, roads & transport
Department of
Police, Roads and Transport
FREE STATE PROVINCE

Enquiries: Mr. LT Sekhaolela
Deputy Director: RAMS
Contacts: 051 409 8582/082 821 9056
Email: Sekhaolelal@freetrans.gov.za

30 July 2021

To: Research Ethics Committee
University of KwaZulu Natal
University Road
Westville
Private Bag X 54001
Durban
4000

To whom it may concern,

ETHICAL CLEARANCE FOR VERUSHKA BALARAM

The purpose of this letter is to inform you that Free State Roads, Police and Transport, hereby grants permission to Verushka Balaram, student number 219052894, to conduct research titled "ENHANCING THE QUALITY AND SAFETY OF ROAD INFRASTRUCTURE BY INTRODUCING AUTOMATED DATA COLLECTION TO ENABLE SUSTAINABILITY OF ORGANISATIONS WITHIN THE BUILT ENVIRONMENT"." by collecting data through an interview process with the highly skilled professionals in the road infrastructure sector at Free State Roads, Police and Transport Department.

I trust you will find the above in order.

Kind Regards,

[redacted]

Mr. LT Sekhaolela
Deputy Director: RAMS Administrator
Department of Police, Roads and Transport

Date: 30/07/2021

ROADS ASSET MANAGEMENT SYSTEMS
Medfontein Building, Room 301, St Andrew Street, P.O Box 690, BLOEMFONTEIN, 9300
sekhaolelal@freetrans.gov.za 051 405 8582
www.fs.gov.za

Appendix B - Participants Consent and Introduction Form

UNIVERSITY OF KWAZULU-NATAL
GRADUATE SCHOOL OF BUSINESS AND LEADERSHIP

Master of Business Administration Research Project

Researcher: Verushka Balaram 082 554 2795

Supervisor: Dr Simon Taylor (071 509 3965)

Research Office: Humanities & Social Sciences Research Ethics Administration

Westville Campus, Govan Mbeki Building

Private Bag X 54001 Durban, 4000

KwaZulu-Natal, South Africa

Tel: +27 31 260 4557 | Fax: +27 31 260 4609

Email: HSSREC@ukzn.ac.za

Date: August 2021/September 2021

Dear Respondent,

My name is Verushka Balaram, who is currently a master's student at the Graduate School of Business and Leadership studies. My contact email is: 219052894@stu.ukzn.ac.za. My supervisor is Dr Taylor who can be contacted on the following email address: taylors@ukzn.ac.za.

You are being invited to consider participating in a study that involves research on "Enhancing the quality and safety of road infrastructure by introducing automated data collection to enable sustainability of organisations within the built environment". The aim and purpose of this research is to understand the methodology behind road assessments, and which is the most efficient and effective to improve sustainability of engineering firms in the civil engineering industry. The study is expected to enrol a sample size of 20 individual from consulting and construction firms. If you agree to participate in this study, it will involve you to participate in an interview process, which will take approximately 15 minutes to complete.

There are no risks associated with participating in this study. The key benefit of participating in this study is an opportunity to share your thoughts and experience on the methodology used to collect road pavement data.

In the event of any problems, concerns, or questions you may have, please contact the researcher at 219052894@stu.ukzn.ac.za or the UKZN Humanities & Social Sciences Research Ethics Committee, using the contact details below:

Humanities & Social Sciences Research Ethics Administration

Research Office, Westville Campus, Govan Mbeki Building

Private Bag X 54001

Durban

4000

KwaZulu-Natal, South Africa

Tel: +27 31 260 4557 | Fax: +27 31 260 4609

Email: HSSREC@ukzn.ac.za

Participation in this study is voluntary and you may withdraw at any point. In the event of refusal/withdrawal of participation you will not incur penalty or loss of treatment or other benefit to which you are normally entitled.

There are no costs involved in participation of this study.

This study is anonymous. No information that is shared will be used outside of this study. Your name will not be included on the questionnaire. All completed consent forms and questionnaires will be stored in a locked office at UKZN.

CONSENT

I _____________________________ have been informed about the study entitled "Enhancing the quality and safety of road infrastructure by introducing automated data collection to enable sustainability of organisations within the built environment", by researcher Verushka Balaram - 219052894

I understand the purpose and procedures of this study.

