INVESTIGATING A STANDARDISED APPROACH TOWARDS PRIORITISATION OF GRAVEL ROADS UPGRADE TO PAVED ROADS IN KWAZULU-NATAL

by

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DECLARATION

This dissertation is the candidate's own work, and work of other authors incorporated within it has been acknowledged and cited accordingly. This dissertation has not been previously submitted at any other institution for obtaining a qualification, and it is confirmed that its publication by the Durban University of Technology will not infringe any third-party rights. This research was conducted at the Durban University of Technology under the supervision of Professor Dhiren Allopi.

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ABSTRACT

Gravel roads are natural earth roads comprising a formation/roadbed layer and an additional top layer of gravel material, referred to as the gravel wearing course (GWC). Gravel materials used for constructing the GWC layer are obtained from local quarries or borrow-pits. The performance of gravel roads is dependent on numerous factors, which include gravel wearing course materials' suitability as well as the geological founding materials of the roadbed layer. The major challenge with gravel roads is that they are overly sensitive to weather conditions as well as to the type and volume of traffic using them. In contrast to paved roads, gravel roads deteriorate faster and require more maintenance since they are not sealed with impermeable layers. As in most countries, South Africa has a substantial proportion of gravel roads within its road network. Gravel roads are cheap to construct when compared to paved ones, however, their maintenance costs are higher than those of a paved road over time, and that poses a challenge as the allocation of road infrastructure funds is usually lower than the gravel road network needs. This results in a maintenance backlog and a rapid rate of gravel road deterioration, as well as an increase in their maintenance costs.

The KwaZulu-Natal Department of Transport, hereafter being referred to as the KZN-DoT, developed a project prioritisation model for all their project categories. This research focused on investigating the methodology that the KZN-DoT implements when prioritizing for gravel roads upgrade to paved. The investigation of the KZN-DoT's prioritisation methodology was achieved through evaluating prioritisation factors considered, traffic baseline being used when selecting gravel roads to prioritise for upgrade as well as through investigating the right time of upgrading a gravel road to paved surface. The aim of evaluating the KZN-DoT's prioritisation model was to enhance it by further proposing its refinements where necessary. Recommendations and conclusions were drawn from the research findings for respective research questions and objectives. This research recommends the addition of some prioritisation factors into the KZN-DoT model and a gravel road performance modelling tool to be developed and used to establish each gravel

road's deterioration pattern and in turn quantify economies of retaining it as a gravel road versus paving it to determine the right time to upgrade them. This is a large study that was conducted by the researcher for the KZN-DoT.

In the context of this research, the phrase, "upgrading of gravel roads" shall mean the upgrading of gravel roads to paved surface i.e., bituminous seal surfacing or asphalt. Whereas, for the KZN-DoT's prioritisation model for gravel roads upgrading to paved shall mean upgrading of gravel roads to blacktop surface which is the term that the KZN-DoT use interchangeably with bituminous seal surfacing. In this research, where the term unpaved and unsealed road is used, it shall mean gravel road.

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
AGL	Annual Gravel Losses
B/P	Borrow pit
CARNS	Community Access Roads Needs Study
CBR	California Bearing Ratio
CSIR	Council for Scientific and Industrial Research
DCP	Dynamic Cone Penetrometer
DR	District Road
EPWP	Expanded Public Works Programme
EVU	Equivalent Vehicle Unit
Gc	Grading Co-efficient
GIS	Geographic Information System
GL	Gravel Loss
GLDM	Gravel Loss Deterioration Model
GLM	Gravel Loss Measurement
GLP	Gravel Loss Prediction
GLPM	Gravel Loss Prediction Model
GPS	Geographic Point System
GRDM	Gravel Road Deterioration Model
GRMS	Gravel Road Management System
GrPSI	Gravel Profile Shape Index
GWC	Gravel Wearing Course
HDM	Highway Development and Management
Io	Oversize Index
HMA	Hot Mixed Asphalt
KZN DOT	KwaZulu-Natal Department of Transport
LL	Liquid Limit

LOS	Level of Service
LR	Local Road
LS	Linear Shrinkage
LTPMTS	Long-Term Performance Monitoring Test Sections
LVR	Low Volume Road
MR	Main Road
NDOT	National Department of Transport
NT	National Treasury
PCE	Passenger Car Equivalency
PCSE	Passenger Car Space Equivalents
PCU	Passenger Car Unit
PI	Plasticity Index
PL	Plastic Limit
PM	Preventive Maintenance
PMS	Pavement Management System
PRMG	Provincial Road Maintenance Grant
PTR	Public Transport Route
RAMS	Road Asset Management System
RED	Roads Economic Decision
RQ	Research Question
RUC	Road User Cost
SANAS	South African National Accreditation System
SANS	South African National Standard
Sp	Shrinkage product
TMH	Technical Methods for Highways
TRH	Technical Recommendations for Highways
VOC	Vehicle Operating Cost
vpd	Vehicles per day

CHAPTER 1: INTRODUCTION

1.1 Background

This study investigates the right time to upgrade a gravel road to paved standards. It also assesses the developed project prioritisation system of the KwaZulu-Natal Department of Transport Provincial Road Network for the upgrading of gravel roads to paved roads. The extent of its assessment includes reviewing the methodology being employed when prioritising the upgrading of gravel roads to paved standards as well as the prioritisation factors that are considered by the KwaZulu-Natal Department of Transport (hereafter referred to as the Department) when ranking projects according to their priorities. This is a large study that was conducted by the researcher for the KZN-DoT.

Prior to the development of the projects' prioritisation system, the KZN-DoT depended mostly on public requests and inputs from its regions to rank road infrastructure projects to be implemented by the KZN-DoT each year. A prioritisation system has been developed by the KZN-DoT for use in formulating priorities in all road infrastructure project categories based on the technical criteria. This research focused on the category of upgrading gravel roads to paved roads.

According to the Department of Transport (1997: 6.1), the KZN-DoT conducted a study in the past, to develop an approach that would allow for the identification of road project priorities and distribute funds across various works programmes. The report mentions that, in the past, the expenditure was skewed, and certain areas were seriously neglected (Department of Transport 1997: 6.2). The study found that the distribution of funds and the prioritisation of road projects must follow two levels. Firstly, the calculation of the proportion of the total funds available for allocation to each Magisterial district. Secondly, determine which roads are most important within each district (Department of Transport 1997: 6.2). The study's overall outcome found that funds must be allocated where they will benefit the maximum number of people, and this includes the projected population for future years (Department of Transport 1997: 6.2). Hence, the recommended approach was that the allocation of funds should be based on population numbers but adjusted to consider other factors.

According to the Department of Transport (1997: 6.5), all the provincial departments tasked with the provision of public services were given an option to direct resources to communities that were previously least served or further develop areas that already had major economic activities taking place. The KZN-DoT opted to bridge the gap between the previously least served communities and the ones with the strongest economies by directing its resources to the former. This resulted in the development of the new strategy by the KZN-DoT to ensure that its plan align with their decision to direct resources to the previously least served communities. Access to rural communities was a major problem in the past since the spatial planning and land usage practices that existed, promoted injustices in the provision of public services. The KZN-DoT's new strategy then became the provision of new gravel roads to the previously disadvantaged communities, especially the ones in the rural areas, to ensure that public services reach those communities. This drastically increased the provincial rural road network size. Maintenance of existing road infrastructure continued in all areas, including those with the strongest economies; however, budget allocations towards road maintenance decreased significantly due to the Department's focus being the provision of the new gravel roads. The KZN-DoT's strategy barred positive results in terms of increased rural road networks to ensure the ease of public service delivery. However, the researcher is of the view that although the Department's strategy was a move in the right direction, the failure to provide an approach to be followed in ensuring preservation of the existing road infrastructure assets resulted in a maintenance backlog and rapid deterioration of the existing road network, which in turn, resulted in an accumulation of maintenance costs.

Figures 1.1 and 1.2 show how the KwaZulu-Natal provincial road network and each road class expanded over a ten-year period during the implementation of the Department's strategy to provide gravel road accesses to rural communities that were previously least served.

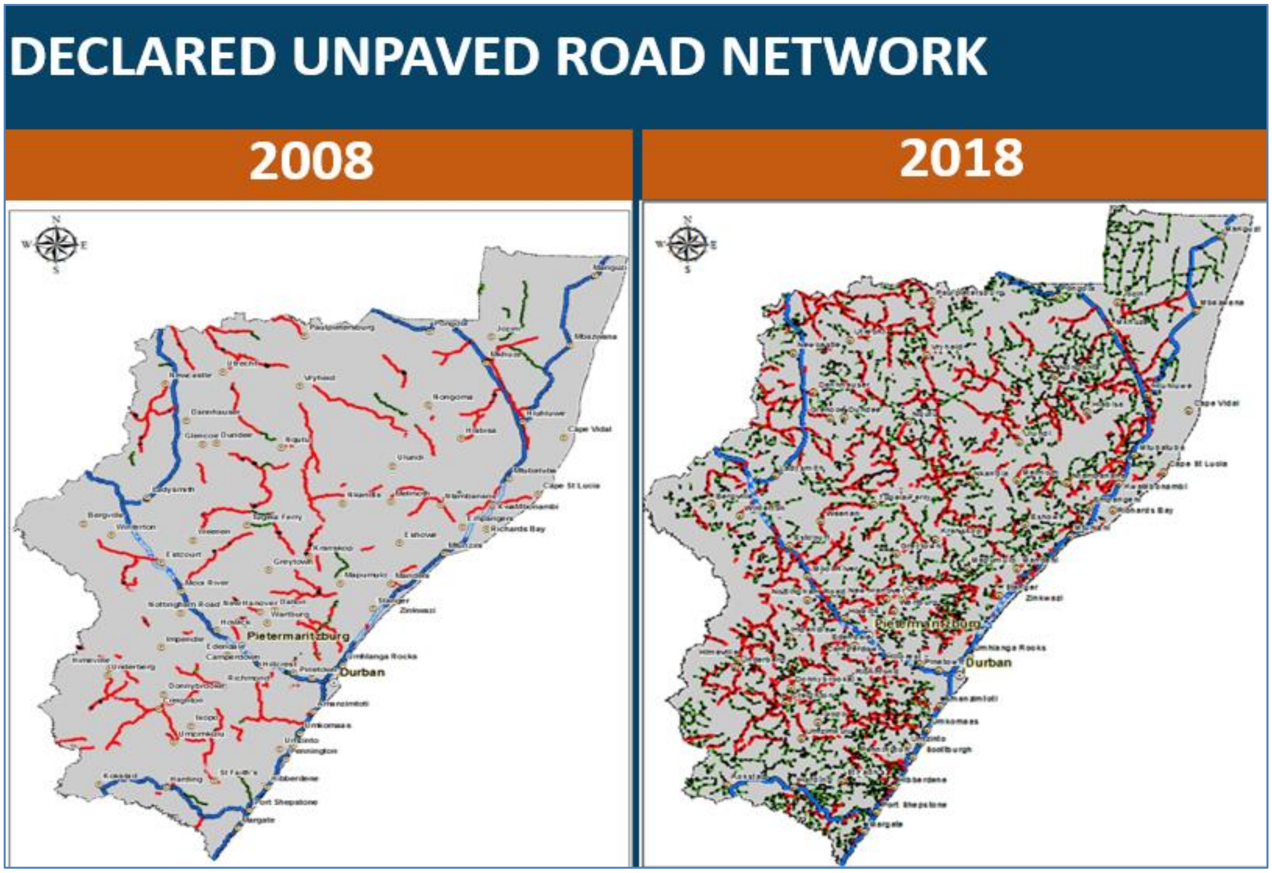


Figure 1.1 KZN DOT road network size in 2008 versus 2018
Ndlovu *et al*. 2018, 2018 SARF/IRF/PIARC Regional Conference for Africa

Roads that are under the ownership of the KZN-DoT which are declared as forming part of the provincial road network are administratively classified into three classes namely, Main Road (MR), District Road (DR) and Local Roads (LR). MR, DR and LR are denoted with P, D and L respectively. P roads connect regions and D roads connect districts within the province of KwaZulu-Natal, whereas LRs are minor collector and residential roads within the local communities. On the KZN-DoT's Geographic Information System (GIS) the said classes of roads are displayed using the assigned colour codes for respective road classes. P, D and L are displayed in red, blue and green respectively. Paved roads are displayed using solid line whereas, the gravel roads are displayed using a dotted line.

Figure 1.2 presents observatory comparisons in terms of the KZN-DoT Road network growth over a ten-year period between 2008 and 2018. However, for Figure 1.2 different colour codes were introduced by the researcher to present KZN-DoT Road classes and road surface status (gravel or paved).

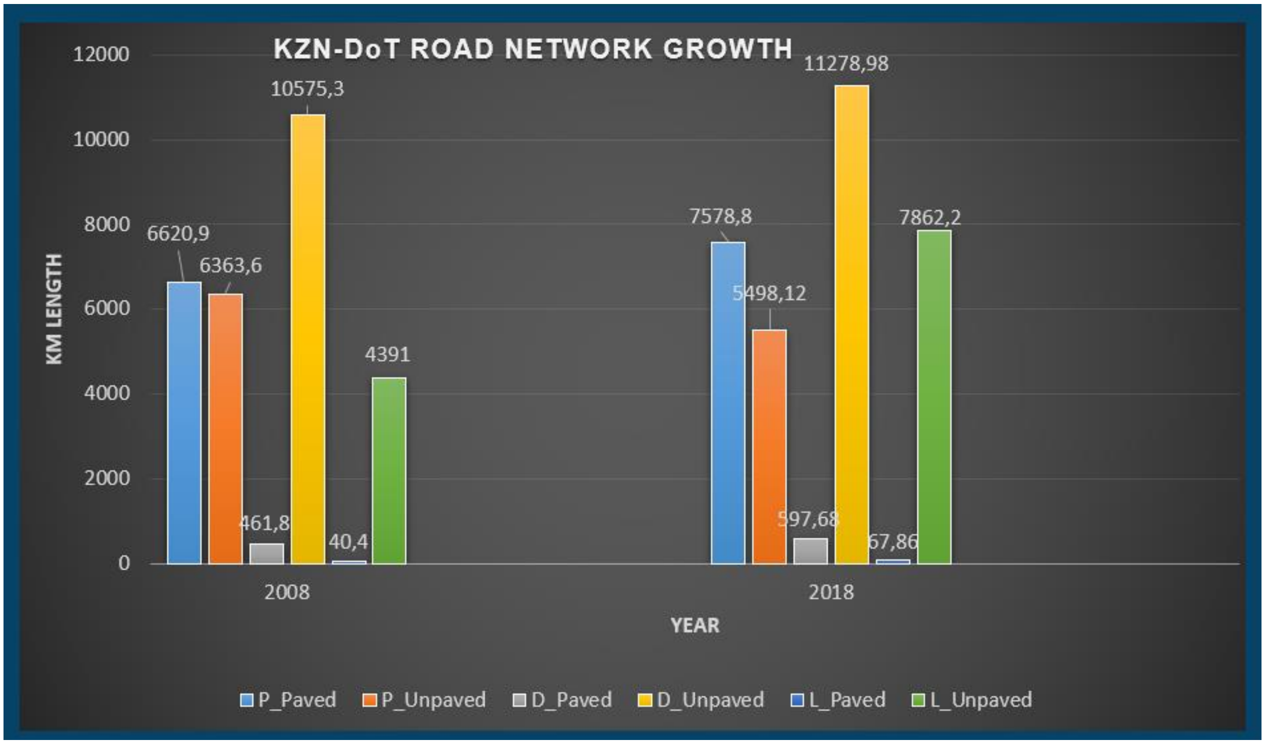


Figure 1.2 Comparison of provincial road provision on different road classes between 2008 and 2018 in KwaZulu-Natal

Ndlovu *et al*. 2018, 2018 SARF/IRF/PIARC Regional Conference for Africa

An increase of the KZN-DoT Road network size was noted, with 28,453 km in length and 32,883 km in length observed in 2008 and 2018 respectively. Which that resulted in KZN-DoT Road network growth of 4,430 km in length.

A drastically increase in number of unpaved L roads was noted. The interpretation to this is that between 2008 and 2018 the provision of new local roads increased by 90%.

The km length of paved L roads between 2008 and 2018 increased by 84%. There was also a notable increase in km length in terms of paved D and P roads between 2008 and

2018. This means that there an increase in the number of D and P unpaved roads that were to paved roads.
The paved P roads increased by 957,9 km and unpaved P roads decreased by xxx between 2008 and 2018. This means that 865,48 km that was part of unpaved P roads in 2008 were upgraded to paved.

1.1.1 The KZN-DoT's prioritisation model for upgrading of gravel roads

In 2015 the KZN-DoT developed a model of prioritising the upgrading of gravel roads to paved. The model prioritises gravel roads needing to be paved using selected prioritisation factors and then assigns applicable points for each factor considered. It uses the GIS system to view gravel roads on respective selected factor layers, and it also uses a traffic baseline of 200 vpd to select gravel roads for upgrade prioritisation. More details on the KZN-DoT prioritisation model are discussed in chapter 2 of this dissertation under subheading 2.4.

1.1.2 Problem statement

A decision to upgrade a gravel road to paved surface should be informed and technically supported by deterioration and maintenance records of that gravel road. In the absence of gravel roads' performance measurement tool and historic maintenance records, a decision to upgrade a gravel road cannot be justified. The KZN-DoT's criteria of selecting gravel roads to prioritise for upgrade is solely dependent on the traffic baseline of 200 vpd irrespective of a gravel road's performance and maintenance history. Once any KZN-DoT's gravel road hits the traffic baseline required, it becomes eligible to be prioritised for upgrading using applicable KZN-DoT's prioritisation factors which are discussed in chapter 2.

KZN-DoT's methodology of selecting gravel roads to prioritise for upgrade using the traffic baseline of 200 vpd might be theoretical correct as past research mention that this is the right decision point to prioritise gravel roads for upgrading. However, the researcher argues that this cannot be the only criteria to use when selecting gravel roads for upgrade prioritisation. Gravel road's performance is influenced by several factors and not only traffic.

1.1.3 Research significance

This study investigated the KZN-DoT's prioritisation model of upgrading gravel roads to paved with the aim to identify gaps within the model and recommend for its refinement where required.

Gravel roads are sensitive to traffic and climate and their performance rely on gravel material's quality and properties, gravel road construction standard and the topography of where they are located. As gravel roads differ in factors mentioned above their behaviour and performance also differs. It then becomes necessary to study each roads behaviour based on the key factors that affect gravel roads. However, when considering the road network size that the KZN-DoT is responsible for, it becomes impractical to closely monitor how each gravel road deteriorates or perform. Gravel roads' performance are largely influenced by geotechnical properties of material (Paige-Green 1989: 4.55). Gravel road's performance is linked to how and at what rate it deteriorates. Amongst other defects that gravel roads experience, the gravel loss is the most critical one in quantifying re-gravelling frequencies and costs over a period of years. Then based on how much a gravel road costs over a certain period as opposed to upgrade it to a paved surface, a decision to upgrade it can be justified.

This research highlighted critical factors which are commonly observed and considered when prioritising for gravel roads upgrade. It then assessed and identified gaps in the KZN-DoT's prioritisation model and recommended for its enhancement based on identified gaps. A gravel loss study was also conducted by the researcher on selected KZN-DoT's gravel roads to observe deterioration pattern of gravel roads based on material, traffic, climate, and terrain. This research provides conclusions on when to upgrade a gravel road based on research findings and results informed by experimental research and literature reviewed.

1.2 Research aim and objectives

The aim of this research is to investigate prioritisation model for upgrade of gravel roads to paved standard implemented by KZN-DoT.

The following are research objectives:

1. To determine the right time to upgrade a gravel road to paved surface.
2. Assess the baseline traffic for gravel road upgrade to paved surface.
3. Identify additional factors that enhances the KZN-DoT model for prioritisation of gravel road upgrade.

The plan was to address the following research questions to achieve the research aim and objectives mentioned above:

1. When to upgrade a gravel road?
2. Is the KZN-DoT's traffic baseline for selecting gravel roads to be prioritised for upgrade ideal?
3. Are there any additional prioritisation factors that need to be considered in the KZN-DoT's prioritisation model for gravel roads upgrade?
4. Is the KZN-DoT's methodology of prioritising gravel roads upgrade ideal?

1.3 Research methodology

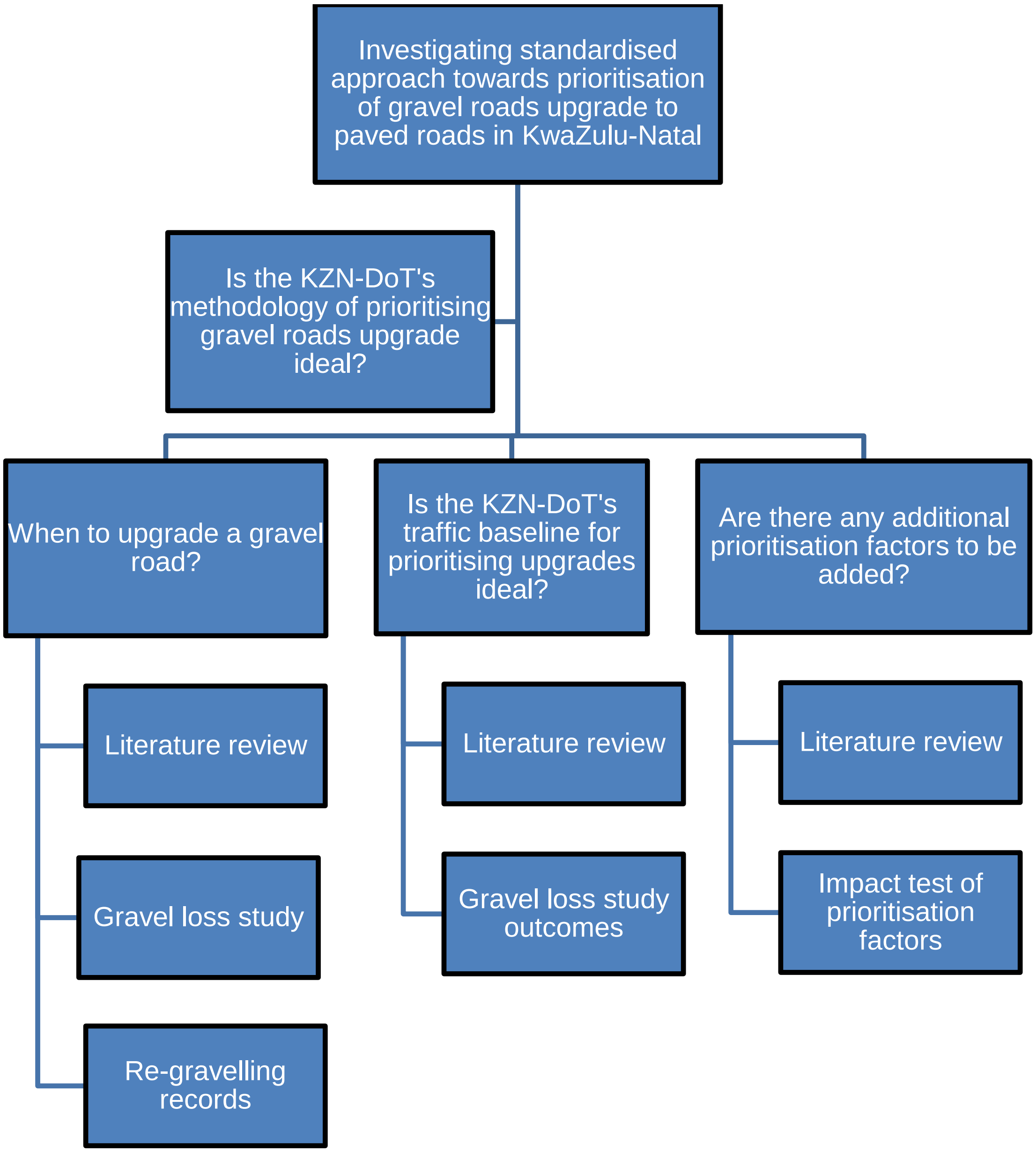
This study adopted a mixed research methodology comprising of both qualitative and quantitative research methods to investigate research outcomes. The research questions (RQ) of this study required different research methods. The following research methods were used in this study to investigate outcomes of each RQ listed below:

1. When to upgrade a gravel road? – The research outcome of this RQ was reached through the review of the existing literature concerned. The literature specified factors to consider in evaluating the right time to upgrade a gravel road i.e., traffic baseline, economic analysis and gravel road performance. The research outcome of this RQ was also reached through analysing experimental data of the GL study that was conducted by the researcher and through observational analysis of re-gravelling records of respective monitoring sections. The research methodology followed to reach the conclusion on this RQ was mixed. It followed both qualitative and quantitative research approaches in the form of existing literature review, experimental and observatory research respectively.
2. Is the KZN-DoT’s traffic baseline for selecting gravel roads to be prioritised for upgrade ideal? – The research method followed in reaching the conclusion on this RQ was a mixed-method comprising of literature review and outcomes of the experimental research of GL. The research approach of this RQ included both qualitative and quantitative approaches. Research outcomes of RQ 1 also addressed this RQ and so this RQ is discussed jointly with RQ 1 in all the chapters of this dissertation.
3. Are there any additional prioritisation factors that need to be considered in the KZN-DoT’s prioritisation model for gravel roads upgrade? – A qualitative research method through a review of existing literature was engaged for the purpose of identifying gaps and recommend additional factors.

Is the KZN-DoT’s methodology of prioritising gravel roads upgrade ideal? – The research outcome of this RQ was reached through analysing all the above three RQs, and so the research methodology followed to reach the conclusion on this RQ was a mixed one using all research methods mentioned from item 1 to 3 above.

Further details on research methodology and design used to reach conclusions on this study are discussed on Chapter 3 of this dissertation. Provided below is the research flow chart.

Research flow chart



1.4 Research scope and limitations

The geographical limitation of this research is within the boundaries of the province of KwaZulu-Natal, which is situated in South Africa. All site surveys for this research were undertaken within the KwaZulu-Natal Provincial Road Network and all the material testing performed for this study was conducted using samples of material obtained from the provincial road network of KwaZulu-Natal. The term, Provincial Road Network, used in this research, refers to the road network that the KwaZulu-Natal Department of Transport is responsible for constructing, upgrading, and maintaining, and this excludes the province's municipal road network as well as the national one.

Road authorities are encouraged to develop their own gravel road performance monitoring systems to assess the behaviour and deterioration trends of each gravel road within their road network and in turn determine the right time to upgrade a gravel road to paved standard using the outcomes of their gravel road deterioration models. The outcomes and findings of this research on the validation of the KZN-DOT's prioritisation model for upgrading gravel roads to paved should be used as a guideline when road authorities are attempting to develop a project prioritisation model for the upgrading of gravel roads to paved standard.

In this research the KZN-DoT's prioritisation model of upgrading gravel roads to paved was investigated by the researcher with the aim to identify gaps in the prioritisation factors considered by KZN-DoT. The researcher also evaluated the appropriateness of the KZN-DoT's traffic baseline being used to select gravel roads to prioritise for upgrading to paved. In addition, the researcher discusses the findings of the gravel loss study which was conducted by the researcher for the KZN-DoT, and then the researcher analyses the results and recommends for enhancement of the KZN-DoT prioritisation model where necessary.

Gravel road performance studies that are normally performed are roughness and gravel loss studies. The focus of this research was only on the gravel loss one, which is extensively discussed in the following chapters. Gravel road roughness is another indicator of how a gravel road performs. However, it affects road users and their cost. Although roughness is part of road performance studies, it does not significantly affect the decision of when to upgrade a gravel road in as much as the gravel loss one does. The more the gravel is lost on a gravel road the lesser is the frequency to maintain it and the more a road agency invests funds to maintain it. Whereas a gravel road can be rough whilst having adequate gravel material. Roughness on a gravel road can easily be solved by rip and blade or rip and recompact without having to haul additional gravel material from quarries. On the other side gravel loss requires re-gravelling which is too costly.

Literature on economic analysis of justifying the need to upgrade a gravel road to paved is discussed extensively in the next chapter. However, this study did not include such analysis in any of the KZN-DoT gravel roads but has instead provided guidance and recommendations on how KZN-DoT and other stakeholders can perform economic analysis when prioritising gravel roads for upgrading to paved.

For gravel loss study, sections with intersections were excluded to form part of the experimental length due to their influence on high gravel loss rate resulting from vehicles' turning movements on intersections.

1.5 Overview and organisation of chapters

The chapters of this dissertation are as follows:

Chapter 1: INTRODUCTION

This chapter discusses the problem statement, research aim and objectives as well as the scope and limitation of the study. It also gives a brief overview of the KZN-DoT's project prioritisation model of upgrading gravel roads to paved roads and discusses the significance of this research.

Chapter 2: LITERATURE REVIEW

This chapter covers relevant literature that has been reviewed to address the research questions. It also leads to the gap in literature that this research fills.

Chapter 3: METHODOLOGY

This chapter discusses research design and methodology used in addressing research questions, aim and objectives.

Chapter 4: DATA ANALYSIS AND FINDINGS

This chapter presents research obtained data, findings in tables and figures, and then the discussions on findings.

Chapter 5: CONCLUSIONS AND RECOMMENDATIONS

This chapter proposes actions to be taken by interested parties, proposes future research, and presents the conclusion based on the research findings.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews existing literature that has been developed in the field of gravel road performance management and discusses in detail two key subjects that are of great importance in determining the right time to upgrade a gravel road to paved standard, which are economic analyses of paving a gravel road versus retaining it as well as common practices being used to assess the GWC performance in terms of gravel loss. Guidelines on how economic analysis should be tackled when assessing the economic viability of upgrading a gravel road to be paved are discussed, as well as some of the gravel road performance studies that have been carried out to date. Gravel road performance studies being reviewed in this chapter are those that are related to gravel loss. Later in this chapter, the relevant literature in terms of prioritisation factors that are being considered world-wide when planning to upgrade a gravel road to paved standard, as well as the theory related to the approach being used when prioritising, are discussed.

2.2 An ideal time to pave a gravel road

An ideal time to upgrade a gravel road to paved standard is informed by several factors. One of the most critical prioritisation factors, which should serve as a final screening method in shortlisting the top-ranking gravel road segments, is the benefit-cost factor The interpretation of what this factor entails varies; however, there are common variables that are being considered under it. Those variables are agency costs, road user costs, environmental and social cost Committee of State Road Authorities (1990: 7) (Draft TRH20) states that “many problems occur in the economic analysis of unpaved roads in comparison with paved roads. Unpaved roads require continual maintenance, and their condition can be significantly affected by period of excessive traffic volumes or inclement weather. The accurate estimation of maintenance costs is therefore difficult. Other aspects such as expressing the effects of dust in residential areas, effects of the economic stimulation of an area through improved roads to a developing area are difficult to consider in economic analyses." According to Paige-Green (1989: 19) "the major costs involved in unpaved roads are the initial construction cost, the routine maintenance costs and the road user costs, their sum being total costs. The accurate quantification of these costs is often difficult as they are generally not accounted for individually."

The agency costs are the costs to the company, which in the context of road asset management simply refers to the capital cost of constructing a road asset as well as the cost of maintaining it over a certain period.

The road user costs are the expenses for the road users generated by using a road. Road user costs are directly affected by the road condition; for example, when a road's riding quality is poor due to roughness and other defects, it affects travel time and fuel of the road user and might even cause damage to the vehicles using the road.

Generally, in the context of evaluating the worth of upgrading a gravel road, economic analysis is performed to assess the cost-benefit of maintaining a gravel road versus that of upgrading it. More details about economic analysis are covered in the next section.

Gravel road performance studies are being conducted to investigate the performance of gravel roads within a road network to monitor each road's deterioration pattern as well as their maintenance frequency. This then assists the road managers to plan for maintenance and timeously project the required maintenance budget. The details of maintenance and budget required on each road then assist the planners to perform an economic analysis of upgrading a gravel road versus keeping it in its gravel state. Gravel road performance studies that are normally performed are roughness and gravel loss studies. The focus of this research was only on gravel loss one, which is extensively discussed in the following chapters. Roughness is another form of gravel road defect which indicates how the road performs. Roughness affects the level of service of a gravel road. It directly affects the travel speed and vehicle operating costs i.e., fuel, time, and vehicle tyres. Gravel road roughness can be caused by poor road construction practices, i.e., flat road profile resulting in potholes, lack of adequate maintenance, non-compliance to the recommended aggregate sizes for GWC layer and unsuitable gravel road material. Paterson (1991: 2) mentioned that "unpaved roads develop roughness through deformations by shear, mechanical disintegration, and erosion of the surfacing material, caused by traffic and surface water runoff". According to Committee of State Road Authorities (1990: 29) (Draft TRH20, 1990) the major controllable factor affecting the vehicle operating cost is the road roughness. Although roughness is part of road performance studies, it does not significantly affect the decision of when to upgrade a gravel road in as much as the gravel loss does. Figure 2.1 shows factors that determine the right time to upgrade a gravel road to paved standard.

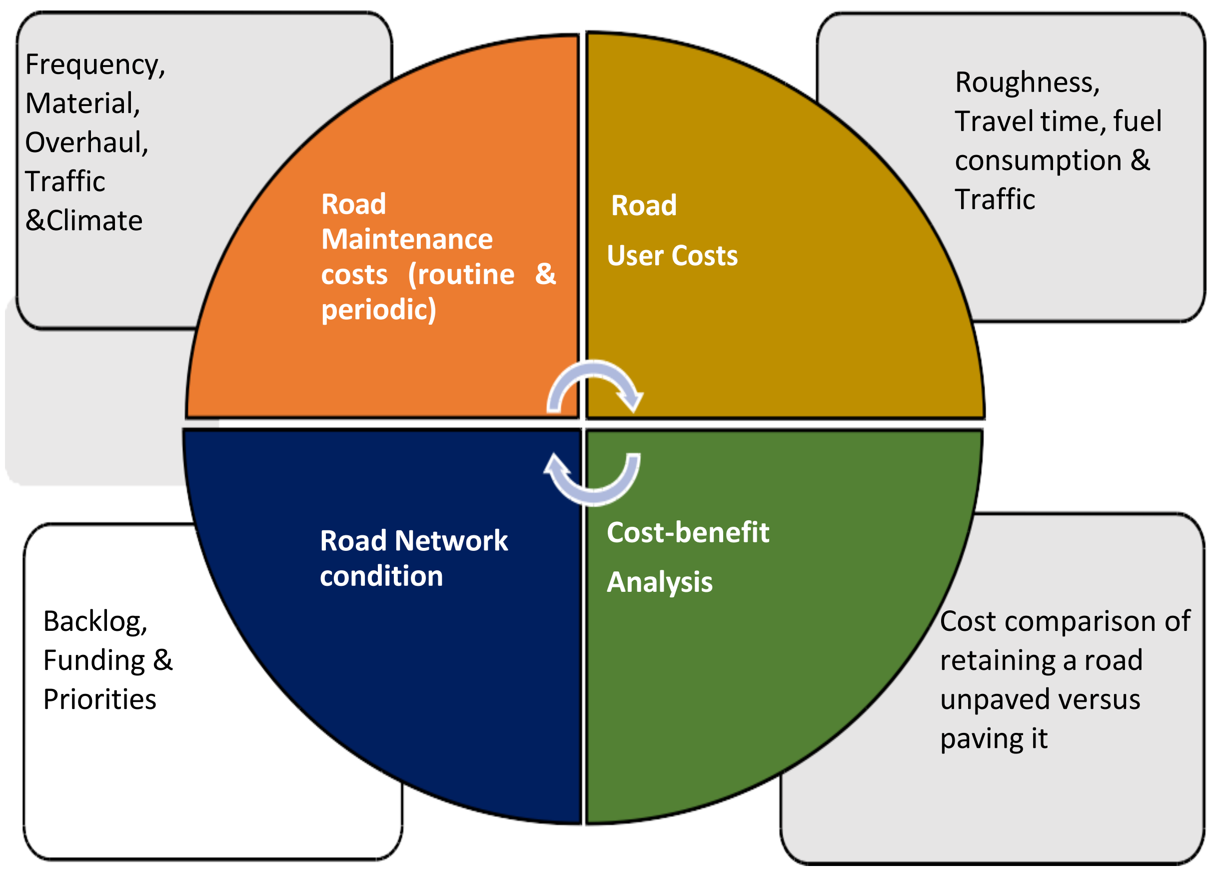


Figure 2.1 Determining cost factors for upgrading gravel roads
Ndlovu *et al*. 2018, 2018 SARF/IRF/PIARC Regional Conference for Africa

2.2.1 Gravel roads performance and related studies

2.2.1.1 Gravel roads

Gravel road definition was discussed under Chapter 1 of this dissertation. Characteristics of a good gravel wearing coarse (GWC) material have been covered extensively in many studies related to gravel roads' performance and they can be summarised as follows, should:

- Have an adequate bearing capacity.
- Be of a low permeable material.
- Provide a smooth and safe riding quality.
- Be resistant to erosion.
- Be resistant to abrasion by traffic.

Since these types of roads are exposed to the environment as they are not sealed with an impermeable pavement layer, they experience the loss of gravel material due to traffic and climate conditions. Construction costs of gravel roads vary and are dependent on each gravel road's intended use and other factors, and their maintenance costs depend on local available road materials' quality, their geographic location, road geometry, climate conditions, as well as traffic volume within each road. According to Weinert (1980: 19), the design and method of construction must take into account the environment in which the road is located as that has a great impact on its life and performance.

In most cases, little attention is given to gravel roads when they are being constructed and low specifications are prescribed for them as opposed to those of paved roads. The quality of local available gravel material that is suitable for road construction, as well as the level of experience of the road construction and maintenance teams, including construction plant operators, play a significant role in ensuring a well-constructed and maintained gravel road that has a durable GWC. Unfortunately, not all gravel quarries and borrow-pits within the country have good gravel material that is suitable for construction of a GWC layer. According to Weinert (1980: i), the cost and material content of a road are largely determined by naturally occurring materials such as rock and soil. Deploying a gravel material of low quality as a GWC often leads to the need to maintain a gravel road more frequently than is the case if the gravel material is of good quality. This then results in high maintenance costs over time.

2.2.1.2 Suitable Gravel Roads Construction Materials

Weinert (1980: 64) mentioned that soil is derived from the weathering of rocks and that rock is the primary source of natural road building materials. A discussion of some of the characteristics of rocks that determine their suitability for road construction is necessary. Construction materials have properties that depend primarily on the mineral composition of the rock and secondarily on its size, shape, arrangement, and bonding between the minerals. Paige-Green (1989: iii) stated that a good knowledge of the geotechnical properties of potential wearing course material, which are significantly dependent on the geological origin, is necessary to differentiate good gravels from poor ones. Further to that the material factor (f) depends on those properties of the material such as plasticity, particle size distribution, particle strength, clay mineralogy and in-situ density. According to Van Zyl et al. (2003) constructing wearing courses with suitable materials to high density and ensuring a proper shape and drainage result in a slower rate of initial deterioration than predicted by existing models.

2.2.1.3 Gravel Roads Surface Distresses

Gravel roads are sensitive to both climate and traffic. Surface distress on gravel roads is linked to GWC material properties, local climate conditions, traffic and road terrain. The properties of a GWC material is determined by its plasticity index (PI), its particle size distribution and its load bearing capacity. Climate influences the rate at which GWC loses its material, and this occurs through rain and wind. The rate of loss of fine particles due to rain is dependent on the road geometry, its terrain, rain intensity and the ability of the GWC material to resist erosion. Whereas the rate of loss of fine particles due to wind is largely influenced by vehicle speeds, lack of adequate moisture within a GWC layer and ability of the GWC to resist disintegration from wind. Traffic-induced loads can cause GWC material to disintegrate rapidly if its bearing capacity is inadequate.

There are several surface distresses that gravel roads experience and the Committee of State Road Authorities (1990: 7) (Draft TRH20, 1990) covers most, if not all of them; the following are amongst the list:

- Erosion – occurs on steep or crossfall sections within a gravel road because of high intensity rainfall. GWC layer with erodible materials tend to experience high rate of gravel loss due to erosion. GWC material with less shear strength is easily erodible when subjected to high water flow over the road surface.
- Corrugations – occurs when fine particles of GWC are loss through dust. According to the Committee of State Road Authorities (1990) (Draft TRH20) materials with adequate plasticity were observed to form corrugation as the fines are lost.
- Gravel loss – Is the loss of GWC materials. The rate of gravel loss is dependent on traffic using the gravel road, climate of the area where gravel road is located, GWC material properties, road geometry i.e., crossfall and road terrain.
- Roughness – results from the loss of fine particles within a GWC layer. The gaps caused by the loss of fine particles then result in coarse particles pitching on the surface, which causes poor riding quality. Depending on the severity of roughness, remedial actions can vary from light grading by means of redistributing fine particles to fill the voids to ripping and reshaping of GWC by grader.
- Potholes – results from loss of fine material at the GWC surface, which then allows the larger gravel aggregate to form borders for water to pond.
- Dustiness – is caused when dry and fine material gets release from the gravel road surface by moving vehicles. The size of dust being released is dependant GWC material properties and the travel speed of the vehicle.

- Rutting – when a GWC has high clay content, it becomes impassable after a lengthy rain season and when vehicles drive over it pushes out muddy fine material, which results in material loss along the wheel path zone. Excessive loose material – the lack of moisture and materials with low plasticity on a GWC layer results in a weak bond between coarse and fine aggregates causing them to be easily erodible. Excessive loose material makes gravel roads unsafe since they become slippery. Loose materials also result in the edge build up, which pose problems on road drainage.
- Stoniness – when aggregates of larger than a recommended maximum size on the GWC i.e., larger than 37, 5 dominates on a gravel road, it becomes excessively stony. This results in rough gravel roads which cause long travel times and damage to tyres.
- Cracks – cracking of the GWC leads to the formation of potholes and is the result of the plasticity being too high. Materials that crack become slippery in wet weather.
- Ravelling – is loose gravel that generates under traffic and spread all over the road prism. When this loose gravel accumulates on the sides of the road it forms windrows and cause drains to block. Loose gravel on the roadway poses safety hazards to vehicles as loose gravel may damage vehicles and windscreens.
- Shape – When the cross-sectional shape of the road is poor i.e., too flat that water cannot drain properly towards the side drains, this results in water ponding and forming of potholes and other defects. Graders assist in reshaping roads and by maintaining crown and crossfall to ensure that roads drain properly.
- Slipperiness – unpaved (earth/gravel) roads surfaces become unsafe when they are slippery. Slipperiness occurs both under dry and wet weather condition. Slipperiness occurs when excessively fine particles or plastic materials are concentrated on top of the road surface.
- Impassibility – occurs when the earth road or GWC material becomes impassable due to weather conditions. This problem is common with earth roads where the in-situ materials are used. According to Committee of State Road Authority (1990) (Draft TRH20, 1990) the pass ability is a function of the shear strength in the top

layer of the wearing course. It is assumed that material with high strength in terms of CBR will provide a trafficable surface under all conditions.

According to Paterson (1991: 143), the following are several modes of deterioration that are important to consider when managing unpaved roads already in existence:

- The roughness of the road affects vehicle speeds and operating costs and can be addressed by managing blading maintenance so that operating costs are offset by blading costs; and
- The loss of surface material on gravel roads makes them susceptible to rutting under traffic and can result in a loss of passability in wet conditions, making it an important factor in determining when to re-gravel.

2.2.1.4 Gravel roads preventive maintenance

According to Mwaipungu and Allopi (2012: 472), A preventive maintenance (PM) strategy is a cost-effective way to preserve a gravel road pavement by preventing degradation before it occurs. PM is a low-cost treatment applied early in the deterioration cycle of a pavement. A pavement PM extends the pavement's service life and maintains its functional condition without substantially increasing its structural capacity. PM activities on gravel roads reduce water infiltration into the pavement structure by maintaining the cross sections and correcting non-load-related surface deficiencies. Researchers agree that PM lowers the life cycle cost of a pavement since applying PM delays re-gravelling maintenance on gravel roads. A reliable quantification of deterioration and maintenance effects are crucial for evaluating alternative maintenance strategies for unpaved roads. Frequency of maintenance blading and gravel resurfacing depends on the economic trade-off between maintenance costs and benefits to road users. (Paterson 1991: 143).

Blading of gravel roads can be defined as a routine maintenance intervention that addresses a gravel road’s surface roughness. According to Paterson (1991:148), it depends on the roughness before blading, the material properties, and the minimum roughness to determine the effectiveness of blading maintenance.

The minimum roughness of blading was found to depend on the material properties being lowest for fine materials and highest for coarse materials (Paterson 1991: 148).

2.2.1.5 Gravel loss

The two main distresses which characterise the deteriorations of a gravel road`s pavement are gravel loss and roughness (Mwaipungu 2015: 5). According to Van Wijk et al. (2019: 737), the most important parameter to predict in the management of gravel roads is gravel loss. Paige-Green (1989: 127) mentioned that the factors affecting the formation of ruts are basically like those influencing the GL. The initial gravel loss and the roughness will normally increase through shear, mechanical disintegration, and erosion of the surface materials caused by traffic, wind and rainwater runoff (Mwaipungu 2015: 5). According to Paige-Green (1989: 66) the GL surveys determine the average change in height of the surface of the levelled section with respect to a set of benchmarks. Henning et al. (2008: 74) mentioned that there are several methods to describe the GL quantity, which includes GL measurements expressed as a total volume loss or as an average height-loss.

During the design, construction, and maintenance phases of a project, it would be helpful to know the variation rate of GL as captured by GLPMs. As a result of this knowledge, gravel roads and gravel materials B/P can also be conserved in the most appropriate way (Mwaipungu and Allopi 2012: 471). The rate at which gravel is lost depends on the material properties, the climate, and the traffic volume. The variability of the material properties within any one material group would also influence the GL. The annual loss, however, increases significantly as traffic increases or material quality deteriorates (Mwaipungu 2015: 170). According to Henning et al. (2008: 17) the deterioration of unsealed roads is mainly due to traffic loading, especially heavy vehicles and climatic conditions. It is likely that the more the material is resistant to ravelling the more it is likely to lose gravel at a higher rate. According to Mwaipungu and Allopi (2012: 5) the vertical grade above 6% on gravel roads results in gravel loss when interfering with rainwater. The factors influencing GL can be divided into five categories, namely (Mwaipungu and Allopi 2012: 472):

i. Road surface distress,
ii. Traffic,
iii. Environmental and types of terrain,
iv. Road geometry and drainage, and
v. Vehicle characteristics.

According to Paige-Green (2017: 54), there will normally be a 50 m long GL monitoring section on a flat and level section of road without culverts or cross-drainage structures, and the section should fit within the trafficked section of road.