I have been given an opportunity to answer questions about the study and have received answers to my satisfaction.

I declare that my participation in this study is entirely voluntary and that I may withdraw at any time without affecting any of the benefits that I am usually entitled to.

If I have any further questions, concerns or queries related to the study, I understand that I may contact the researcher at 219052894@stu.ukzn.ac.za.

If I have any questions or concerns about my rights as a study participant, or if I am concerned about an aspect of the study or the researchers, then I may contact:

Humanities & Social Sciences Research Ethics Administration

Research Office, Westville Campus, Govan Mbeki Building

Private Bag X 54001

Durban

4000

KwaZulu-Natal, South Africa

Tel: +27 31 260 4557 | Fax: +27 31 260 4609

Email: HSSREC@ukzn.ac.za

_____________________ _____________________

Signature of Participant Date

Appendix C – Ethical Clearance Approval Letter

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

08 October 2021

Verushka Balaram (219052894)
Grad School Of Bus & Leadership
Westville Campus

Dear V Balaram,

Protocol reference number: HSSREC/00003400/2021
Project title: An integrated solution for pavement management and monitoring systems in South Africa
Degree: Masters

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 14 September 2021 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

This approval is valid until 08 October 2022.
To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

All research conducted during the COVID-19 period must adhere to the national and UKZN guidelines.

HSSREC is registered with the South African National Research Ethics Council (REC-040414-040).

Yours sincerely,

[redacted]

____

Professor Dipane Hlalele (Chair)

/dd

Humanities and Social Sciences Research Ethics Committee
Postal Address: Private Bag X54001, Durban, 4000, South Africa
Telephone: +27 (0)31 260 8350/4557/3587 **Email:** hssrec@ukzn.ac.za **Website:** http://research.ukzn.ac.za/Research-Ethics

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

INSPIRING GREATNESS

Appendix D – Interview Guide

INTERVIEW QUESTIONAIRE

1. What is your qualification?

2. How long are you working in the Civil Engineering Industry?

3. The South African road network is valued at over R2tn (2016), yet there is a maintenance backlog of R197Bn.
   3.1 How important is road condition assessment for strategic planning at government level?

   3.2 Considering limited funding, how should road agencies address this backlog?

4 Roads are designed based on structural requirements, yet they are maintained based on functional (surface) condition.
   4.1 In your opinion how do Pavement Management Systems influence road maintenance strategies.
   4.2 What are the challenges in determining maintenance strategies based solely on functional characteristics?

5 Methodologies derived to collect data for PMS systems
   5.1 What are the accepted methods of conducting road condition assessments undertaken by yourselves as a pavement engineer and your organisation?

   5.2 Why has this type of methodology been chosen for road assessments?

   5.3 From your years of experience within pavement engineering what are the advantages and disadvantages of undertaking manual methods of visual assessments out on site?

6 Recent advances in technology have allowed engineers to access big data, and eliminate the challenges associated with manual condition assessments. At present, the technology is often expensive to own and operate, however the data outputs from the technology can be used to save billions of rands to the fiscus because of the increased resolution and accuracy.

   6.1 Are you aware of the various technological advancements in industry that are capable of measuring road conditions quickly and accurately? Elaborate.

6.2 Would you consider adopting an automated approach? Elaborate on your answer. (Min 50 words)

7 Perspective of the methodologies

7.1 Which methodology of road condition assessments in your view are the most trusted? Please Elaborate.

7.2 Which of the two road condition methodologies are considered safer?

8 Impact an integrated system for pavement engineering have on the South African organisations and the economy at large.

8.1 Do you think utilization of technological advancement can help make organisations and road agencies work more effectively and efficiently to obtain results quicker so roads can be safer for road users? (Yes/No) Elaborate on your answer.

8.2 Do you think technological advancement for road infrastructure can help businesses become more sustainable and profitable and at the same time improving the economy? Please elaborate.

Appendix E – Turnitin Report

ORIGINALITY REPORT

2%	2%	1%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.transport.gov.za Internet Source	<1%
2	s3.amazonaws.com Internet Source	<1%
3	www.researchgate.net Internet Source	<1%
4	res.mdpi.com Internet Source	<1%