2.2.1.6 Gravel Loss Prediction (GLP)

GLP is the process of estimating the rate at which the gravel wearing course will lose its gravel thickness over a certain period. This process requires road authorities to assess their gravel roads closely by conducting surveys on different sections of gravel roads to establish the rate of gravel loss and, in turn, be able to predict future gravel losses. According to Paige-Green (1989: 28) the prediction of the expected GL is of utmost importance for both unpaved road design and maintenance planning as the gravelling and re-gravelling operations are the most expensive construction and maintenance procedures. Reducing re-gravelling frequencies to optimum level through predicting the gravel loss as threshold for optimal maintenance interventions is required (Adewole 2013: 34). According to Paige-Green (2017: 17), the rate of loss of gravel from unpaved roads under traffic and climatic conditions is a function of many factors, including climate, pavement shape, traffic, material properties and construction quality, and varies from a few mm per year to 40 or 50 mm per year.

According to Paige-Green (1989: 129) the geotechnical properties i.e., particle size distribution and plasticity in particular influence the performance of the materials significantly. The grading and plasticity are related almost entirely to the geological composition of the parent rock (Paige-Green 1989: 173).

2.2.1.7 Gravel Loss Prediction Models (GLPM)

A gravel loss prediction model predicts gravel material performance based on distress-specific variables (Mwaipungu 2015: 44). A GLPM has been regarded as one of the critical tools in the management of gravel roads. It monitors the rate at which GWC loses its gravel by predicting a change in the gravel layer depth (mm) over a specified period of analysis. According to Mwaipungu (2015: ii), a gravel loss prediction model cannot easily be transferred from one geographical location to another, particularly if the locations differ in climatic conditions, gravel material characteristics, construction and maintenance quality, terrain, traffic characteristics, and driving behaviours. He added that existing international gravel loss prediction models lack the capability to address the local characteristics when used locally, resulting in inaccurate predictions.

The latter is the main reason for countries to develop a GLP model suitable for their local conditions. The authors of various articles on gravel road performance agree that most existing international gravel road loss prediction models cannot account for intangible characteristics of the locality and do not cope with climate and material variability. (Mwaipungu 2015: 13). In order to predict future road conditions and provide information on how roads perform, performance modelling of gravel roads is required (Adewole 2013: 21). The GLPM can be used to evaluate the effects of different wearing courses on unsealed roads, thereby providing valuable input to unsealed road design and management (Van Wijk et al. 2019: 737).

According to Mwaipungu and Allopi (2012: 476), GLPMs are the basis for establishing a cost-optimised grading cycle that is economically viable. Mwaipungu and Allopi (2012:11) mentioned that the effectiveness of deterioration prediction models, therefore, must be quantified not only using traffic data, but also considering road geometry, material properties, climate, and the level of maintenance. A GLPM is effective when accompanied by an effective gravel road maintenance management system; otherwise, as the gravel wearing course is progressively reduced in thickness, other defect developments such as the formation of ruts and erosion gullies will accelerate the gravel loss beyond the model's predictive capacity (Mwaipungu 2015: 202).

2.2.1.8 Setting out GL monitoring sections.

According to Paige-Green (2017: 6), each experimental section must be clearly identified with some sort of permanent marking (sign boards or roadside cairns), as well as recording of the GPS coordinates of the start and end points and any important points within the section.

Mwaipungu (2015: 97) mentioned that setting out of the monitored test section was accomplished through the installation of the reference benchmarks, and the installation of the monitoring pegs. Each monitored test section was based on a localised referencing system, where a height was allocated to the first reference benchmark, and the heights were determined for the rest of the reference benchmarks and monitored pegs. Three reference benchmarks were installed as a safeguard against missing or damaged pegs. Twelve pegs were installed per monitored test section at twenty metre intervals.

According to Paige-Green (2017: 54) a GL monitoring section will normally be 50 m long, on a flat and level section of road with no culverts or cross-drainage structures and should fit within the trafficked portion of the carriageway. The benchmarks should be placed at each end of the section and at least 3 should be installed, and preferably in the road and placed such that they are unlikely to be affected by subgrade movements.

2.2.1.9 Measurement of GL

According to Paige-Green (2017: 54) the loss of gravel from unpaved roads is an essential part of investigation of innovative materials or construction techniques. Numerous techniques ranging from the incorporation of metallic sensors, the excavation of holes, etc.., have been used in attempting to quantify GL. However, only precise levelling surveys have been found to be sufficiently accurate for research and monitoring purposes.

According to Paige-Green (2017: 17), GL measurements are complicated and time-consuming and there is no simple method that is accurate enough to obtain useful readings within a reasonable period. Methods, for example, using dips from string lines at fixed points, have generally proved to be insufficiently accurate. The standard method of measuring GL is by using precise levelling surveys of a carefully demarcated section of the road and relating the average height of this section of the road to a few stable benchmarks over an extended period. The actual measurement points at each monitoring should be as close to the previous monitoring as possible. This is usually best done using two tape measures, one laterally across the road and one longitudinally down the road, zeroed at fixed points (Paige-Green 2017: 18). According to Mwaipungu (2015: 95), there are different methods to describe the gravel loss quantity, including:

i. Each cross-section of the measurement can be expressed as a total area, thus allowing a total volume loss calculation.
ii. Taking the measurement at a point and calculating an average height loss.

Van Wijk et al. (2019: 737) assessed the origins, input parameters, and output of four available GL prediction models, namely, the Transport and Road Research, HDM-4, Australian and South African models, found that the accuracy of predicting is in general low amongst the models, and they predict very different GL results (Van Wijk et al. 2019: 737). From the latter, it can be concluded that there is no 100% accurate approach to determine GL on gravel roads.

The process of GL measurement involves comparing the average height of a section of road over time with the height of fixed benchmarks. During monitoring, the heights of each of the benchmarks should be determined and checked against the previous heights to ensure that there has been no movement relative to each other. Van Zyl et al. (2003: 7) stated that their method of measuring GL varied from precise levelling to dips taken from a referenced stringline.

Based on similar studies reviewed below, the frequency of measuring the gravel loss on respective predetermined monitoring test sections vary from three to twelve months. On a study carried out by Van Zyl et al. (2003: 7) GL was measured at seven cross section positions at 20 m intervals of 100 m monitoring section every three months for a duration of twelve months. Yadav et al. (2018: 10) state that for GL determination on their study, 60 m long sections were divided into 10m intervals, and the GL was measured in six months interval. Then Paige-Green (1989: 55) had 50 m long GL measurement sections, and at every six months a GL levelling survey was carried out on each section. Henning et al. (2008: 68) mentioned that their GL surveys were undertaken seven times at six-monthly periods.

Most recently performed gravel loss surveys have been undertaken over a period not exceeding twelve months in total with the GL readings being taken every six months on fixed positions across predetermined monitoring test sections. One of the longest GL studies was undertaken during the 1980s in Southern Africa by Paige-Green (1989) and it was undertaken over a period of seven years.

2.2.1.10 Material sampling and testing

According to Paige-Green (2017: 41), it is up to the researcher carrying out the experiments to define which tests are necessary and how many should be done.

i. The Testing Laboratory

According to Paige-Green (2017: 41), every type of experimental investigation will require high quality laboratory testing. The requirements depend on the materials and the intent of the investigation. A unique testing regime is necessary, whether the materials are subgrade soils and gravels, natural borrow materials, processed layer aggregates, surfacing chippings and bitumen, asphalt aggregates and binders, cemented materials or cementing agents.

According to the South African National Accreditation System (SANAS) (2020: 3) the Accreditation Act recognises SANAS as the only National Accreditation Body for the Republic of South Africa for conformity assessment, calibration, monitoring of Good Laboratory Practices. SANAS operates in accordance with the requirements, criteria, rules, and regulations as laid down in the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act No. 19 of 2006 (South African National Accreditation System 2020: 4). Organisations carrying out quality control and related activities are assessed and accredited by SANAS when they meet the expected competency standard as outlined under each applicable accreditation category of SANAS. This is done to ensure that the testing laboratory produce results of high quality. The plan for this study was to outsource a local SANAS accredited laboratory to undertake both material sampling and testing. This was planned to ensure that any appointed laboratory would well manage the number of samples to be tested and that the test results would be of high quality and acceptable. An attempt to outsource a SANAS accredited testing laboratory was made after compiling a technical specification for sampling and testing services. The specification for sampling and testing was compiled by the researcher in consultation with Department's materials senior engineer.

Due to a lengthy procurement process involved when procuring a service provider for a government entity, the procurement of the testing laboratory was unsuccessful. After months of trying and failing to secure service provider to conduct material sampling and testing, it was agreed that the services and testing will be undertaken internally in one of the Department’s laboratories located in Hluhluwe. Material testing was done under the auspice of a SANAS accredited agent.

2.2.1.11 Review of past gravel loss studies’ findings

The following were the findings of respective GL studies that the respective researchers reviewed:

i. This study by Paige-Green (1989) found that the particle size distribution and plasticity are the most important material properties. It also found that the rate of gravel loss is affected mainly by traffic and that an important overlying influence of the geotechnical properties is present. *Formulation and application of a Gravel Loss Model in management of gravel roads in the Iringa Region, Tanzania*

   This study by Mwaipungu (2015) formulated a locally statistically accurate GLPM for marginal gravel materials employed to surface gravel roads in the Iringa region. The study found need to change Gravel Co-efficient (GC) range from 12-34 to 23-72 inclusive for marginal materials. The reason for the recommendation in the change of GC range was that for materials that were part of the study and deviating to the original GC specification performed relatively well. The study also found that a modelling exercise can be performed locally by using variables obtained or derived from materials test results, such as consistency and particle size distribution. The study also found that the results of Grading Modulus (GM) for sampled gravel materials in the Iringa region have shown the GM of below 2.0 indicates that the dominate particle size distributions are fine, and above 2.0 are coarser.

ii. Use of Gravel Loss Prediction Models in the design and management of unsealed road pavements

On this study Van Wijk et al. (2019) reviewed the four widely used GL prediction models in the design and management of unsealed roads namely, the Transport and Road Research, HDM-4., Australian, and South African models. Furthermore, the study investigated whether material classification systems could be used as reliable indicators of GL by examining their relationship with predicted GL. The study found that the Australian and South African models have a strong correlation with the plastic factor and this correlation was used to develop re-gravelling frequencies based on traffic, climate, and plastic factor values. The study also found that there is no strong correlation between gravel loss and any of the soil classification systems.

2.2.2 Economic analysis of upgrading a gravel road

Past research including Kerali et al. (1991), Committee of State Road Authorities (1990), Namibia Roads Authority (2014) and Paige-Green (2017) recommend determining the viability of upgrading gravel roads based on their economic analysis. For economic analysis to be satisfactorily performed, road authorities need to have a proper gravel road management system (GRMS) in place to keep track of each gravel road’s performance throughout its lifecycle, as this helps in determining the frequency and cost of maintenance activities needed by each gravel road. According to Paterson (1991: 143), several economic analysis models can evaluate the trade-offs between different maintenance and construction policies by using models of roughness progression and gravel loss and further an analysis of the trends in roughness and thickness of surfacing material over time can provide insight into unpaved road deterioration and maintenance.

The maintenance frequency as well as capital costs of constructing a gravel road are used to calculate the cost of retaining a gravel road unpaved over a 10- or 20-year period. The same applies for the cost evaluation of the paved road option, and then the two are being compared to find an economically viable option.

The next sections cover the literature reviewed in terms of how economic analysis can be approached to determine whether it is economically viable to pave a gravel road or not. The section also gives a brief overview on models that are used to carry out economic analysis. As most gravel roads are low volume roads, a suitable tool for assessing economic viability on low-volume gravel roads is also discussed. The traffic benchmark used to classify a road as a low-volume road varies from one country to the other, but they generally carry a traffic volume of less than 400 vpd. According to Archondo-Callao (1999: 1), roads carrying traffic of less than 200 vpd are low volume roads, and according to Bijl and Corea (2017: 1), low volume roads carry a traffic of less than 300 vpd. According to Paige-Green (2017: 6), the total life-cycle costs include the construction, maintenance and operating costs, which all need to be monitored for the experimental section and then discounted over the analysis period.

2.2.2.1 An overview of existing economic analysis models

i. Roads Economic Decision Model (REDM)

RED is a software tool developed by the World Bank that performs economic analyses of road maintenance and investment options tailored to the characteristics of low-volume roads.

ii. HDM-III Model

The first step towards the development of fully integrated road investment appraisal models for developing countries was made by the World Bank in 1968 when a study was initiated to develop a system of evaluating the effects of construction and maintenance standards on road user costs for low volume roads (Pienaar et al. 2000:1).

In four large field studies conducted between 1973 and 1982, models for predicting road deterioration and vehicle operating costs were developed (Pienaar et al. 2000:1). According to Pienaar et al. (2000:2), in 1987, the World Bank developed HDM-III, a comprehensive model making use of:

- Kenya study: linked road deterioration with road user costs.
- Caribbean study: examined how road geometry affects vehicle operating costs.
- India study: analysed the operational problems of Indian roads in relation to narrow pavements and the high proportion of non-motorised traffic.
- Brazil study: extended the model relationships' validity.

According to Kerali et al. (1991: 35), HDM-III is used to calculate the annual transport costs for both alternative strategies. For example, if the present value of costs for a gravel road alternative exceeds that of a sealed road, a sealed road would be economically feasible under the given conditions because its total transport costs are lower.

iii. The HDM-4 Model

According to Pienaar et al. (2000: 2), when the decision was made to begin developing the HDM-4, the HDM-III contained technical relationships dating back over ten years. It was necessary to incorporate the results of the extensive research that had been conducted in the intervening period into the road deterioration models, despite the fact that much of the road deterioration models were still relevant (Pienaar et al. 2000: 2). A major improvement in vehicle technology after 1980 allowed typical vehicle operating costs to be significantly lower than those predicted by HDM-III models in terms of vehicle operating costs. As a result, an update of the technical relationships was recognised as necessary(Pienaar et al. 2000: 2).

HDM-4 is the World Bank's Highway Development and Management Model, developed by the International Study of Highway Development and Management Tools, and according to Archondo-Callao (1999: 1), it presents a good framework for evaluating road investments and maintenance, but is not specifically tailored to low-volume roads.

iv. Comparison of HDM III and HDM-4 Models

According to Pienaar et al. (2000:2), unlike HDM-III, which was focused on the economic analysis of projects, HDM-4 now also analyses road management plans and investment strategies. HDM-4 interfaces with external systems (e.g., road network information systems and pavement management systems) through the import and export of intermediate files (Pienaar et al. 2000:4). In addition to having a wider application than HDM-III, HDM-4 requires more input data than HDM-III (Pienaar, Visser and Dlamini 2000: 10). The HDM-4 provides an extensive range of upgrading options, pavement types, seals, and other maintenance options (Pienaar et al. 2000: 18).

2.2.2.2 Related studies and problems associated with economic analysis of low-volume gravel roads

According to Paterson (1991: 143), in order to evaluate alternative maintenance strategies for managing unpaved roads, deterioration and maintenance effects must be quantified accurately. Maintenance blading and gravel resurfacing frequency is determined by the economic trade-off between maintenance costs and the benefits of reducing road-user costs. (Paterson 1991: 1). The same applies when it comes to the economic break-even point for upgrading gravel roads for all-weather use (Paterson 1991: 143).

According to the Committee of State Road Authorities (1990: 7) (Draft TRH20, 1990), many problems occur in the economic analysis of unpaved roads in comparison with paved roads, as unpaved roads require continual maintenance and their condition can be significantly affected by periods of excessive traffic volumes or inclement weather, and the accurate estimation of maintenance costs is therefore difficult.

Committee of State Road Authorities (1990: 31) (Draft TRH20, 1990) reviewed a sub-programme of the World Bank HDM3 programme which was adapted for South African conditions, and which was found to be useful for the analysis of road user costs. The programme considers vehicle operating and travel time costs.

According to Kerali et al. (1991: 35), the break-even traffic levels i.e., 200 vpd are calculated by calculating and comparing their transport costs for different types of roads. (Kerali et al. 1991: 35).

According to the Namibia Roads Authority (2014: 2-1), the Highway Development and Management System Version 4 (HDM-4) has become the standard software for performing economic evaluations, and this software is not particularly well-suited to the low volume road economic evaluation, where the AADT is below approximately 200 vehicles per day. For this reason, an overview is given of a software tool, the Roads Economic Decision Model (REDM), an initiative developed by the World Bank specifically for this situation. Namibia Roads Authority (2014: 6-12) highlighted differences between the RED and HDM-4 model and mentions that RED has been customised for low volume roads and offers several advantages which are contrasted with HDM-4.

Archondo-Callao (1999: 1) states that a customised tool for evaluating the economic implications of developing and maintaining low-volume rural roads is lacking. He further mentions that the World Bank's Highway Design and Maintenance Standards Model (HDM-III) and the Highway Development and Management Model (HDM-4), provide an excellent framework for evaluating the economic impact of road investments and maintenance, but they are not specifically tailored to low-volume roads (traffic of less than 200 cars per day). The inputs required are impractical for low traffic levels, and they do not capture all the benefits associated with rural road investments. As a result, highway agencies responsible for low-volume roads require a simplified economic evaluation model to meet their planning and programming needs without requiring unrealistic or costly input parameters (Archondo-Callao 1999: 1).

According to Kerali et al. (1991: 40), by using the HDM-III model of the World Bank, one can determine the traffic levels at which converting pavement standards becomes economically feasible. Several analyses were conducted on the break-even traffic levels based on the climate, topography, and subgrade strength with the computer package incorporating the World Bank's HDM-III model. As a result of the analysis, upgrades from gravel to sealed roads have a very low break-even traffic level. This means that if traffic levels for paving a road exceed the break-even point, transportation costs will rapidly rise and sealing becomes economically justifiable (Kerali et al. 1991: 40).

The findings confirm the importance of sealing a road at an early stage.

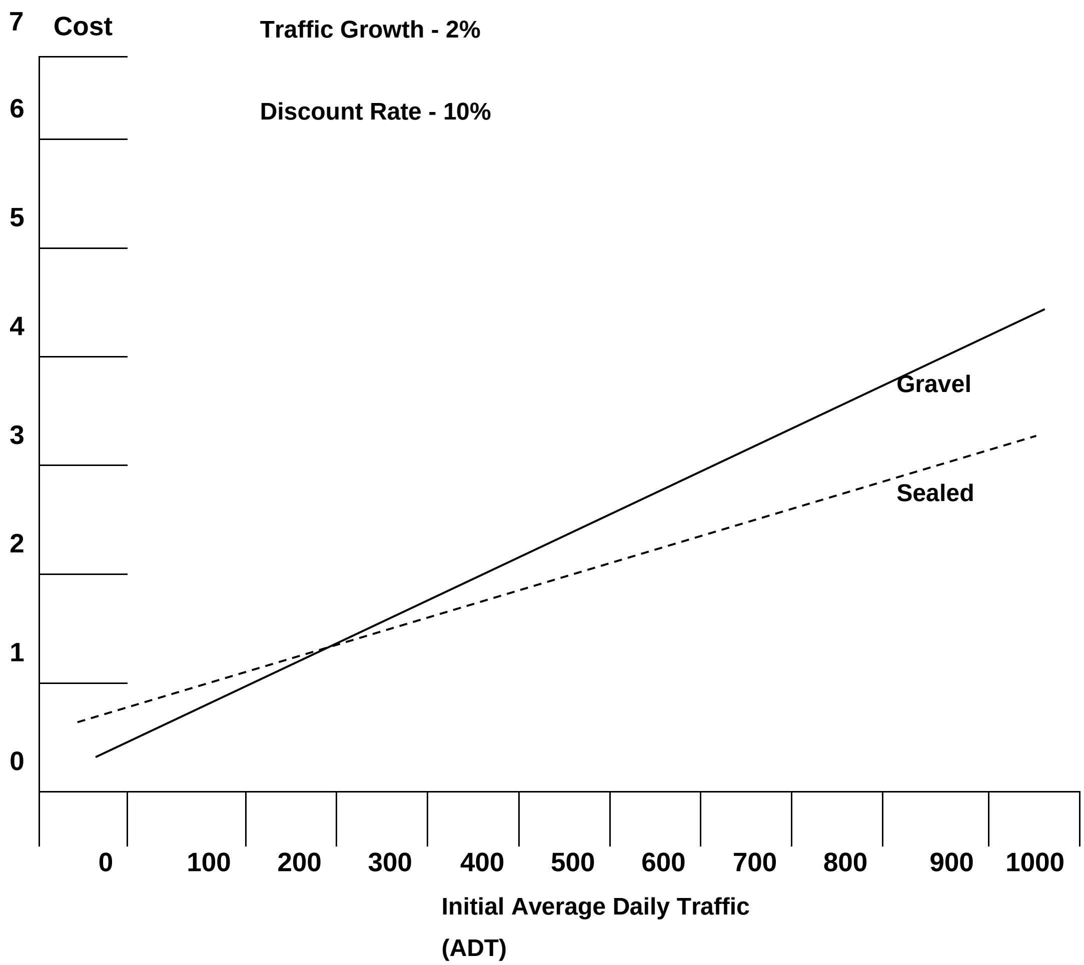


Figure 2.2 Relationship between total transport cost and traffic level
Adopted from Peterson (1991)

Luhr and McCullough's (1983: 26) found that an increase of traffic to more than 200 vpd will bring the total cost of the aggregate-surfaced road very close to the cost of the surface treatment and asphalt concrete pavements. Jahren et al. (2005) suggest that since most roads with more than 200 vehicles per day are paved, the recommendation is to seriously consider upgrading roads with that volume of traffic i.e., 200 vpd. According to their analysis, although paved roads are less expensive to maintain than gravel roads, this is still a good basis for justifying the necessary investment, and experience has shown that this is a satisfactory decision point. In addition to the above, they state that anecdotal evidence suggests that most government agencies have been able to finance improvements when traffic has reached these levels. In addition, they suggest that since incorporating gravel road upgrades into a construction plan often takes several years and since traffic volume is increasing, especially in urban fringe areas, it seems reasonable to start planning for the upgrade when the number of vehicles per day reaches 100.

2.2.2.3 Comparison of version 4 (HDM-4) and RED

According to Archondo-Callao (1999: 2), in RED, reduced transport costs are measured by assessing consumer surplus, which measures the benefits to road users and consumers. Archondo-Callao (1999: 2) further adds that in addition to simplifying the process, RED addresses the following additional concerns:

- ensuring reduction of the low volume input requirements road applications.
- resolving the higher level of uncertainty associated with the input requirements; andResolving concerns regarding assumptions made, especially the road condition assessment and the economic development forecast.

In addition to adopting the consumer surplus approach, HDM can also be used to evaluate low-volume roads, but it is not highly customised for this purpose and input requirements are higher (Archondo-Callao 1999: 2).

Both the afore-mentioned economic analysis tools were extensively discussed in the Namibian Road Authority Economic Evaluation Manual, which further highlighted advantages and disadvantages for each tool. The table below was extracted from the Namibian Road Authority Economic Evaluation Manual and highlights some of the advantages and disadvantages of each tool.

Table 2.1 Advantages and disadvantages of HDM-4 and RED

MODEL	ADVANTAGES	DISADVANTAGES
HDM-4	• Globally used model. • Extensive research on VOC and deterioration relationships. • Can be used for strategic planning i.e., can assess networks. • Now includes non-motorised traffic (NMT).	• High data requirements. • Does not include social benefits. Cannot deal with passability and trafficability issues. • Road roughness is often not an appropriate measure of condition for LVRs, the model is not well suited for low traffic levels.
RED	• Has limited data requirements. • Can accommodate NMT and some social benefits. • Can be run from a spreadsheet. • Can accommodate impassability issues. • Can be used for ranking projects. • Well suited for traffic levels in the range 50 to 200 vpd.	• NMT categories are limited to four. • Would have to be calibrated for low-volume sealed roads.

Namibia Roads Authority 2014

2.3 Factors and methodology for prioritising gravel roads upgrade

The prioritisation methodology and factors used to determine gravel roads that need to be upgraded to paved surface vary worldwide and from one road authority to another. Traffic count is one of the factors that is commonly considered by most road authorities. There seems to be no consistency in terms of the traffic baseline being used worldwide when selecting gravel roads to be prioritised for paving. The reasons for this, amongst others, could be the difference in terms of the gravel road network size when compared to other states/road authorities. Available road infrastructure funding also influences number of gravel roads being upgraded. Prevailing local conditions i.e., climate and material suitability differ per state or region.

2.3.1 Prioritisation factors and methodology

According to the Department of Transport and Public Works (2019: 14), the branch's strategic plan for its road assets is implemented through a planning approach and methodology rooted in asset management policies, strategies, and plans. Asset management policies serve as a link between an organisation's organisational plan and its asset management strategy. The goal of asset management is usually to achieve the organisational objectives by establishing a set of principles or guidelines.

For a road authority to accurately determine the right timing to upgrade an unpaved road, it has to have performance management tools in place to predict deterioration patterns (Ndlovu and Allopi 2021: 37). Most researchers recommend upgrading gravel roads to paved when the total transport cost of a road becomes high due to high traffic and the rapid deterioration rate of the road. Committee of State Road Authorities (1990: 32) (Draft TRH20, 1990) mentions that benefit-cost studies of the alternative strategies of retaining the unpaved road or upgrading it to an appropriate paved road should be carried out. According to Committee of State Road Authorities (1990: 32) (Draft TRH20, 1990), the total benefits of each upgrade option should then be compared. Among the benefits are reduced operating costs, improved safety and reduced time spent on the vehicle. Each alternative's benefits and costs are calculated based on the "economic cost" (i.e., excluding after-tax subsidies) and discounted over their expected design lives. For direct comparisons between the first and subsequent years, discounting is required. When comparing unpaved roads with paved roads, many problems arise. During adverse weather conditions or periods of excessive traffic, unpaved roads can be significantly affected requiring continuous maintenance to remain in good condition.

Historic and recent studies have emphasised the importance of assessing the GWC’s behaviour under different traffic and climatic conditions i.e., Paige-Green (1989) and Mwaipungu R.R. (2015). Past research i.e., Van Wijk et al. (2019), Paige-Green (1989) and Mwaipungu and Allopi (2012) recommend that the Gravel Loss Deterioration Model

(GLDM) be formulated and used by road authorities in making an informed decision as to when each gravel road should be upgraded.

Variations in terms of traffic baselines being considered world-wide for the selection of gravel roads to be paved is evidence that the decision to upgrade is most influenced by country/road authorities' strategies, which are dependent on the factors mentioned above.

According to Cole County Missouri Commission (2001: 1), the gravel roadway must meet minimum vehicular volume of 125 vpd or more for it to be considered for upgrade to paved.

According to the Livingstone Shire Council for Infrastructure Services (2017: 2), priority will be given to roads with higher than 150 vpd. Cole County Missouri Commission (2001: 2) also considers the functional classification of a gravel road, the amount of traffic using it, as well as its maintenance history/records, as some of the major factors for establishing gravel road priorities for their pave requirements.

In Dissanayake and Patel (2016) study, the primary objective was to develop standardised guidelines to identify the most suitable roadway surface for a particular roadway section with given conditions. The study aimed to assist decision makers in determining whether to convert a roadway surface from gravel to paved or vice versa, or to maintain the road in its present state. According to the study report, the wide variation in traffic volumes and the variations in local conditions and scenarios presented local agencies with a great challenge in determining the appropriate surface type for rural roads, especially considering budget constraints. A survey was then conducted to determine the factors affecting the choice of a road surface type, which later served as the basis for developing guidelines. Multi-criteria assessment was used to develop general guidelines. The key factors in decision-making with regards to paving were identified as agency cost, safety, vehicle operating cost (VOC), traffic volume, purpose of road usage, and public preference.

In the South African context, major developments in road projects' prioritisation and road asset management systems started as far back as in the early 80s. Even though respective studies in relation to both unpaved and paved road asset management were carried out within the country but were never performed throughout all its provinces. Paige-Green (1989) is amongst other well-known studies that were undertaken during that decade and led to the formulation of the gravel specification and gravel loss prediction model suitable for South African conditions. This resulted in the compilation of the Committee of State Road Authorities, 1990 (Draft TRH20, 1990) manual.

According to Paige-Green (1989) prior to 1989 study, South Africa used international calibrated models to predict gravel loss on the country's unpaved gravel roads. It must be noted, however, that the study had 110 monitoring test sections, which were only in the northern part of the country, formerly known as the Transvaal province, as well as in Namibia (Paige-Green 1989: 3.29). It is assumed that studies similar to his can still be undertaken in other provinces to test if the rate of GL and the roughness prediction of the model is suitable for their local conditions since the climate and material types vary within the country. Van Zyl et al. (2003: 2) mentioned that road authorities in South Africa are generally satisfied with the roughness deterioration models and gravel loss models described in Committee of State Road Authorities, 1990 (Draft TRH20, 1990) and have implemented these in local road management systems to prioritise remedial actions and evaluate the cost effectiveness of upgrading to surfaced standards. Van Zyl et al. (2003: 2) further added that investigation into the performance models and their personal communications with the authors of Committee of State Road Authorities, 1990 (Draft TRH20, 1990) revealed that the road sections, on which the performance study were based were not constructed to specific standards. Apart from the model being highly sensitive to certain parameters, the Committee of State Road Authorities, 1990s roughness deterioration model shows variable sensitivity in the midrange of several parameters, for example, traffic (Van Zyl et al. 2003: 5). A similar trend is found when analysing gravel loss. The results of the sensitivity analysis confirm that traffic and climate are the major uncontrollable parameters influencing the performance model. Gravel road performance is sensitive to vehicle type distribution and not only to the number of vehicles per day travelling on that gravel road (Van Zyl et al. (2003: 10). Henning et al. (2008: 17) also mentioned that gravel roads' deterioration is mainly affected by the heavy vehicles than is by the number of vehicles travelling on that road.

According to Macioszek (2019: 1) heavy vehicles within the traffic stream significantly reduces traffic capacity, which move at a lower speed when compared to passenger cars. Further to that they occupy more space on the road and put greater pressure on the road surface. The traffic stream comprising of a mixed composition is converted from mixed vehicle types into passenger car equivalents (PCE). For the conversion exercise, PCE factors appropriate for a given group of vehicles are used. PCE conversion values vary from one country to another. The reason being that the vehicle type lengths are not always of the same unit length whereas, the PCE conversion factors are based on the unit length of each vehicle type as opposed to a passenger car length.

The Western Cape Government branch has been one of the most active branches within the country in terms of the formulation of gravel road management strategies and the advancement of established theory in the gravel road management area of study. The following is the list of other significant contributions and studies made by the Department of Transport and Public Works in Western Cape as far as the historical development in road management systems is concerned:

In 1980, when the historical development of road management systems was put in place, the Cape Provincial Administration's Department of Roads recognised that formal procedures were necessary for developing maintenance strategies and policies based on objective data, as well as identifying and prioritising rehabilitation and resealing projects. (Department of Transport and Public Works 2019: 22). Over the past 30 years, the preservation strategy of the branch has defined and refined this approach to asset management. The Pavement Management System (PMS) was initiated in 1981 with the help of the Council for Scientific and Industrial Research (CSIR) and was developed and enhanced in-house with the assistance of consulting engineers. PMS supports decision-making at the strategic level, as well as providing a repository of information on pavement structures as they are built. A PMS can provide functional and structural condition reports. This system identifies candidate resealing projects and prioritises resealing projects. The Gravel Roads Management System (GRMS) was developed in 1989 to expand the scope of the PMS to include unpaved gravel roads. According to, this new system was implemented and managed by a team of consulting engineers, and it provides data on GWCs, visual surveys, and dynamic cone penetrometers (DCPs).

October (2016: 102), mentioned in his paper, which looked at the issue of limited resources and the need for optimization within an asset-management and lifecycle-costing context, that a Decision Support Process for the upgrading of roads in the Western Cape has become essential given the scarcity of suitable gravel materials, road infrastructure backlog conditions and budgetary constraints. He further mentioned that this leads to a description of the Deighton Total Infrastructure Management System, which is used to develop the Road Network Preservation Model for determining the sustainability of the road assets, which summarises the impacts of the preservation model across all road programmes and highlights the current trends specific to gravel road maintenance and gravel road upgrade programmes.

Henderson and Van Zyl (2017: 3) mentioned that with limited resources, the Road Network Management Branch of the Western Cape struggles to maintain and provide a safe and economical road network. They further mentioned that with the unpaved network's poor state, it is imperative that the branch utilises its available funds in the most efficient and effective manner possible. The issue of road infrastructure budget constraints is a country-wide problem since the existing road network extent far exceeds available maintenance funds. This then leads to a maintenance backlog. According to Futshane and Vezi (2015: 65), most of the district municipalities within the country were allocated equal funds during the 2011-2012 financial year. The equal allocation was due to the non-availability of road network information, which made it hard to quantify maintenance backlogs. According to COTO Road Asset Management Sub-Committee (2012) minutes, the Provisional Road Maintenance Grant (PRMG) requirements were subject to revision based on the revised allocation criteria from 2013/2014 onwards. The members of the COTO Road Asset Management Sub-Committee (2012) had a discussion regarding the PRMG allocation criteria. They agreed that it was to be based on the extent of the provincial road network, the traffic volumes, the visual condition indices on the network and geo-climatic and topographic factors. Committee of State Road Authorities (1994) (TRH22, 1994) and Committee of Transport Officials (2013) (TMH22, 2013) provide guidance and methodologies on how the road infrastructure assets should be managed within South Africa. They both set a framework on how road networks should be managed, and how its condition data can be used to identify and prioritise projects.

2.4 KZN-DoT project prioritisation model for the upgrading of gravel roads

The KZN-DoT's developed model of prioritising gravel roads needing to be upgraded to paved standard provides for the comparison and ranking of the gravel road segments using the relevant selected prioritisation factors. The KZN-DoT's project prioritisation system is GIS-based and uses spatial data to assess and compare competing gravel road segments (Department of Transport Project Planning Framework 2018: 3). Each prioritisation factor is represented as a separate GIS shape file layer. These factors were carefully selected to ensure that the KZN-DoT's project priorities align with national and provincial strategies. Much of the factor data comes directly from the Provincial Growth and Development Programme. (Department of Transport Project Prioritisation System 2015: 7).

Each prioritisation factor has its own weighting that depends on its importance when being compared to other factors (Department of Transport Project Prioritisation System 2015: 8). The total score of each road segment is determined by adding all the scores taken from each factor layer of that gravel road segment. Gravel road segments are then ranked in the order of their priorities, using the total scores as a key indicator. The KZN-DoT prioritisation model uses a traffic baseline of 200 vpd to select gravel road segments to be prioritised for pave requirements. In cases where it proves to be uneconomical to maintain a gravel road segment, the traffic baseline drops down to 150 vpd (Department of Transport Project Prioritisation System 2015: 4).

Listed below are prioritisation factors which are being considered in the KZN-DoT prioritisation model for the upgrade of gravel road to paved:

1. Projected Traffic Count
2. Road Classification
3. Strategic and Primary Road
4. Public Transport Routes
5. Tourism Routes
6. Agricultural Land
7. Priority Intervention Areas
8. Industrial Areas
9. Commercial Areas
10. Densely Populated Areas
11. Social Facilities
12. Abnormal Load Routes

Table 2.2 shows the prioritisation factors which are considered by the KZN-DoT under each project category when prioritising projects.

Table 2.2 Prioritisation factors applicable to each project category

Factor		Project Category							
		New Gravel road	*Upgrade to Blacktop*	*Capacity & Geometric upgrades*	*New Blacktop road*	*Pedestrian Bridge*	*Vehicular Bridge*	*Social Facility Access*	*Road Safety*
Ref	**Name**	**Score**							
1	Projected Traffic Count		Yes		Yes		Yes		Yes
2	Level of Service			Yes					
3	Road Classification	Yes	Yes	Yes	Yes		Yes		
4	Strategic & Primary RD		Yes	Yes	Yes		Yes		
5	Public Transport Routes	Yes	Yes	Yes	Yes		Yes		
6	Tourism Routes		Yes	Yes	Yes		Yes		
7	Agricultural Land	Yes	Yes		Yes		Yes		
8	Priority Intervention Areas	Yes	Yes		Yes		Yes		
9	Industrial Areas		Yes		Yes		Yes		
10	Commercial Areas		Yes		Yes		Yes		
11	Densely Populated Areas	Yes	Yes		Yes		Yes		
12	Social Facilities	Yes	Yes		Yes	Yes	Yes	Yes	
13	Abnormal Load Route		Yes	Yes	Yes		Yes		
14	Loss of life (drowning)					Yes	Yes		
15	Pupil Days Lost					Yes	Yes		
16	Comm Members Days Lost					Yes	Yes		
17	Travel Distance Saved					Yes	Yes		
18	Dist from Surf or Gvl Rd							Yes	
19	Accidents								Yes

Department of Transport Project Prioritisation System (2015: 8)

As mentioned earlier under the abstract of this dissertation that the phrase ‘upgrade to blacktop’ means upgrading of gravel roads to bituminous sealed or asphalt roads. Although there are twelve prioritisation factors listed on Table 2.2 under the category of upgrade to blacktop, KZN-DoT only considered ten prioritisation factors to prioritise their gravel roads upgrading. The two factors that were excluded are Public Transport Route and Abnormal Load Route and the reason for their exclusion was that the data that corresponds to them was still to be collected by the KZN-DoT.

Table 2.3 shows the weights and scores that the KZN-DoT allocates for each prioritisation factor. Each road segment is assigned scores under the identified prioritisation factor. To arrive at the scores for each road segment under each factor, the factor weight is applied (Department of Transport Project Prioritisation System 2015: 10).

Table 2.3 Prioritisation factors' weights and scores

Factor			Project Category													
			Basic Points	New Gravel road	Upgrade to Blacktop	Capacity & Geometric upgrades	New Blacktop road	Pedestrian Bridge	Vehicular Bridge	Social Facility Access	Road Safety	New Gravel road	Upgrade to Blacktop	Capacity & Geometric upgrades	New Blacktop road	Pedestrian Bridge
				Weights								Score				
1	Projected Traffic Count Total	>2 000	12		3		3		3		3		36		36	
		1 000-2 000	10										30		30	
		600-999	8										24		24	
		400-599	6										18		18	
		200-399	4										12		12	
		<200	1										3		3	
2	Level of Service	E	12			3								36		
		D	8											24		
		C	4											12		
		B	2											6		
		A	1											3		
3	Road Classification	1	12	3	4	1	4		2			36	48	12	48	
		2	10									30	40	10	40	
		3	8									24	32	8	32	
		4	4									12	16	4	16	
		5	2									6	8	2	8	
		6	1									3	4	1	4	
4	Strategic & Primary RD	CS	12		2	1	2		1				24	12	24	
		SS	6										12	6	12	
		Pr	2										4	2	4	
5	Public Transport Routes			TBD	TBD	TBD	TBD		TBD			TBD	TBD	TBD	TBD	
6	Tourism Routes	PT	12		2	1	2		1				24	12	24	
		ST	6										12	6	12	
		LT	2										4	2	4	
7	Agricultural Land	Lps	12	2	1		1		1			24	12		12	
		Sps	6									12	6		6	
		Lcom	8									16	8		8	
		Scom	4									8	4		4	
		Lorc	5									10	5		5	
		Sorc	3									6	3		3	
		Lsub	3									6	3		3	
		Ssub	2									4	2		2	
8	Priority Intervention Areas	PR1	12	1	1		1		1			12	12		12	
		PR2	8									8	8		8	
		PR3	5									5	5		5	
		PR4	2									2	2		2	
		PR5	1									1	1		1	
9	Industrial Areas	Lin	12		2		2		1				24		24	
		MIN	6										12		12	
		Sin	2										4		4	
10	Commercial Areas	Lco	12		2		2		1				24		24	
		Mco	6										12		12	
		Sco	2										4		4	
11	Densely Populated Areas	Large	12	1	1		1		1			12	12		12	
		Small	3									3	3		3	
12	Social Facilities (Capped at 20 points) (Nil on Class 1-3 roads for upgrade to Blacktop and for new blacktop categories)	Hosp/Clin	12	2	1		2	1	1	1		24	12		*24*	*12*
		Sch	8									16	8		*16*	*8*
		Court/Pension Point	6									12	6		*12*	*6*
		Pol	6									12	6		*12*	*6*
		Shop/Post Office/Hall	4									8	4		*8*	*4*
		Public Transport	4									8	4		*8*	*4*
		Place of Worship	4									8	4		*8*	*4*
13	Abnormal Load Route	Yes	12		1	1	1		1				12	12	*12*	

Department of Transport Project Prioritisation System (2015: 10)

Figure 2.3 shows how the gravel roads are assessed using the GIS prioritisation factor layer.

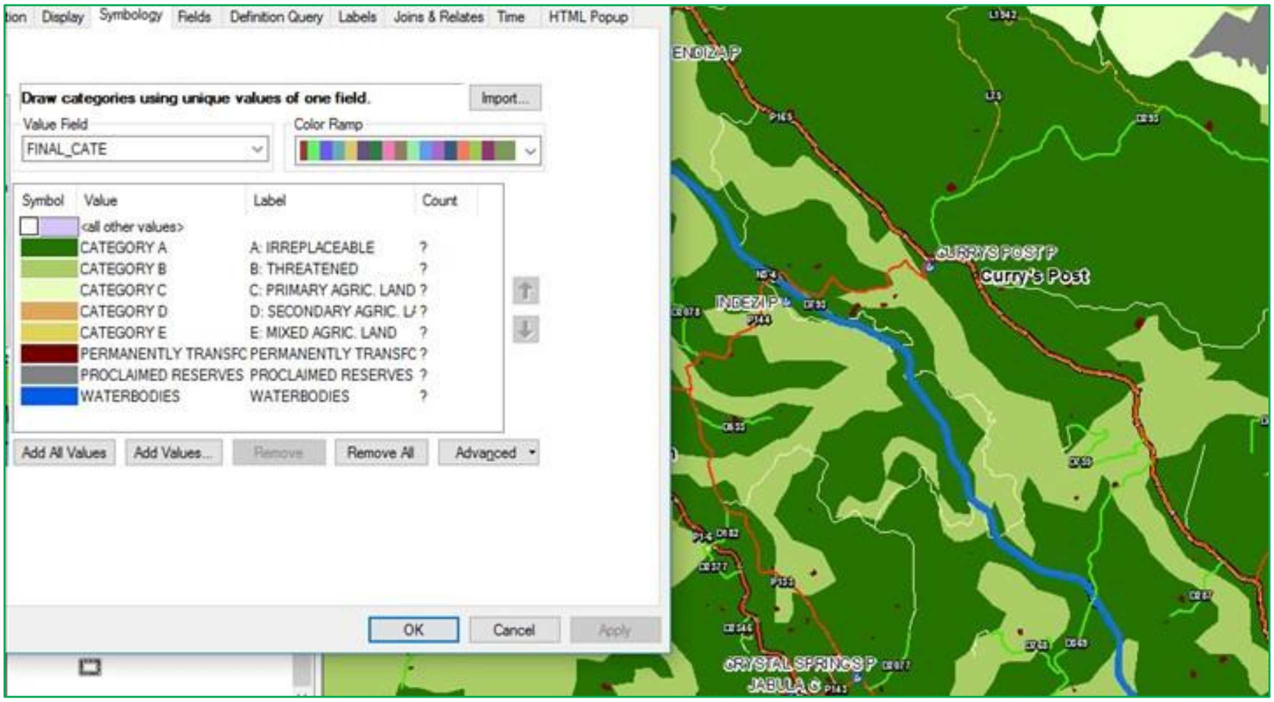


Figure 2.3 Prioritisation factor presented on a GIS layer
Image captured by Gugulethu Ndlovu

The KZN-DoT collected data that corresponds with respective prioritisation factors. The data was then used to create GIS shape file layers for each prioritisation factor, for example, the layer shown on Figure 2.3 is for Agricultural land, and within it there are different categories represented by different symbology. To view the category applicable to a certain gravel road, the assessor scrolls and zoom in that gravel road and then identifies the category in which the road is located by viewing the colour coding. Then an assessor assigns applicable score for that road based on the points and weights allocated for that category.

Upon completion of the prioritisation process, projects are then grouped into the following traffic count categories:

- ≥1000 vpd
- ≥400 and < 1000 vpd
- ≥200 and < 400 vpd (Department of Transport Project Prioritisation System 2015: 4).

All gravel road segments within a project category of upgrading gravel roads to paved are then ranked according to their scores and the ranking is then used to place them within a priority group according to the following table:

Table 2.4 Project priority groups

Priority Group	Ranking by Total Score	Ranking by Total Score
Very high	Top 5%	100-95%
High	4.9% to 20%	95-80%
Medium	19.9% to 40%	80-60%
Low	39.9% to 70%	60-30%
Very low	69.9% to 100%	30-0%

Department of Transport Project Prioritisation System (2015: 11)

The following are the priority rankings corresponding with respective priority groups:

Table 2.5 Project priority rankings

Very high	Priority A
High	Priority B
Medium	Priority C
Low	Priority D
Very low	Priority E

Department of Transport Project Planning Framework (2018: 16)

2.5 Summary/ lessons from literature

The reviewed literature highlighted that there is a variation in terms of the traffic baseline considered by road authorities to for prioritise gravel road upgrades. However, most research recommended a traffic baseline of 200 vpd as an ideal threshold to consider paving a gravel road. Literature also highlighted that gravel road performance is mainly affected by vehicle type distribution, especially heavy vehicles and not only by the number of vehicles travelling on a gravel road. In all the studies reviewed in terms of the prioritisation factors considered for upgrading a gravel road to paved, none of them have provided guidance on how traffic counts expressed as vpd can be adjusted to consider heavy vehicles. It then becomes necessary that this research close this gap by introducing the adjustment of traffic counts to passenger car equivalents (PCE). Meaning a mixed traffic stream which consist of trucks, buses, taxis, cars, etc., is converted to equivalent units of a passenger car. The concept of converting a mixed traffic stream into PCE units is widely used in the field of traffic engineering when assessing traffic flows at the intersections to determine the level of service of an intersection.

Past research on gravel roads is not as advanced as for the paved roads i.e., traffic loading is only considered when undertaking pavement design for gravel road upgrade, road pavement reseals and rehabilitation. The concept of traffic loading on gravel roads has not been given satisfactorily attention by the past research as is the case with paved roads. It can then be too complex to adjust traffic counts based on traffic loading principle and therefore, adjusting traffic counts by PCE values is the fair way to compensate for vehicle type distribution.

Literature reviewed also highlighted the importance of carrying out economic analyses to justify for a need to upgrade a gravel road. There is a gap identified by the researcher in terms of factors considered in the KZN-DoT's prioritisation model since economic analyses are not considered on their prioritisation model.

Studies reviewed in terms of gravel road performance prediction are evident that gravel loss study needs to be undertaken to predict gravel road’s future deterioration pattern. Gravel loss determines the frequency and cost of re-gravelling a gravel road, and both this serve as input data for carrying out economic analysis of upgrading a gravel road. In the absence of gravel road performance prediction model and re-gravelling records, it becomes impossible for a road authority to quantify how much of a cost to company a gravel road is. This then presents a challenge in justifying the necessity of upgrading a gravel road. Therefore, gravel loss study is considered essential in predicting how each gravel road will perform or cost.

According to the literature reviewed in terms of the gravel loss studies carried out, there is no exact period on how long a gravel loss study should be. The period and frequency of measuring gravel loss varies however, for most studies the frequency of measuring gravel loss has been six months with the minimum duration of the gravel loss study been 12 months. A need to carry out gravel loss study based on local conditions i.e., materials, climate, topography, and traffic has been overly emphasised by the past research. The reviewed literature highlighted that the gravel loss prediction models are not transferable from one geographic location to the other especially, when the key dependant variables are not the same for both locations. Therefore, since there has been no gravel loss study performed within the province of Kwazulu-Natal, there was a major need to carry out a gravel loss study using local materials and local climate conditions.

Paige-Green (2017) who undertook one of the longest gravel loss studies mentioned that GL measurements are complicated and time-consuming and there is no simple method that is accurate enough to obtain useful readings within a reasonable period. Paige-Green (2017: 41), also mentioned that the decision of defining the type and number of tests to be done lies with the researcher carrying out the experiment. However, for most of the GL studies reviewed by the researcher, the grading analysis and plasticity index were the common tests carried out. The literature also highlighted the relationship between the plastic factor of a material and gravel loss.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter discusses the research design and methodology that have been used by the researcher in investigating an ideal time to pave a gravel road, ideal traffic baseline of selecting gravel roads for upgrading as well as the one used in investigating the prioritisation factors that can be added into the KZN-DoT prioritisation model. The methodology used in assessing the suitability of the KZN-DoT's prioritisation methodology KZN-DoT is also discussed in this chapter.

In assessing the ideal time of upgrading a gravel road to paved surface road, a GL study was undertaken on selected gravel roads' sections within the KwaZulu-Natal provincial road network, and in addition to that, the re- gravelling records of respective monitoring sections and the relevant literature were analysed and reviewed, respectively. For this study, the investigation of the right time to upgrade a gravel road to paved standard road was approached in two ways. The first method was by measuring annual gravel losses on all monitoring sections. The second one was by analysing re-gravelling records. Survey height readings obtained from predetermined fixed measurement positions were used to measure GL through comparing them with the heights of fixed survey benchmarks installed within each monitoring section. The outcomes of this investigation are discussed in the next chapter of this dissertation.

The following section details the selected research design and methodology used in addressing each research question. It also discusses the processes including the work programme followed where applicable.

3.2 An ideal time to pave a gravel road

The GL study conducted on KZN-DoT Road network was used together with the re-gravelling records to assess GWC performance and their re-gravelling frequencies respectively on selected monitoring sections. The findings were then used to draw conclusions regarding the right time to upgrade a gravel road to a paved surface road. The following paragraphs describe the method and the research design followed in carrying out this study.

3.2.1 Re-gravelling records

Determining an appropriate time for upgrading gravel roads to paved standards can just be a matter of viewing and comparing gravel roads' maintenance records and their usage demand within the road network, and then identifying those that are often being maintained. Following that, cost comparisons of retaining or paving a gravel road can be made to determine economic viability for each option. However, this approach is ideal when gravel roads are re-gravelled at their optimal frequencies, whereby such frequencies are informed by performance modelling tools.

For this study, the investigation of the right time to upgrade a gravel road to a paved standard road was approached in two ways. The first method is through measuring GL and the second one is through analysing re-gravelling records. Gravel road maintenance records were obtained from gravel road maintenance managers responsible for roads selected for this study. The re-gravelling records for each monitoring section were viewed, arranged, and used by the researcher to establish re-gravelling frequencies. The re-gravelling frequencies from respective sections were then later compared with the predicted ones per section based on extrapolated annual gravel losses discussed under chapter 4 of this dissertation. Table 3.2 shows the re-gravelling records and frequencies for each monitored section. It also shows the dominant surface defects that were observed on each monitored section during road condition surveys which occurred simultaneously with GL surveys. In chapter 4 of this research, the gravel loss outcomes of respective sections are interpreted based on surface defects that were observed under each section. Table 3.1 shows the abbreviations of gravel road surface defects which are shown in Table 3.2.

Table 3.1 Defects abbreviations

Defect Description	Defect Abbreviation
Corrugation	C
Dust	D
Excessive Fines	EF
Loose Gravel	LG
Loose Material	LM
Potholes	P
Roughness	R
Rutting	R

Table 3.2 Re-gravelling records of monitored section.

Road Number	Monitoring Test Section (km)	Re-gravelling Dates	Re-gravelling Frequency (years)	Surface Defects	Material Type	Traffic Volume	Climate Zone
D1268(1)	0.7 - 0.82	Sep-05 Nov-11 Oct-18	7	R + EF	Shale	>600	Dry Sub-Humid
P734	17.40 - 17.52	Feb-12 Aug-14 Oct-17	3	EF	Shale	>600	Humid
P361	17.20 - 17.32	May-05 Jun-11 Oct-18	7	LG + D + EF	Dolerite	400 – 600	Dry Sub-Humid
P191(2)	2.28 - 2.4	Feb-07 Mar-12 Sep-18	6	R + EF	Dolerite	>600	Dry Sub-Humid
P355	5.80 - 5.92	Nov-07 Sep-15	8	LG + C + EF	Dolerite	200 - 400	Dry Sub-Humid
P555	0.5 - 0.62	Feb-06 Jul-12	6	R + Rt	Shale	200 - 400	Dry Sub-Humid
D1268(2)	1,88 - 2.0	May-09 Aug-17	8	R + EF	Shale	400 - 600	Dry Sub-Humid
D1384	0.25 - 0.37	Apr-04 Mar-11 May-18	7	R + C + LM	Dolerite	200 - 400	Humid

Road Number	Monitoring Test Section (km)	Re-gravelling Dates	Re-gravelling Frequency (years)	Surface Defects	Material Type	Traffic Volume	Climate Zone
D299(2)	km 6.8 - 6.92	May-08	5	R + LM	Shale	200-400	Humid
		Aug-13					
		Jul-18					
D770	km 0.4 - 0.52	Apr-12	3	R + LM	Shale	400 - 600	Humid
		Jul-15					
		Oct-18					
D1240	km 11.1 - 11.22	Nov-07	4	R	Dolerite	400 - 600	Humid
		Apr-12					
		Jun-16					
P379	km 3.0 - 3.12	Aug-11	3	L + D + P	Dolerite	>600	Humid
		Dec-14					
		Sep-17					

3.2.2 Gravel loss study processes

The GL study comprised the following processes which are further discussed within the next pages:

- Identification of GL monitoring test sections.
- Setting out of the GL monitored test sections.
- Preliminary surveys of the remaining GWC material.
- Monitoring of GL at fixed measurement positions.
- Measurement of gravel loss.

3.2.2.1 Identification of GL monitoring test sections

Identification of GL monitoring test sections comprised the following structured process:

i. *Climate:*

In similar studies, climate is either expressed in terms of Weinert N-value or Thornthwaite’s moisture index. The latter was adopted as a criterion for this study to select monitoring test sections. Thornthwaite’s moisture indices are dependant both on vegetation and climate and provide more sensitive differentiation between climatic regions than Weinert N-value. The Weinert N-value is season dependant. Figure 3.1 shows Thornthwaite’s moisture index for South Africa. The Thornthwaite’s moisture indices in which the monitoring sections of this study are located are shown with a star. The Thornthwaite’s moisture indices that were selected by the researcher are humid and dry-subhumid.

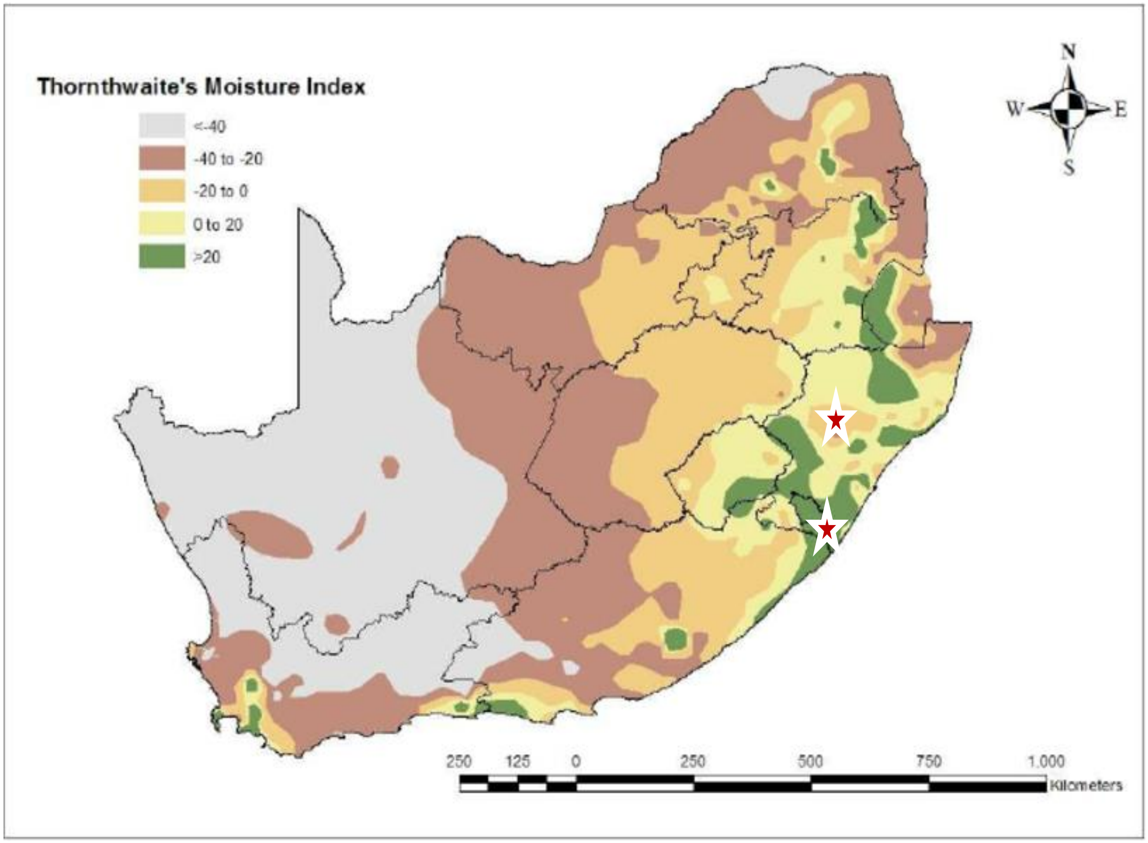


Figure 3.1 Thornthwaite's moisture index for South Africa
Adopted from internet available: https://www.researchgate.net/figure/Thornthwaites-moisture-index-for-South-Africa_fig1_42431923

A GIS map displaying Thornthwaite's moisture indices was used by the researcher to locate and identify provincial gravel roads falling under the respective Thornthwaite's moisture zones in KwaZulu-Natal.

In general, there are five Thornthwaites' moisture indices, which are arid, semi-arid, dry-sub-humid, moist sub-humid and humid. Of these five moisture indices, four were identified to be in existence within the KwaZulu-Natal province, and those are semi-arid, dry sub-humid, moist sub-humid and humid.

Figure 3.2 shows how gravel roads falling on different Thornthwaite's moisture indices within the KwaZulu-Natal province were identified and selected by the researcher. It should be noted however, that for this study the GIS symbology used to define Thornthwaites' moisture indices were changed from what appears on Figure 3.1. Moisture indices corresponding with each of the redefined GIS symbology are shown in Figure 3.2.

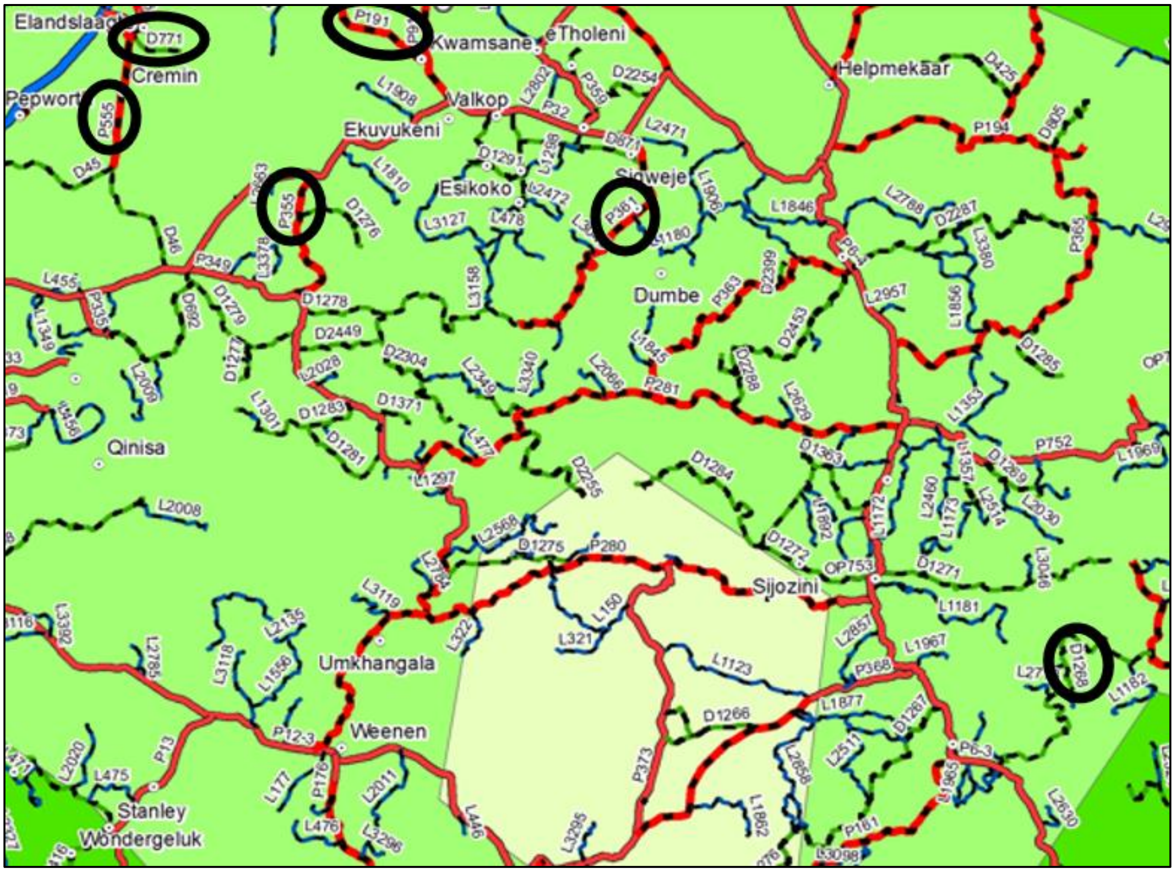


Figure 3.2 Identifying and selecting gravel roads based on Climate Regions
Captured by Gugulethu Ndlovu from KZN-DoT GIS system.

GIS symbology used in Figure 3.2 and their description:

- humid
- moist sub-humid
- dry sub-humid
- semi-arid

To identify gravel roads falling under each moisture index zone, a GIS layer consisting of provincial gravel roads was switched on and then respective roads falling under each moisture index zone were displayed.

No rainfall records were available for all selected gravel loss monitoring sections due to the non-availability of close rainfall stations to record annual rainfall depth (mm) and frequencies. However, this does not impact negatively on annual GL results since the study adopted the use of Thornthwaite's moisture indices instead of the Weinert's N-values.

ii. *Material type:*

A gravel materials' database containing a list of existing quarries and borrow-pits found within the province of KwaZulu-Natal was viewed by the researcher to establish the number of available gravel sources and the type of materials found under each source. Following that the most dominant types of materials were identified and located on a GIS map. Materials which dominate throughout the province of KwaZulu-Natal were found to be shale, dolerite, granite, and sand. At first, the aim was to conduct experiments on all four most dominant type of materials, however, due to resources shortage and time constraints only the top two of the available materials were selected for this experiment. Figure 3.3 shows the KZN-DoT's materials database of gravel quarries that are used to construct and re-gravel KZN-DoT's gravel roads.

QUARRY_NUMBER	MAT_TYPE	ROAD	KM_TRAVELLED	OFFSET	OFFSET DISTANCE (KM)	MAT_TYPE	Y	X
D3/P68/145	DOLERITE	P68	43,0	ADJ		BR DOLERITE	-74663,55	-3381146,9
B2/10-2/381	DOLERITE	P10-2	0,2	RHS		BR DOLERITE	-152813,69	-3192556,34
CR11/C3/D642/120	DOLERITE	D642	5,0	ADJ	4,0	BR DOLERITE	-180393,17	-3353683,32
A3/36-1/69	DOLERITE	P36/1	6,7	ADJ		BR. WEATHERED DOLERITE	-63227,08	-3114384,7
MARITZ DRIFT	DOLERITE	D284	9,6	NORTH		BROWN DEC. DOLERITE		
TREK BOER	DOLERITE	D325	3,5	RES		BROWN DEC. DOLERITE		
B2/19/321	DOLERITE	P19	37,7	ADJ	0,3	BROWN SUGAR DOLERITE	-126036,31	-3235472,96
E3/348/166	DOLERITE	348	4,0	RHS	5,0	DEC DOL		
B1/DNR/3/6/1	DOLERITE	1/11	2,1	LHS	1,0	DEC DOL		
B1/32/344	DOLERITE	P32	5,4	ADJ	0,2	DEC DOL	-112753,12	-3161392,38
B1/30/356	DOLERITE	P30	4,3	RHS		DEC DOL(SUGAR)	-140165,71	-3165594,33
DZI-HLUHLUWE GAME RE	DOLERITE	P 235	28,8	ADJ	0,0	DEC. DOLERITE	95859,76	-3125244,57
E2/235-2/20	DOLERITE	P235	31,1	ADJ	0,6	DEC. DOLERITE	94553,77	-3123534,56
B3/12/133	DOLERITE	P12-1	18,0	ADJ		WEATHERED DOLERITE /BLACKSHALE		
BP1/544/391	DOLERITE	P 544	4,5	RHS	0,7	WEATHERED DOLERITE AND HARD DOLERITE		
E3/476/400	BASALT	D476	4,0		0,0	BASALT		
E3/2-7/454	BASALT	P2/7	237,0	ADJ	0,6	BASALT		
E3/D464/456	BASALT	D464	5,3		0,1	BASALT	107267,25	-3072145,54
E2/P425/246	BASALT	P425	14,0	RHS	0,1	BASALT		
A1/308/292	BASALT	P 308	9,8	RHS	4,0	BASALT		
E3/D496/351	BASALT	D496	6,0	ADJ		BASALT	65759,59	-3056925,62
E3/D429/378	BASALT	D529	16,0	RHS		BASALT	51373,92	-3035541,85
E3/D463/394	BASALT	D463	1,4	ADJ		BASALT		
E3/2/399	BASALT	D81	0,5	LHS		BASALT		
E3/D464/330	BASALT	D464	13,0			BASALT	101199,95	-3075101,09
LOT H 59	BASALT	D722	1,4	SOUTH	10,0	BASALT	117887,92	-3090360,36
E3/2/419	BASALT	P2/6	9,7	WEST		BASALT	119573,06	-3136268,71

Figure 3.2~~3~~ Provincial materials database
KwaZulu-Natal Department of Transport

Table 3.3 shows the gravel materials found in quarries of the KwaZulu-Natal province. There are twenty-three different types of gravel materials that are used to construct and maintain gravel roads within the province of KwaZulu-Natal. For this study the researcher decided to select two of the most dominant materials within the province to ensure that the monitored sections are manageable. Shale and dolerite were found to be the top two gravel materials that are deployed as the GWC on provincial roads. To determine the percentage representation for each material type, the number of gravel roads that used each type of material were listed. Then the most dominating materials were identified through calculating the percentage representation.

Table 3.3 Dominant materials in KwaZulu-Natal

No	Material Type	No. of Roads Surfaced	Percentage	Ranking in terms of usage on roads
1	**Dolerite**	**181**	**22%**	**2**
2	Basalt	20		
3	Berea Red	1		
4	Calcrete	4		
5	Conglomerate	2		
6	Earth	1		
7	Ferricrete	60		
8	Fine White Sand	13		
9	**Granite**	**98**	**12%**	**3**
10	Gravel	1		
11	Hard Stone	1		
12	Ironstone	1		
13	Mudstone	20		
14	Rhyolite	6		
15	River Gravel	1		
16	Sand	13		
17	**Sandstone**	**64**	**8%**	**4**
18	**Shale**	**323**	**39%**	**1**
19	Siltstone	2		
20	Silty Sand	3		
21	Tillite	18		
22	UMgubaan	1		
23	Volcanic Ash	1		

Adopted from Ndlovu *et al*. 2018, 2018 SARF/IRF/PIARC Regional Conference for Africa

Figure 3.4 graphically presents the materials representation percentage as discussed on Table 3.3.

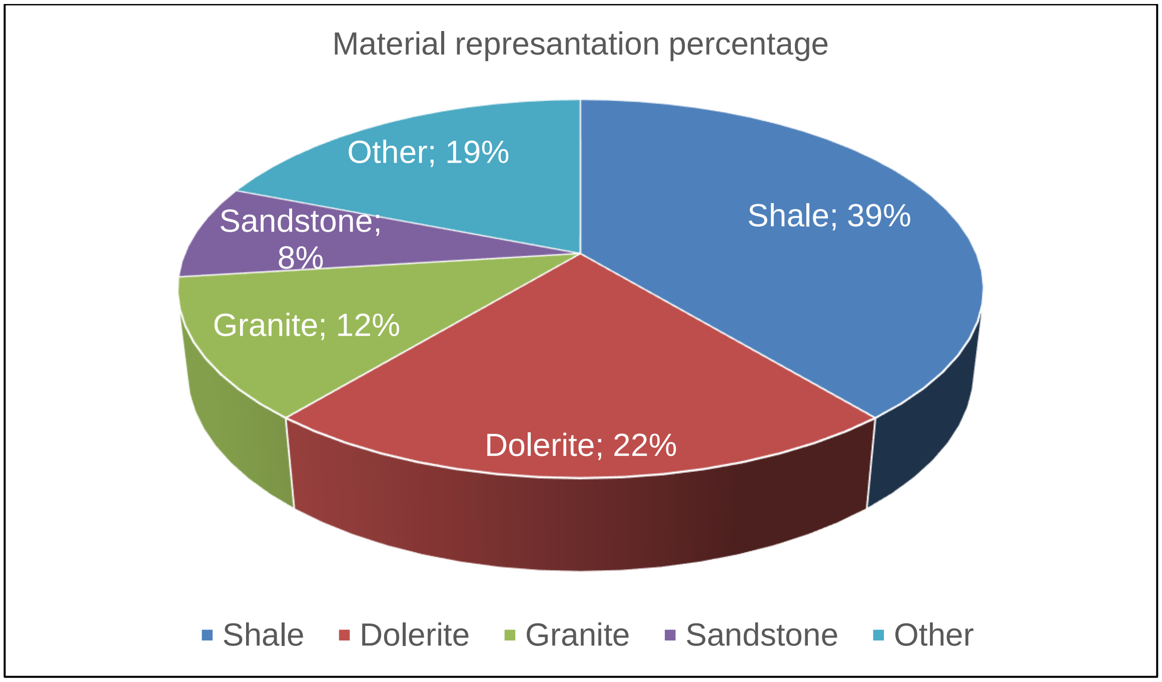


Figure 3.34 Graphical representation of gravel materials found in KwaZulu-Natal
Ndlovu *et al*. 2018, 2018 SARF/IRF/PIARC Regional Conference for Africa

It should be noted however, that there are further classifications and variability amongst some materials type, for example, a shale found and extracted from a certain quarry might be different from the other one hauled from a different one in terms of colour, its mineral composition and behaviour when deployed as a gravel wearing course. It is important to note that in this study these distinctions amongst material types were not considered.

iii. *Traffic:*

Table 3.4 shows an experimental design matrix that was developed by the researcher to select GL monitoring sections. Three traffic categories were considered for selecting monitoring sections. Traffic categories considered were those falling between the vehicle per day range of 200 - 400, 400 - 600 and those >600. The researcher's decision to select these traffic ranges are as follows:

- The minimum threshold of 200 vpd for traffic range 200-400 vpd was selected on the basis that this is a theoretical recognised baseline traffic that justifies for upgrading gravel roads to paved roads. Then the upper limit of 400vpd for traffic range 200-400 vpd, is the maximum threshold that most road authorities use to define low-volume gravel roads.
- Then for the other two traffic ranges 400-600 and >600, the traffic was added in the increments of 200 from the minimum threshold of 200 vpd, with an assumption that since the impact in maintenance cost is theoretical argued to be significant when traffic reaches 200 vpd, so the researcher's impression was that for every additional 200 vpd the impact should be rapid in terms of gravel loss and maintenance costs.

There were no traffic monitoring stations within or nearby experimental length and the manual traffic counts that were conducted in the recent years were used as a basis in selecting sections conforming with relevant traffic categories being considered. Sections with intersections were excluded to form part of the experimental length due to their influence on high gravel loss rate resulting from vehicles' turning movements on intersections. influence high rate of gravel loss.

Table 3.4 Experimental design matrix for GL study

No.	Traffic Volume (vpd)	Material Type	Climate Zone	Road Terrain
1	200 – 400	Shale	Humid	3-5%
2	200 – 400	Shale	Dry Sub-Humid	3-5%
3	200 – 400	Dolerite	Humid	3-5%
4	200 – 400	Dolerite	Dry Sub-Humid	3-5%
5	400 – 600	Shale	Humid	3-5%
6	400 – 600	Shale	Dry Sub-Humid	3-5%
7	400 – 600	Dolerite	Humid	3-5%
8	400 – 600	Dolerite	Dry Sub-Humid	3-5%
9	>600	Shale	Humid	3-5%
10	>600	Shale	Dry Sub-Humid	3-5%
11	>600	Dolerite	Humid	3-5%
12	>600	Dolerite	Dry Sub-Humid	3-5%

iv. *Road Terrain and Geometry*:

This was the last criterion that was used in selecting the 120m long GL monitoring sections after following the processes mentioned from i to iii above.

As a last step, a rolling vertical gradient of approximately 3% - 5% was used as a uniform in selecting a 120m strip of GL monitoring section on respective gravel roads. Intersections, cross-drainage structures, road sections on cross-falls and curved sections were eliminated from being part of GL monitoring sections. Paige-Green (2017: 6) states that the location of the experimental sections should be such that the outside influences are as constant as possible, and the latter was excluded based on this statement. In most of the GL studies, researchers agree that road terrain is one of the major contributors to GL. This then made it essential to consider selecting a uniform road terrain slope to be used when selecting monitoring sections for this study. The major motivation to this approach was to eliminate the number of sections for the purpose of making the study manageable.

3.2.2.2 Setting out of the GL test sections

Consultation and various engagements with the land surveyors of the KZN-DoT were made prior the commencement of this study. However, prior to the involvement of surveyors in this study, the researcher reviewed related literature to ensure that the setting out of the GL monitoring sections follows a recommended approach and adheres to the industry norms.

The KZN-DoT's gravel roads maintenance teams and respective gravel roads' foremen were informed about GL experimental sections and made aware of their location and the reasons for having them. They were advised to inform the monitoring teams of any actions affecting monitoring sections, this included maintenance activities like blading. For this study, the blading maintenance on monitoring sections was kept at a minimum frequency and followed a uniform approach in terms of the days of blading monitoring sections. The light blading on monitoring sections was only done to control roughness levels of GWC surfaces and for sections to be kept safe and accessible for traffic using them.
The following sections explain the procedures followed in setting out the test sections:

i. *Survey specification and procedure for GL measurement sites*

The survey specification was compiled by KZN-DoT's surveyors after several meetings held with the researcher prior to the commencement of surveys. The survey specification was in accordance with the KwaZulu-Natal Department of Transport Survey Manual (2011). Table 3.5 shows survey benchmarks that were installed on each monitored section. Each site had three or four benchmarks. Benchmarks were used as reference points in determining average change in height of the GWC surface during gravel loss surveys.

Table 3.5 Survey benchmarks for GL study

PROJECT SURVEY COORDINATES LIST			
WGS84 SYSTEM(Y,X,Z)			
D1240-GL1	-61502,314	3233595,436	1485,173
D1240-GL2	-61487,187	3233654,196	1487,478
D1240-GL3	-61471,17	3233706,517	1488,286
D1268-GL1A	45631,858	3194062,321	699,879
D1268-GL2A	45519,664	3194095,887	701,622
D1268-GL3A	45631,931	3194045,78	700,491
D1268-GL1B	45107,518	3193719,645	771,186
D1268-GL2B	45333,173	3193739,337	770,783
D1268-GL3B	44993,266	3193704,746	775,147
P191-GL1A	-103436,873	3138280,562	1175,44
P191-GL2A	-103427,801	3138158,795	1170,145
P191-GL1B	-112610,561	3147657,268	1066,551
D1384-GL1	-64743,568	3226706,502	1467,616
D1384-GL2	-64869,447	3226812,113	1469,253
D1384-GL3	-64876,341	3226957,121	1326,697
P355-GL1	-103797,44	3158824,25	982,759
P355-GL2	-103769,018	3158775,792	979,813
P355-GL3	-103754,65	3158711,59	976,713
P361-GL1	-126447,245	3153799,971	1211,672
P361-GL2	-126479,264	3153850,087	1215,35
P361-GL3	-126459,615	3153917,171	1219,424
P379-GL1	-64227,694	3226914,507	1537,616
P379-GL2	-64273,596	3226962,202	1539,697
P379-GL3	-64303,34	3227001,105	1541,253
P555-GL1	-93362,345	3144326,529	1129,854
P555-GL2	-93301,329	3144339,025	1130,633
P555-GL3	-93280,26	3144912,722	1137,885
P555-GL3N	-93258,577	3144388,566	1131,943
D299-GL1	30082,306	30064,136	735,264
D299-GL2	30024,125	30097,148	748.429
D299-GL3	30067,326	30004,176	752.135
D770-GL1	30144,883	30012.090	654,124
D770-GL2	30152,226	30046,156	663,457
D770-GL3	30167,249	30059,245	659,752
P734-GL1	28170,674	31205,587	847,426

PROJECT SURVEY COORDINATES LIST			
WGS84 SYSTEM(Y,X,Z)			
P734-GL2	28201,456	31236,147	7826,154
P734-GL3	28341,612	31264,009	7651,435

ii. *GL measurement positions*

The adopted method of measuring gravel loss for this study was through taking the measurement at a point and calculating an average height loss.

Following the meetings held with KZN-DoT surveyors it was agreed that the gravel loss readings should be taken at every 10-metre interval to increase accuracy and across 7 positions of the road prism being monitored. Figure 3.5 shows the positions where the gravel loss readings were taken across the GL monitoring sections. Figure 3.5 was drawn by the researcher prior to holding meetings with KZN-DoT surveyors.

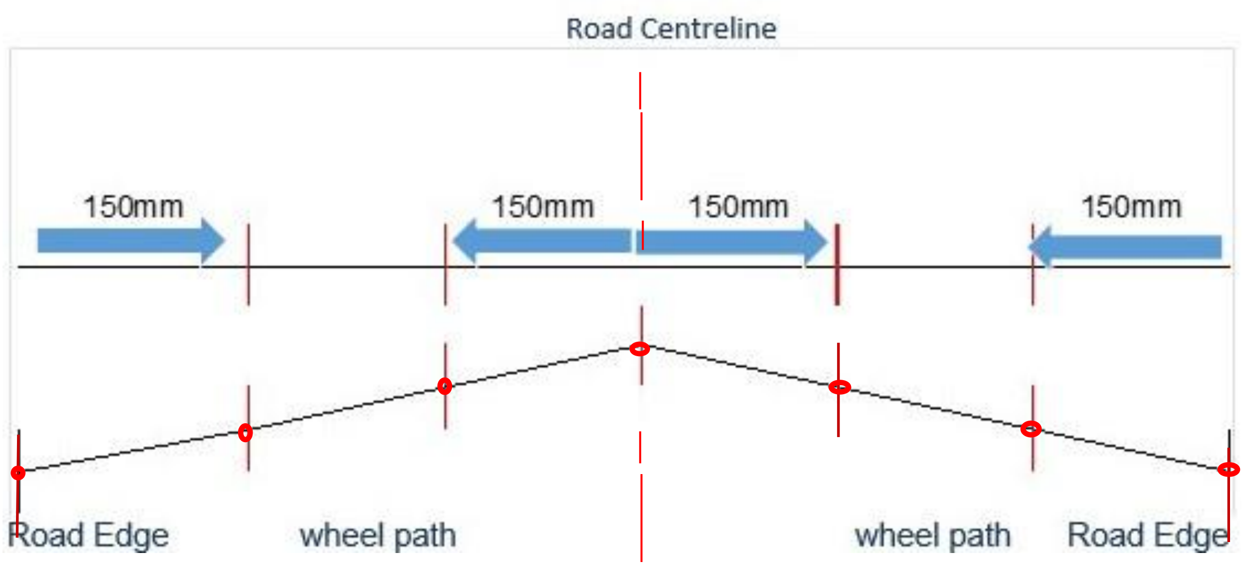


Figure 3.45 GL measuring positions across the road.
Compiled by Gugulethu Ndlovu

Profile heights readings were taken at the road edge, inner and outer wheel paths of both sides as well as on centreline of a monitored road prism. The GWC surface height at each cross-section was estimated by taking the average of the readings over the carriageway width at the cross-section. The average height of monitored section was then determined by taking the average of 13 cross sectional heights. The gravel loss on each monitored section was then determined by comparing the average height of the monitored section from previous survey.

iv. *The procedure of setting out the GL monitoring sections:*

- Installation of Survey Control Points

  After the identification of 120m GL monitoring sections, teams of KZN-DoT's surveyors installed either three or four control points in total along two sides of each monitoring section. The control points were used as reference markers for the setting up of and for taking readings from fixed gravel loss measurement positions across and along monitoring sections.

  A long steel rod was driven down to the ground by hammer and concrete was cast around it to hold and make it visible. Teams and grader operators were then informed about control points that were installed on various monitoring sections so as not to damage them when carrying out routine road maintenance activities like blading/grading.

- Setting up of the fixed gravel loss measurement positions

  This stage involved the initial road prism survey, and this is where the gravel road's edges and centreline were defined. This was achieved by means of carrying out tacheometry survey along and across each GL monitoring section. The control points were used as a reference in locating coordinates of all the fixed gravel loss measurement positions.

3.2.2.3 Preliminary surveys of the remaining GWC material

One year prior to the initial GL survey taking place on monitoring sections, investigations were undertaken and continued annually to check the remaining GWC material and assess road surface defects on respective sections. The main aim of this was to ensure that there was an adequate amount of gravel thickness required to perform GL surveys and to note the GWC surface defects prevailing on the respective monitoring sections. Images showing a GWC condition on the respective monitoring sections were captured and this was done to make comparisons at a later stage between the GWC's indicator test results and the failures noted. The indicator tests, which are sieve analysis and plasticity index (PI) of the gravel wearing course material as well as the GWC density and CBR tests were performed at a later stage during GL surveys. The indicator tests were performed to check material properties influencing the rate of GL. More information on GWC material testing is discussed later in this chapter.

KZN-DoT surveyors from all the regions concerned who were part of this study from the setting up of the GL monitoring sections ensured that the pits were dug by the GWC investigating teams at exact spots that were agreed upon. The GWC depth readings in mm were then measured using a scale ruler. For uniformity, during preliminary investigations of the remaining GWC depths, the positions of holes to be dug for the checking of the GWC depth were randomly selected and made uniform for all monitoring sections. Surveyors had a significant role to play during the GWC depth surveys. They provided guidance in terms of where to dig a hole to ensure that the fixed GL measurement positions were left undamaged. Table 3.6 shows the pits' positions that were selected randomly by the researcher on respective years for measuring the remaining GWC depth.

Table 3.6 Pits positions for GWC depth checks

Year: 2018	Year: 2019	Year: 2020
chainage(m) 60 – 70	chainage(m) 40 – 50	chainage(m) 50 – 60
chainage(m) 90 – 100	chainage(m) 70 – 80	chainage(m) 80 – 90

Figure 3.6 shows how the remaining GWC depths investigations were carried out by the researcher and KZN-DoT assessing team.

Figure 3.6 Investigation of GWC depth
Captured by Gugulethu Ndlovu

GWC depths were recorded, then backfilling and compaction of the loose material was carried out. In Chapter 4 of this dissertation, the annual GWC depths that were observed from respective monitoring sections over a three- year period are discussed.

First, 12 gravel loss monitoring sections were selected using the experimental design matrix shown as Table 3.4 of this dissertation. However, following extensive checks of available traffic under each monitoring section, the researcher found that three out of twelve sections did not meet the required traffic count for respective traffic categories that they were selected for. As a result, another desktop observation using the same process mentioned earlier was carried out by a researcher to identify three monitoring sections to replace those that did not conform in terms of the traffic count criteria. The three sections that were found to be non-conforming to traffic requirements had lower traffic counts than those anticipated. The said sections were then abandoned from the list of monitoring sections to be surveyed. The sections listed on Table 3.4 of this dissertation are the final ones that are conforming to required traffic counts for respective traffic categories.

3.2.2.4 Monitoring of GL at fixed measurement positions

The initial survey phase covered the initial level checks of GWC surface on all 12 monitoring test sections. This phase was the first of the three phases undertaken to quantify gravel losses on respective monitoring test sections. The initial survey phase was for determining the initial level readings of the GWC layer across seven fixed measurement positions at every 10m interval for the full extent of monitoring sections.

The other two phases for GL study survey were:

i. Measurement of GL on fixed measurement positions after six months from the date of initial surveys.
ii. Measurement of GL on fixed measurement positions after twelve months from the date of initial surveys.

The height readings were taken across seven fixed positions at the surface of the GWC layer and at every 10m interval along each monitoring section for the measurement of GL.

Surveys conducted during each site’s GL monitoring visit were changes in road surface levels and prevailing road condition. The road test sections were monitored for a period of two years, starting from October 2018, with the initial GWC depth and initial survey heights taken December 2018 and September 2019, respectively.

Table 3.7 Schedule for GL monitoring surveys

Test Section	Gravel Loss Monitoring dates		
	Initial survey	1st GL survey	2nd GL survey
D299(2)	16/09/2019	16/03/2020	16/09/2020
D770	16/09/2019	16/03/2020	16/09/2020
P734	09/09/2019	No data	09/09/2020
D1384	12/09/2019	16/03/2020	14/09/2020
D1240	13/09/2019	13/03/2020	15/09/2020
P379	12/09/2019	16/03/2020	14/09/2020
P555	11/09/2019	11/03/2020	11/09/2020
D1268(1)	09/09/2019	09/03/2020	07/09/2020
D1268(2)	09/09/2019	10/03/2020	08/09/2020
P355	10/09/2019	No data	09/09/2020
P361	10/09/2019	No data	09/09/2020
P191(2)	11/09/2019	No data	10/09/2020

GL surveys for 4 out of 12 monitoring sections were not undertaken during the first GL survey phase as their scheduled days fell within the country's level 5 Covid-19 Lockdown, where the work of this sort was not allowed to take place. However, the annual gravel loss (AGL) measurements were not affected by this since the second phase of the GL survey was carried out on all monitoring sections a year after the initial surveys took place.

Figure 3.7 shows how GL measurements were carried out.

Figure 3.7 GL survey on P734 road

3.2.2.5 Measurement of gravel loss at predetermined intervals

i. *Gravel loss study extent*

Like many other GL studies carried out to date, this study only covered monitoring of the GWC layer in terms of surface level losses and prevailing defects on all test sections. No observations and monitoring of the *in-situ* subgrade layer were undertaken on respective monitoring sites to measure its influence on GL. No Dynamic Cone Penetrometer (DCP) and on-site moisture content tests were carried out on sites during GL surveys. However, the California Bearing Ratio (CBR), Atterberg Limits and Grading Analysis tests were carried out during the study to measure each GWC's strength as well as their material properties that influence the rate of their GL.

ii. *Gravel Roads Maintenance Records*

Gravel road maintenance records of all monitoring sections were obtained from the respective road maintenance managers of the Department's local offices. There were difficulties experienced during this process as some of the records were not readily available and some were tracked through the service providers' payment certificate records that had information of the re-gravelling work limits that were undertaken by each service provider. The records of re-gravelling activities that have been carried out on the respective monitoring sections are discussed in Chapter 4 of this dissertation.

3.2.2.6 Sampling and testing

Sampling and testing require the testing of samples from all layers and not only the GWC, as roads perform in a holistic manner, with each layer contributing to the performance of the layer above (Paige-Green 2017: 11). However, for this study, the experimental layer (GWC) was the only layer that was sampled and tested. Although the information regarding the performance of underlying layers could have assisted more in understanding other root causes and factors influencing the rate of GL, since the material sampling and testing was only for the purpose of performing indicator tests on a GWC material with the aim of investigating geotechnical properties that contribute to the rate at which the GWC deteriorates under respective traffic volumes and climate conditions. The sampling and testing of GWC material from respective gravel loss monitoring sections was carried out in accordance with Committee of State Road Authorities, 1981 (TMH5, 1981) and respective South African National Standard of civil engineering test methods (SANS 3001) respectively. However, the test apparatus used were those complying with Committee of State Road Authorities, 1986 (TMH1, 1986) requirements as the South African National Roads Agency Ltd. (2013: 2) does give allowance for their usage up until they are worn out.

3.2.2.7 Sampling procedures

Sampling of GWC material was carried out in accordance with Committee of State Road Authorities (1981: 12) (TMH5, 1981) guidelines.) The guidelines provide details on the sample size required to perform certain laboratory tests and, on the procedure to be followed when sampling materials from road layers, borrow-pits, and quarries.

The sample size of material which was to be extracted from respective monitoring sections was informed by the type of tests that were intended to be performed for this study. According to Paige-Green (1989: 9.3), the plasticity and grading characteristics of materials are the main contributors to their performance as wearing course gravels. He also added that plasticity and grading tests results for gravel materials of the same geological classification vary considerably depending on the condition and stage of weathering.

The following are tests that were performed for this study:

- Grading Analysis
- Plasticity Index
- Density Determination
- California Bearing Ratio (CBR)

Below is the material sampling procedure and checklist that was compiled by the researcher for this study prior to the material sampling taking place on 12 selected monitoring sections. Both the sampling procedure and checklist were compiled in accordance with Committee of State Road Authorities (1981) (TMH5, 1981) requirements.

1. Surveyors shall advise the material teams of where the samples must be taken along each test section to avoid encroaching on the survey.
2. Two pits shall be dug by the materials team at positions to be mentioned by the surveyors of which both shall be at centre line between 50m and 60m as well as between 80m and 90m.

3. Samples of material extracted from the pits will only consist of gravel wearing course material and no underlying layer shall be dug to prevent the contamination of the gravel material samples.
4. Fine material forming part of the gravel wearing course material will be well swept using a brush, collected by a scoop, and put together with the course material in a sample bag.
5. The samples extracted from test pits will be used for indicator tests (grading analysis and plasticity index determination) and for density determination. In accordance with Committee of State Road Authorities (1981:36) (TMH5, 1981), the sample size for indicator tests must be 10kg and densities must be 40kg of which both results in 50kg. However, it is further stated that the minimum sample size should be 70kg for allowance purposes in case more material is needed (Committee of State Road Authorities 1981:12) (TMH 5, 1981).
6. Three plastic bags shall be provided per test pit, and this is to ensure that each of them carries 20 - 25kg of material for better handling.
7. Tags shall be used to write important details about each sample, such as road number, sampling position and material description.
8. Ropes will be used to tie the tags to the corresponding sample bags.
9. Sample bags will be loaded and placed with care in the vehicle transporting them to testing area or collection point.
10. The head office laboratory shall be used as a collection point prior the transportation of material samples to Hluhluwe Material Testing Laboratory.

3.2.2.8 Material sampling checklist

The following was equipment which needed to be brought to the sites to sample the material accordingly. KZN-DoT’s area offices were requested to bring their equipment and resources as mentioned under comments column of the table. The rest of the equipment was brought to sites by the KZN-DoT’s head office team. The researcher compiled the material sampling checklist shown in Table 3.8

Table 3.8 Material sampling checklist

Item	Description	Quantity	Yes	No	Comments
1	Temporary roadwork signs including cones	For both sides of the roads			Area office to bring
2	Measuring Tape	1			Area office to bring
3	Plastic bags	6/test section			Head Office to bring
4	Pick	1			Area office to bring
5	Shovel	1			Area office to bring
6	Spade	1			Area office to bring
7	Brush	1			Head Office to bring
8	Scoop	1			Head Office to bring
9	Tags	6			Head Office to bring
10	Rope for tying tag	6			Head Office to bring
11	Water	20 litres			Area office to bring
12	Filling material from the nearest borrow-pit	-			To be identified on site
13	Labourer	4			EPWP labourer from respective area offices
14	Safety protective clothing including hand gloves (for each worker)	For each worker			Area office to bring

Compiled by Gugulethu Ndlovu

3.2.3 Laboratory testing

The following are the tests that were performed in accordance with the below prescribed test methods:

DESCRIPTION	TEST METHOD
Sieve analysis	SANS 3001 – GR1:2013
Liquid limit	SANS 3001 – GR10:2013
Moisture content	SANS 3001 – GR12:2013
Density	SANS 3001 – GR 30:2015
CBR	SANS 3001 – GR 40:2013

Each road will have a 120m long monitoring test section, which will be set-up by the departmental surveyors. Each monitoring test section will be divided into 10m intervals along the road to increase the degree of accuracy in terms of gravel loss measurements (GLM).

Across every 10m interval, there will be seven positions where the internal surveyors will be taking level readings during the three above mentioned stages.

The number of indicators (test pits) for material sampling will be two along each section and will be located at 40m and 80m intervals, of which their positions should be uniform along all test sections and randomly selected during different stages of sampling to avoid biases in results.

Each local accredited laboratory, when returning their quotations shall also submit a curriculum vitae of the materials technician they intend using on site for sampling as well as for the testing of gravel material.

The service providers should note that the outcome/results of these test will be used to draw findings and conclusion on an internal research study, and it is therefore vital that these samples and tests be conducted in an ethical manner.
The awarded service provider shall be liable to correct any errors that might arise because of his negligence. The said corrections shall be done at his own costs.

The bidders should also meet all supply chain management requirements for this quotation for them to be further considered by the relevant bid committees.

Figure 3.8 Material preparation prior to testing
Captured by Gugulethu Ndlovu

Figure 3.9 Grading analysis for the study
Captured by Gugulethu Ndlovu

3.3 Research design and methodology of investigating additional prioritisation factors and validating KZN-DoT project prioritisation model

3.3.1 Validation of KZN-DoT project prioritisation model

3.3.1.1 Study Area

Figure 3.10 shows the selected study area of uMngeni Local Municipality and its boundaries. The uMngeni Local Municipality falls under uMgungundlovu District Municipality and was selected as the study area for the testing of the developed project prioritisation methodology for the upgrading of the KwaZulu-Natal provincial gravel roads to paved standard.

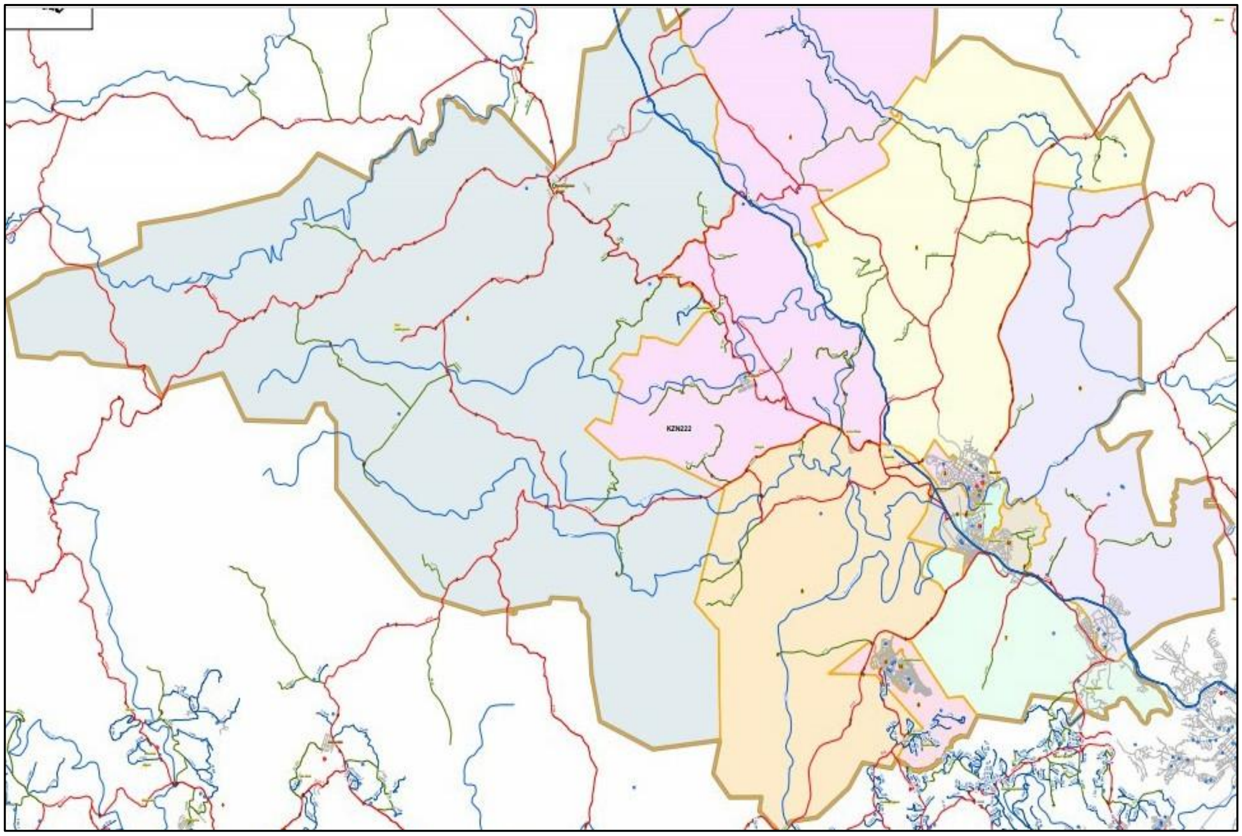


Figure 3.10 uMngeni Municipality map
KZN-DoT KZ222 map book

The selection of this local municipality as a study area was influenced by the different factors and characteristics that it exhibits; for example, different land uses available within this municipality attract different types of vehicle classes found on each road segment. A notable difference in terms of social classes of people residing within this municipality's boundaries is, amongst other reasons, for its selection since one of the prioritisation factors adopted by the system is directly linked to the social classes of the affected population.

3.3.1.2 Methodology used to test developed prioritisation system

The following processes were followed for the testing of the developed prioritisation system:

i. *Identification of gravel roads within study area*

Refer to Figure 3.11, the study area was identified and an A0 size map of the study area was printed and used to capture all the gravel roads falling within its boundaries, as well as to clearly display the traffic count data over the corresponding gravel road segments. Then the length of each gravel road segment was obtained from the KZN-DoT's GIS.

Figure 3.11 Traffic count displayed on an A0 size map
KZN-DoT map

ii. *Segmentation of Gravel Roads*

The segmenting of all gravel roads falling within the study area was then carried out in accordance with the Committee of Land Transport Officials (2000: 11) (Draft TMH12, 2000) guidelines. On sections where a significant change in terms of traffic volume, long stretches exceeding 5km before reaching an intersection and where the land use change was noted and observed respectively, a new segment was introduced. Figure 3.12 shows how the mapping of gravel road segments was achieved using the GIS software.

Figure 3.12 Segmentation of KZ222 unpaved roads
KZN-DoT GIS map

The different colour coding reflected on the roads represent the number of segments that each road has. For example, P133 road has got five road segments, and each segment is represented by its colour. Segment one of P133 starts on its intersection with P1-6 and ends on its intersection with D2677. It is represented by a solid yellow colour code. Then segment two of P133 starts on its intersection with D2677 and ends on is intersection with P143. Segment two is represented by a solid blue colour. Then its segment three which is represented by a dotted green colour starts on its intersection with P143 and ends on its intersection with D182.Segment four of P133 is represented by a solid pink colour and starts from its intersection with D182 and ends on its intersection with D533. Then its last segment which is number five is represented by a solid green colour and starts on P133's intersection with D533 and ends on its intersection with P144.

iii. *Prioritisation factors*

The factors being used to prioritise the upgrading of gravel roads to their paved standard vary from one country and road authority to the other. A notable driving force which influences the choice of prioritisation factors that each country or road authority selects includes but is not limited to the respective country's strategies and policies.

In chapter two the KZN-DoT's prioritisation model of upgrading gravel roads to paved was extensively discussed. The researcher investigated additional factors to be incorporated through the reviewal of related existing literature. Those additional recommended factors are economic analysis of upgrading as well as traffic composition consideration i.e., heavy vehicles and passenger car. Furthermore, an impact made by adding the researcher's recommended prioritisation factors, except the economic analysis one on the KZN-DoT model was evaluated by the researcher. In evaluating the impact of traffic composition factor on project priorities, a researcher reviewed relevant literature on how the adjustments of traffic counts can be carried out to accommodate traffic composition. The theory of converting traffic consisting of mixed types of vehicles i.e., buses, trucks to passenger car equivalents (PCE) was the closest literature that was relevant for a researcher to base the traffic counts adjustment on.

In testing the impact made by adjusting traffic counts into passenger car equivalents on the KZN-DoT model priorities, the researcher used the concept of adjusting traffic counts using the corresponding PCE units. Details on the conversion of a mixed traffic into PCE units are discussed on the next paragraphs.
all the gravel roads within the boundaries of the study area were considered irrespective of their traffic volume, whereas on the developed project prioritisation system, only gravel road segments with traffic >200vpd.

Amongst the prioritisation factors listed below which are part of the KZN-DoT's model, the ones that are marked with and asterisk (*) next to them were not incorporated into the KZN-DoT prioritisation model at the time of this research. . However, the researcher did evaluate the impact made by adding the Public Transport Route (PTR).

- Projected Traffic Count
- Road Classification
- Strategic and Primary Road
- Public Transport Routed standard*
- Tourism Routes
- Agricultural Land
- Priority Intervention Areas
- Industrial Areas
- Commercial Areas
- Densely Populated Areas
- Social Facilities
- Abnormal Load Routes*

The following are additional recommended prioritisation factors to be considered for inclusion on the KZN-DoT:

- PCE adjusted traffic counts
- Economic analysis

Although the concept of the Passenger Car Equivalents (PCE) is usually used during traffic flow studies to convert the traffic stream made up of different vehicle types into a homogeneous one composed of passenger cars the same principle can be used to adjust traffic volume by dividing the unit length of every vehicle type found on respective gravel road segments by the unit length of a passenger car to establish a fair comparison in terms of traffic volume. A study conducted by Van Zyl et al. (2003) which assessed gravel road specifications in South Africa and their impact, found that a more rapid deterioration occurs when heavy vehicles form more than 15% of the ADT within a road. Considering the impact that the heavy vehicles have on gravel roads in terms of their contribution towards gravel roads' deterioration and the need for frequent maintenance, it is essential that traffic composition is considered when prioritising for gravel roads upgrade

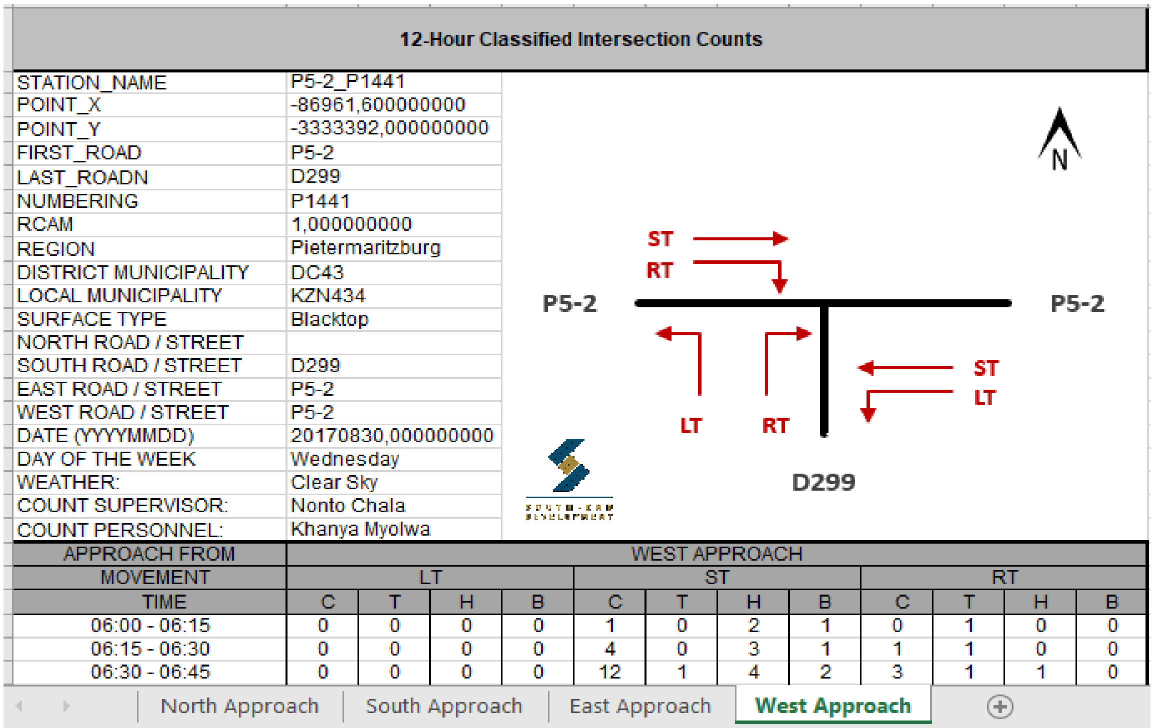
Outcomes of using the PCE concept in adjusting traffic counts on respective gravel roads are further discussed later.

Economic Analysis

Economic analysis is an approach being used by the decision makers and road asset managers in establishing the economies of retaining a gravel road as it is and maintaining it as and when required versus that of upgrading to a paved standard and maintaining it. Recommendations are that the economic analysis be carried out on top priority/scoring projects, the percentage threshold of which should be determined by the KZN-DoT, or any other road authority based on their available road budget.

iv. *Traffic count data*

The traffic count data of all gravel roads in the study area concerned was readily available at the start of this research. The traffic studies were undertaken in 2016 by different agencies that were appointed by the Department of Transport. The traffic data obtained was presented in different formats by the appointed agencies. The 12-hour traffic count data that was submitted by the agencies had some discrepancies in some of the gravel road segments, which necessitated a refinement of the traffic counts. The refinement of the traffic counts was then carried out. Recent traffic count data was used for testing the developed prioritisation methodology, whereas for the developed prioritisation methodology, an old traffic count data which was adjusted by applying a traffic growth rate was used. Figure 3.13 shows the traffic data that was used by the researcher to quantify traffic counts for each gravel road segment within the study area.



12-Hour Classified Intersection Counts

STATION_NAME	P5-2_P1441
POINT_X	-86961,600000000
POINT_Y	-3333392,000000000
FIRST_ROAD	P5-2
LAST_ROADN	D299
NUMBERING	P1441
RCAM	1,000000000
REGION	Pietermaritzburg
DISTRICT MUNICIPALITY	DC43
LOCAL MUNICIPALITY	KZN434
SURFACE TYPE	Blacktop
NORTH ROAD / STREET	
SOUTH ROAD / STREET	D299
EAST ROAD / STREET	P5-2
WEST ROAD / STREET	P5-2
DATE (YYYYMMDD)	20170830,000000000
DAY OF THE WEEK	Wednesday
WEATHER:	Clear Sky
COUNT SUPERVISOR:	Nonto Chala
COUNT PERSONNEL:	Khanya Myolwa

APPROACH FROM	WEST APPROACH											
MOVEMENT	LT				ST				RT			
TIME	C	T	H	B	C	T	H	B	C	T	H	B
06:00 - 06:15	0	0	0	0	1	0	2	1	0	1	0	0
06:15 - 06:30	0	0	0	0	4	0	3	1	1	1	0	0
06:30 - 06:45	0	0	0	0	12	1	4	2	3	1	1	0

North Approach | South Approach | East Approach | **West Approach**

Figure 3.13 Traffic counts format
Department of Transport traffic count database

Figure 3.14 shows the traffic count stations that were viewed by the researcher to locate relevant traffic count data for the desired intersection.

Figure 3.14 Traffic stations
Department of Transport traffic stations database

The traffic count stations were located on all road intersections within the study area and given reference numbers. The traffic stations were used to record all the movements of traffic approaching them. The recording of traffic volume approaching or departing each road intersection occurred concurrently on all traffic stations over a period of 12 hours during the normal days of the week.

v. *Conversion of traffic counts to equivalent passenger cars*

In terms of traffic composition, the gravel road segments within the study area consisted of cars, taxis, heavy trucks, and heavy buses.

Table 3.10 shows the PCE values that were used to convert a mixed vehicle type of traffic found on respective gravel road segments of the study area concerned into traffic volume represented as the number of equivalent passenger cars units.

Table 3.9 has been used as a reference guide in compiling Table 3.10:

Table 3.9 PCSE values

Vehicle	Average Length (m)	Space Headway (m)	Total Space (m)	Basic PCSE	Recommended Values		
					2-Lane 4-Lane	Narrow 2-Lane	1-Lane
Car	4.0	32.0	36.0	1.0	1.0	1.0	1.0
Utilities (Pickup)	4.5	36.0	40.5	1.0	1.0	1.0	1.0
Heavy Bus	14.0	44.0	58.0	1.6	1.8	2.0	2.2
Light Truck	5.0	40.0	45.0	1.3	1.3	1.4	1.5
Medium Truck	7.0	44.0	51.0	1.4	1.5	1.6	1.8
Heavy Truck	9.0	48.0	57.0	1.6	1.8	2.0	2.4
Trailer	11.0	50.0	65.0	1.8	2.2	2.6	3.0

Adopted from Mikolaj and Remek 2015, available: https://www.sciencedirect.com, DOI: 10.1016/j.proeng.2015.07.126

Table 3.10 Passenger Car Equivalent (PCE) values

Vehicle type	Average Length (m)	PCE Value
Car	4.0	1.0
Mini-Bus (Taxi)	5.8	1.5
Heavy Bus	14.0	3.5
Heavy Truck	9.0	2.25

3.4 Summary

This section covered research methods that the researcher used in investigating the right time of upgrading a gravel road, and the one used in validating the KZN-DoT's traffic baseline considered when prioritising gravel road upgrade. It also covered research methods used by the researcher in identifying gaps in the prioritisation factors that are considered on the KZN-DoT's prioritisation model.

The literature reviewed by the researcher in chapter two gave guidance on the methodology to be employed in researching each RQ. It should be noted that for some RQs that needed to be researched i.e., whether the KZN-DoT's prioritisation methodology is ideal, there were no past research for a researcher to refer to as this is a broadly defined RQ. As a result, the researcher broke the said RQ into small components for it to get addressed. To address it a combination of all other RQs was researched.

In investigating the right time to pave a gravel road a researcher has used mixed research methods, both qualitative and quantitative approaches. For a qualitative one, the literature was reviewed by the researcher to view what factors to consider when figuring out the right time of upgrading a gravel road. Most of the literature reviewed highlighted a need for road authorities to carry out economic analysis to justify a need to upgrade a gravel road. Economic analysis factor has drawn researcher's attention based on the number of authors who mentioned its importance. For a quantitative approach in determining the right time of upgrading a gravel road, GL study and re-gravelling records on and of monitored test sections were undertaken and observed respectively by the researcher. Both their analyses are discussed on chapter four of this dissertation.

In terms of validating the traffic baseline used by KZN-DoT to select gravel roads to prioritise for upgrade, both the literature and outcomes of the GL study were used by the researcher to draw conclusions. The researcher also noted another gap in prioritisation factors considered by the KZN-DoT when prioritising gravel road upgrade. Several researchers mentioned the importance of considering vehicle type distribution and not only the number of vehicles per day for traffic factor. The researcher identified this factor gap in the KZN-DoT's prioritisation model through literature reviewed. Several research made mention of this necessary considerations when prioritising for the upgrading of gravel roads. However, since amongst the literature reviewed by the researcher none of the literature showed how this can be achieved. To measure the impact of considering vehicle type distribution on project priorities, the researcher applied a quantitative approach through adjusting the traffic counts of respective gravel roads by the PCE values. The project priorities of the KZN-DoT's prioritisation model were then presented and compared by the researcher against the project prioritise that considered vehicle type distribution factor.

CHAPTER 4: DATA ANALYSIS AND FINDINGS

4.1 Introduction

This chapter presents the results, analyses of data and research findings in tables and graphical format, and the outcomes are then discussed.

4.2 Data analysis and findings from the GL study and re gravelling records

4.2.1 GWC depth readings

Observations of the GWC depth change was undertaken annually to observe the remaining GWC thickness on each of the 12 monitoring sections. This was done to ensure that there is still enough GWC to carry out GL surveys at scheduled dates. Providing information regarding the observations and measurements of GWC depths and their changes was not necessary on this dissertation. However, these were presented only to check relationship between the GWC depths losses and GL height. The annual GWC depth losses on the respective GL monitoring sections were then determined at the end of 2019 and 2020 using the data that was collected from 2018 to 2019 and 2019 to 2020, respectively.

Table 4.1 shows the GWC loss in depth for readings taken between end of 2018 - end of 2019 and end of 2019- end of 2020.

Table 4.1 Annual GWC depth readings

No.	Climate	Material	Traffic	Road number	GWC loss - in depth (mm)		Mean (mm)	Std. (mm)
					2018-2019	2019-2020		
1	Humid	Shale	200-400	D299(2)	18	21	20	2
2		Shale	400-600	D770	24	26	25	1
3		Shale	>600	P734	33	33	33	0
4		Dolerite	200-400	D1384	12	14	13	1
5		Dolerite	400-600	D1240	22	23	23	1
6		Dolerite	>600	P379	25	24	25	1
7	Dry Sub-humid	Shale	200-400	P555	8	11	10	2
8		Shale	400-600	D1268(2)	6	8	7	1
9		Shale	>600	D1268(1)	21	22	22	1
10		Dolerite	200-400	P355	8	8	8	0
11		Dolerite	400-600	P361	12	24	18	8
12		Dolerite	>600	P191(2)	19	23	21	3

4.2.2 GL results

Annual GL measurements of all selected monitoring sections were carried out after the last GL survey, which took place in September 2020. As mentioned, in the previous chapter, the GL study entailed three phases of surveys. The first one was for capturing initial GWC profile height readings within each test section's boundaries. This was done to establish the initial GWC surface levels. Then the next two phases, which occurred six and twelve months later from the initial GL survey, were for capturing profile height readings to measure the difference in previous GWC surface levels. The difference in GWC's profile heights against survey benchmarks ones was then interpreted as the GL.

The height of the GWC surface at each cross-section was estimated by taking the average of the readings over the road width at the cross-section. The average GWC surface level of each test section was determined by taking the average of all 91 cross-sectional heights along each monitoring section. The gravel loss on each site was then determined by comparing the average height of the site from previous surveys.

Table 4.2 shows the GL results for all 12 monitoring test sections:

Table 4.2 Gravel Loss results

Climate	Material	Traffic	Road number	Gravel loss - in height (mm)		Mean (mm)	Std. (mm)	Annual gravel losses (mm)
				0-6 months	6-12 months			
Humid	Shale	200-400	D299(2)	11	16	13,5	4	27
	Shale	400-600	D770	15	24	19,5	6	39
	Shale	>600	P734	no data	36	18	25	36
	Dolerite	200-400	D1384	8	14	11	4	22
	Dolerite	400-600	D1240	14	19	16,5	4	33
	Dolerite	>600	P379	19	28	23,5	6	47
Dry Sub-humid	Shale	200-400	P555	9	11	10	1	20
	Shale	400-600	D1268(2)	16	22	19	4	38
	Shale	>600	D1268(1)	20	25	22,5	4	45
	Dolerite	200-400	P355	no data	10	5	7	10
	Dolerite	400-600	P361	no data	17	8.5	12	17
	Dolerite	>600	P191(2)	no data	22	11	16	22

It is noted from Table 4.2. that the minimum and maximum average annual gravel loss during the entire survey period was10mm and 47mm respectively, and the mean of this variation was 30mm. This average annual gravel loss was slightly above the one obtained by Mwaipungu (2015: 183) where the average annual gravel loss was 24mm. The standard deviation of both average annual gravel losses is 4mm. Whereas the annual predicted gravel losses by Paige-Green (1989: 6.13)'s model ranged from a low of 4.5mm to a high of 65mm. This is evidence that the gravel loss model can not be transferred from one geographic location to the other unless the influencing variables are similar for both locations. The standard deviation between Paige-Green (1989)'s predicted maximum annual gravel loss and this study's one is 13mm.

From Table 4.2 a huge variation in terms of annual gravel losses on monitored sections of this study was noted. This variation in gravel loss was influenced by traffic, climate and GWC material. As traffic increased the rate of gravel loss also increased. Sections located in humid climate region experienced gravel losses higher than the ones located in the dry sub-humid climate region. The rate of gravel loss on monitered sections surfaced with shale was higher than the ones surfaced with dolerite. As highlighted on Chapter 2 that there are material properties i.e., aggregate grading and plasticity factor of material which directly affect the rate of gravel loss, analysis based on material properties are provided on page 107 of this dissertation.

Table 4.3 and Figure 4.1 show the relationship between GWC depth and height losses. From figure 4.1 it is noted that there is no correlation in terms of GWC depth and height losses. Ideally the GWC depth losses that were determined on respective monitored sections are not an accurate reflection of the average depth losses for each entire section since the GWC depth readings on respective sites were only taken from two test pits during each visit. The GL which is also referred to on this dissertation as GWC height losses was determined for each site following a traditional and normal procedure of measuring gravel loss. Therefore GL readings are more accurate than the GWC depth readings. GLs were higher than the measured GWC depth losses. In order to compare the two in a fair manner, GWC depth checks would need to be carried out on more pits per section. However, the latter is impractical when also undertaking gravel height losses simultaneously since excavating a pit affects GWC heights. It is advisable to stick to the traditional method of measuring gravel loss heights using installed survey benchmarks.

Table 4.3 Comparisons of Gravel depth and height losses

Climate	Material	Traffic	Road number	GWC depth losses	GWC height losses	Std. (mm)
Humid	Shale	200-400	D299(2)	20	27	5
	Shale	400-600	D770	25	39	10
	Shale	>600	P734	33	36	2
	Dolerite	200-400	D1384	13	22	6
	Dolerite	400-600	D1240	23	33	7
	Dolerite	>600	P379	25	47	16
Dry Sub-humid	Shale	200-400	P555	10	20	7
	Shale	400-600	D1268(2)	7	38	22
	Shale	>600	D1268(1)	22	45	16
	Dolerite	200-400	P355	8	10	1
	Dolerite	400-600	P361	18	17	1
	Dolerite	>600	P191(2)	21	22	1

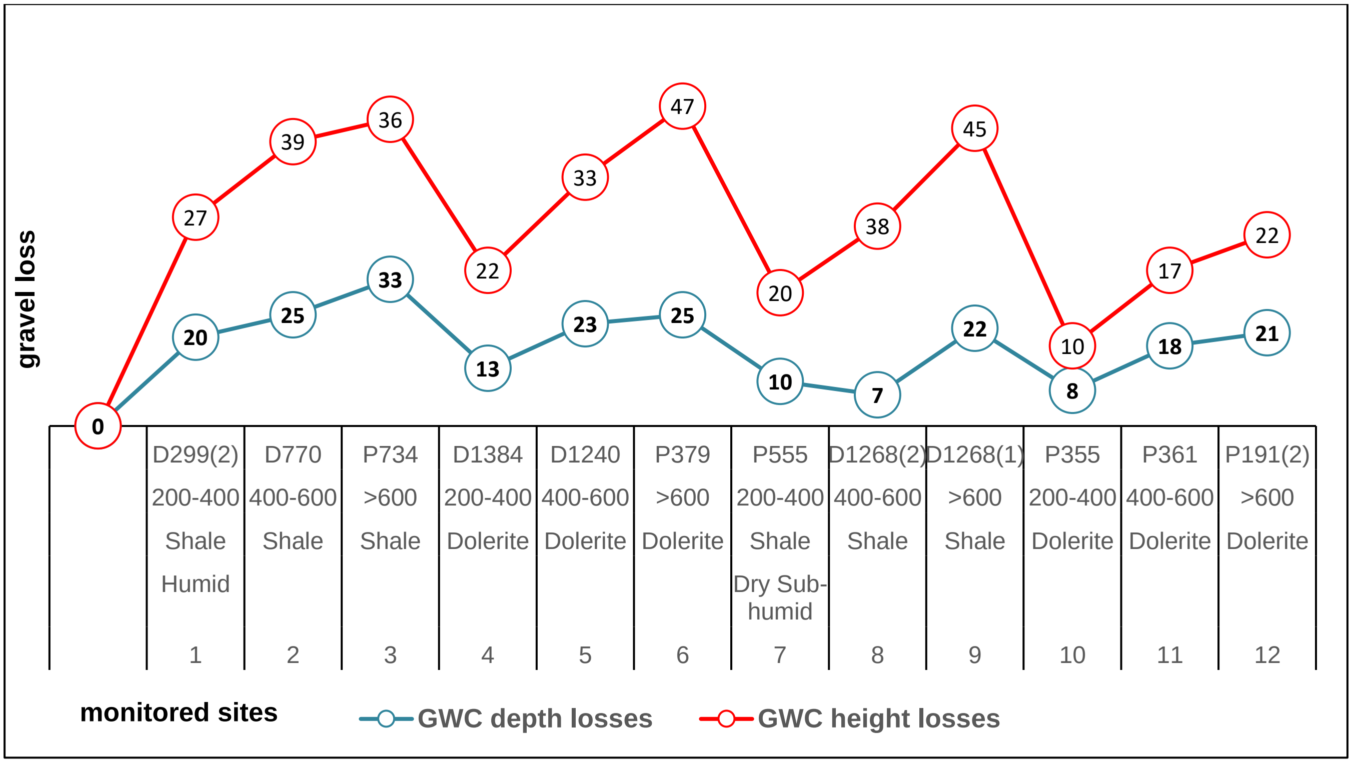


Figure 4.1 Correlation of GWC depth and gravel height losses

Table 4.4 shows the predictions of annual gravel losses for each monitored section based on the measured gravel losses as per Table 4.2 Gravel losses were predicted from year two (2) to year eight (8). The gravel losses shown under year 1 are annual gravel loss figures from Table 4.2 . Predictions of annual gravel losses on each site were based on an assumption that gravel losses will follow the same pattern as for the year 1 on respective sites.

Re-gravelling frequencies were also estimated by the researcher based on the predicted gravel losses. The frequency of regravelling on each site was determined through accumulation of gravel loss per year up until a year in which gravel loss will reach an accumulated150mm. The predicted re-gravelling frequencies for respective sites were then compared with the ones available on maintenance records. Table 4.4 also shows re-gravelling frequencies for each case as mentioned above. Discussions on re-gravelling frequencies and comparisons thereof are further covered on the next pages.

Table 4.4 Predictions of gravel loss and re-gravelling frequencies

Climate	Material	Traffic	Road number	Accumulative Annual GL future predictions (mm)									
				Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Re-gravelling frequencies	
												Predicted	Existing
Humid	Shale	200-400	D299(2)	27	54	81	108	135	162			6	5
	Shale	400-600	D770	39	78	117	156					4	3
	Shale	>600	P734	36	72	108	144	180				5	3
	Dolerite	200-400	D1384	22	44	66	88	110	132	154		7	7
	Dolerite	400-600	D1240	33	66	99	132	165				5	4
	Dolerite	>600	P379	47	94	141	188					4	3
Dry Sub-humid	Shale	200-400	P555	20	40	60	80	100	120	140	160	8	6
	Shale	400-600	D1268(2)	38	76	114	152					4	8
	Shale	>600	D1268(1)	45	90	135	180					4	7
	Dolerite	200-400	P355	10	20	30	40	50	60	70	80	16	8
	Dolerite	400-600	P361	17	34	51	68	85	102	119	136	9	7
	Dolerite	>600	P191(2)	22	44	66	88	110	132	154	176	7	6

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Figure 4.2 shows the correlation between the existing and predicted re-gravelling frequencies. The blue in this figure represents the predicted re-gravelling frequencies whereas the orange one represents the existing ones.

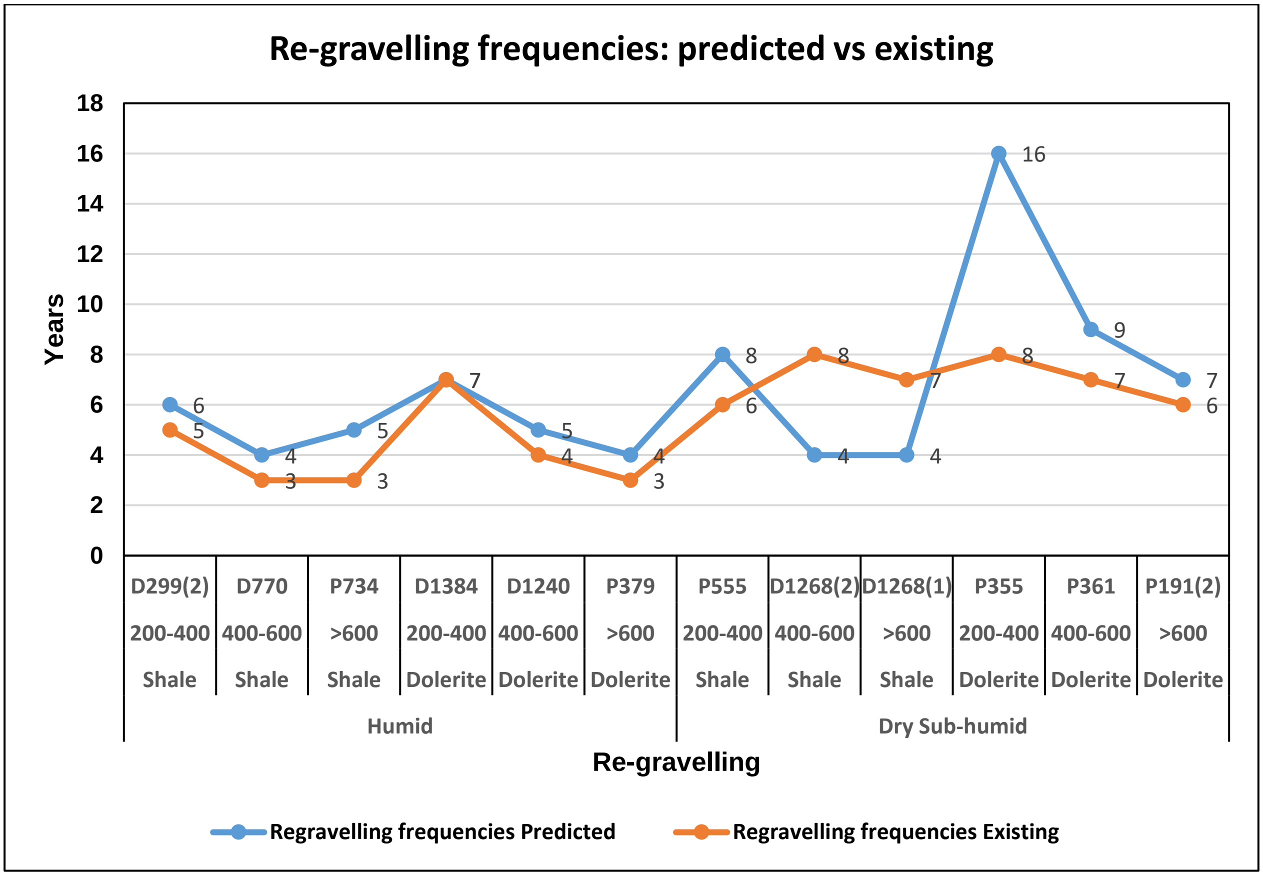

Figure 4.2 Re-gravelling frequencies (predicted vs existing)

4.2.3 Discussions on re-gravelling frequencies

From figure 4.2 the predicted re-gravelling frequencies in most cases are higher than the frequency at which re-gravelling occurred on each section. This could mean that over the years the re-gravelling of these monitored sites occurred some years earlier than required. There is, however, not much difference in terms of monitored sections' existing and predicted re-gravelling frequencies as the average standard deviation when considering all sites is 1.53. There are those few events where significant difference is noted.

Re-gravelling of road sections at their optimal timing i.e., at predicted re-gravelling frequencies can results in huge maintenance costs savings since the re-gravelling activity is a costly maintenance intervention. Major observations were that a dolerite performs well in dry-sub-humid region and their re-gravelling frequencies are longer than of other sites concerned. There could, however, be other underlying reasons to this for example, quality of their construction and material properties.

Climate and traffic seem to contribute more towards gravel loss, and since gravel loss is directly proportional to re-gravelling frequencies, the monitored sections located in a humid climate region and with high traffic have shorter re-gravelling frequencies. Although material properties greatly influence the rate of gravel loss, there seem to be a distinct response in terms of gravel loss for gravel roads surfaced with shale and dolerite. Clarity on whether this distinct behaviour between shale and dolerite is influenced by material properties i.e., aggregate grading and plasticity of a material, will be concluded on when discission material test result of each monitoring section.

4.2.4 Discussions of annual GL

The rate of GL on gravel roads that are surfaced with shale material is higher than that experienced by those that have dolerite GWC. A rapid rate of GL loss is noted on shale-surfaced gravel roads located in humid regions when compared to those located in dry sub-humid climate regions. When comparing the rate of GL for gravel roads surfaced with shale material and located in a dry sub-humid climate region to that of the dolerite located within the same climatic region, the former still shows a higher rate of losses than the latter. Although dolerite surfaced gravel roads in humid climate regions show a higher rate of GL than those located in dry sub-humid regions, the difference in gravel loss is not huge.

The climate factor is seen to be one of the major contributors to the rate of gravel loss.

The results also highlight the impact made by traffic volume on each monitoring section. A notable increase in GL as the traffic volume increases is observed. The use of shale material as a GWC, particularly on gravel roads located in humid climate regions, should be avoided where an option to use other suitable gravel material is available. This is because shorter re-gravelling frequencies were noted on GWC with shale material and in particular humid regions, this implies that responsible road authorities will need to spend their budgets more often on re-gravelling gravel roads when shale is deployed as a GWC. However, avoiding using shale as a GWC material should be informed by its poor material properties and the stage of its decomposition i.e., G9, G10 quality material.

The following tables and figures present the findings of respective GWC material tests that were performed to link or interpret GWC performance. Table 4.5 shows the legends that represent respective monitored sections. These legends were used on Figure 4.2 and Appendix 1 to represent each site.

Table 4.5 Legends for monitoring test sections

Legends	Material and climate zone	Traffic category (vpd)
	Shale-Humid	200-400
	Shale-Humid	400-600
	Shale-Humid	>600
	Shale-Dry Sub-Humid	200-400
	Shale-Dry Sub-Humid	400-600
	Shale-Dry Sub-Humid	>600
	Dolerite-Humid	200-400
	Dolerite-Humid	400-600
	Dolerite-Humid	>600
	Dolerite-Dry Sub-Humid	200-400
	Dolerite-Dry Sub-Humid	400-600
	Dolerite-Dry Sub-Humid	>600

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Figure 4.3 originates from Committee of State Road Authorities, 1990(TRH20), 1990 and was redrawn on this dissertation to analyse material test results of respective monitored test sections.

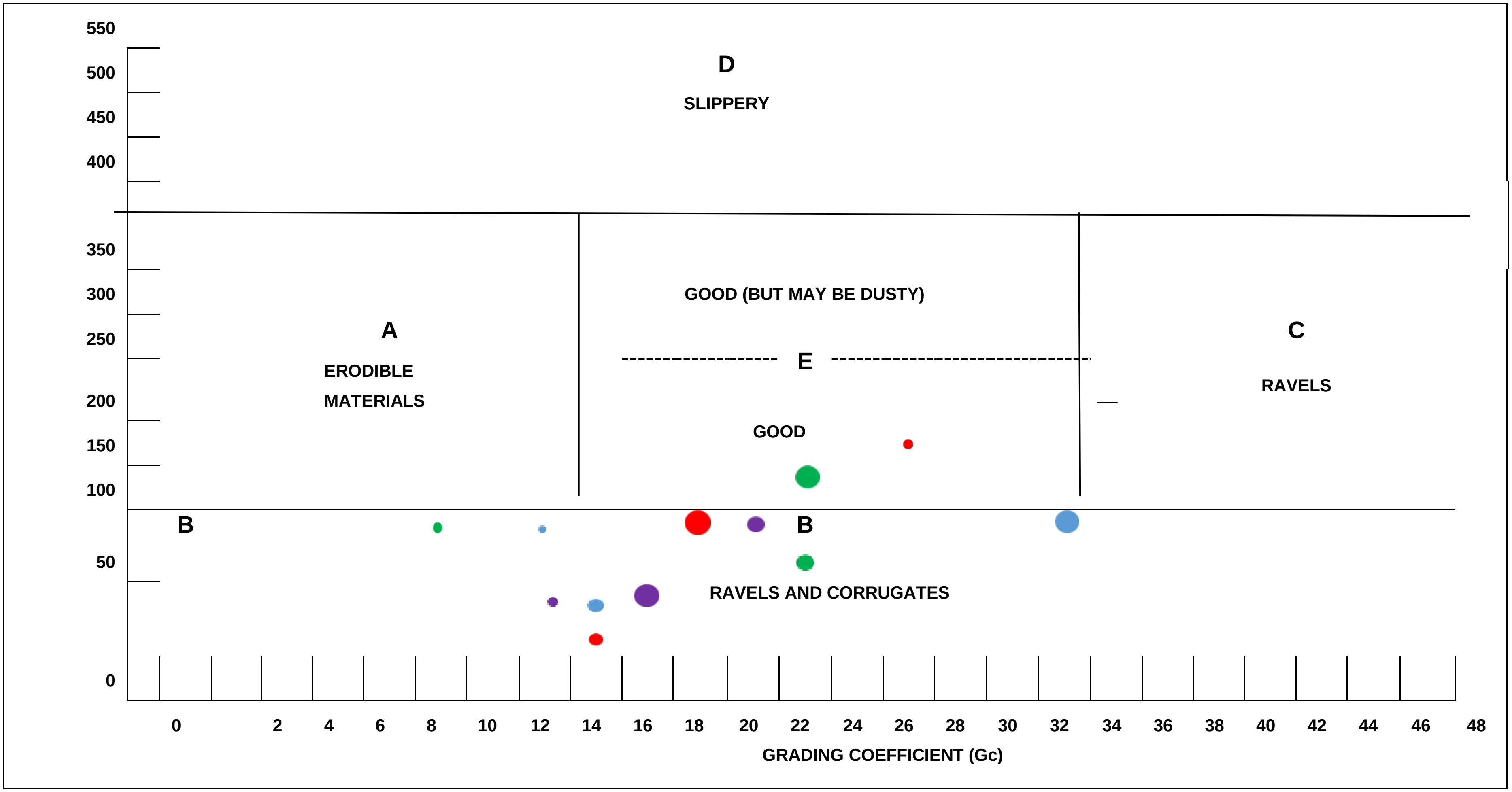

Figure 4.3 Material classification
Committee of State Road Authorities, 1990 (Draft THR20, 1990)

Table 4.6 also originates from Committee of Transport Officials, 1990 (TRH20, 1990)and redrawn on this dissertation.

Table 4.6 1Recommended material specifications for unpaved rural roads

Maximum aggregate size	37,5 mm
Oversize index (Io)[a]	5 per cent
Shrinkage product (Sp)[b]	100 - 365 (max. of 240 preferable)
Grading coefficient (Gc)[c]	16 - 34
CBR: =15 at = 95 per cent Mod AASTHO compaction and OMC[d]	

Committee of State Road Authorities, 1990 (Draft THR20, 1990)

IO = Oversize Index (per cent retained on 37,5 mm sieve)

Sp = Linear shrinkage x per cent passing 0,425 mm sieve

GC = (Per cent passing 26,5 mm – per cent passing 2,0 mm) x per cent passing 4,75 mm/100

Table 4.7 was drawn by the researcher following the completion of material tests that were carried out on samples that were obtained from respective monitored test sections. Table 4.7 was drawn to classify and analyse respective GWC materials test findings. The findings were then used to analyse root causes or factors influencing the rate of gravel loss on each monitored test section.

Table 4.7 highlights the properties that are considered essential for analysing material's behaviour and performance as far as gravel loss is concerned, with plasticity factor and material's grading the leading ones.

Table 4.7 Data analysis based on material classification

Material	Climate Zone	Traffic Category	Maximum Size (37.5mm)	Oversize Index Io (5 per cent)	Shrinkage Product (Sp) 100-365	Grading Coefficient (Gc) 16-34	Plasticity Index (PI)	CBR @ 95% Mod AASHTO & OMC =15	Maximum Dry Density (kg/m³)	TRH 14 Classi-fication (1985)	Material Perfor-mance
Shale	Humid	200-400	63	22%	81,18	14,69	9,1	16(10)	2169	G9	Ravels & Corrugates
Shale	Humid	400-600	41	6%	22,4	16,45	6,2	4(6)	2167	NA	Ravels & Corrugates
Shale	Humid	>600	38,6	3%	75,2	31,71	4,2	12(5)	2168	G9	Ravels & Corrugates
Shale	Dry Sub-Humid	200-400	38	11%	47,52	15,08	15,8	10(5)	2190	G9	Ravels & Corrugates
Shale	Dry Sub-Humid	400-600	45,4	9%	49,8	21,88	6,1	17(8)	2253	G8	Ravels & Corrugates
Shale	Dry Sub-Humid	>600	46,7	11%	29,43	17,84	13,9	7(10)	2083	G10	Ravels & Corrugates
Dolerite	Humid	200-400	64,8	29%	97,68	10,24	18,8	25(18)	1791	G7	Ravels & Corrugates
Dolerite	Humid	400-600	42	6%	62,4	23,16	7,3	6(3)	2179	G10	Ravels & Corrugates
Dolerite	Humid	>600	38	8%	132,72	22,94	8,4	12(6)	2010	G9	Good
Dolerite	Dry Sub-Humid	200-400	37,8	1%	159,39	30,3	9,7	29(6)	2372	G8	Good

Material	Climate Zone	Traffic Category	Maximum Size (37.5mm)	Oversize Index Io (5 per cent)	Shrinkage Product (Sp) 100-365	Grading Coefficient (Gc) 16-34	Plasticity Index (PI)	CBR @ 95% Mod AASHTO & OMC =15	Maximum Dry Density (kg/m³)	TRH 14 Classi-fication (1985)	Material Perfor-mance
Dolerite	Dry Sub-Humid	400-600	56	21%	29,7	16,04	5,3	32(5)	2378	G7	Ravels & Corrugates
Dolerite	Dry Sub-Humid	>600	59,6	22%	92,69	19,07	5	6(10)	2054	G10	Ravels & Corrugates

Compiled by Gugulethu Ndlovu

4.3 Gravel loss discussions

4.3.1 Discussions on gravel loss and influencing material properties.

It is desirable that the GWC materials located in dry climate regions have high PI and those that are in wet climate regions have low PI. The reason for this preference is that if a material with high plasticity content is exposed to prolonged period of rainfall it results in a weak GWC layer and the development of rutting of the GWC material. The development of rutting is due to loss of material strength. Therefore, a high plasticity material in wet region results in a worse performing GWC. On the other side, materials with high PI are desirable for gravel roads located on dry climate regions. This is due to the low frequency of rain on gravel roads located in dry climate regions.

A gravel material with high PI content keeps the GWC aggregates bonded and hence resist a high rate of gravel loss. When a GWC material has low PI content on a dry climate region, it fails to bind large aggregates together and this results in disintegration of particles and influence gravel loss.

Gravel road monitored test sections of this study were located both in humid and dry sub-humid, which corresponds with wet and moderate climate regions respectively in accordance with Weinert N climate regions.

In accordance with material codes mentioned on TRH14 page 3, all the monitored test sections of this study are either within the selected layer or subgrade layer classification category i.e., G7-G10 gravel-soil. One monitored site (D770) which is surfaced with shale and in humid region with a traffic count ranging 400-600 vpd, could not be classified in terms of TRH14, meaning material properties of this site did not even match the G10 quality requirements. However, it should be noted that although its GWC material quality had deteriorated beyond the subgrade requirements, its PI was within an acceptable range that matches with higher material categories i.e., G2, G3 and G4 which should be a minimum of 6%. There was a notable higher rate of gravel loss on D770 when compared to P734 which is surfaced with shale and within the humid region as well, but with a traffic count higher than of D770. It can be concluded that the higher gravel loss rate on D770 than P734 is linked to its GWC quality which had deteriorated further than the one required for subgrades.

TRH14, 1994 states that G7 materials should have a maximum aggregate size not greater than two thirds of the compacted layer thickness after compaction. This means that for a GWC of 150mm thickness, a maximum acceptable aggregate size after compaction should be 100mm in thickness. When considering all monitored test sections of this study with GWC classified as G7 the maximum aggregate size was 64,8mm. There are no grading requirements from a G8-G10 natural gravel material categories in terms of TRH14. However, all sites with GWC material classified as G8-G10 and including one site which is unclassifiable, met the G7 acceptable maximum aggregate grading since they had maximum aggregate size ranging from 38-63.

On figure 4.3 two monitored test sections' GWC materials fell within a good material classification category. Those sections had same material which is dolerite but were in different climate regions and fell within different traffic ranges. What can be highlighted from their materials test results is that their maximum aggregate sizes were within the recommended value of 37,5mm and their oversize index fell within the acceptable range which is 5% in line with TRH20 guideline. Their materials' PI fell within an acceptable range of 6-12 percent as per TRH14's recommendation. The said PI range is actually the recommended one for G2 and G3 graded gravel as well as G4 natural gravel. One of sites with good material is P355 which had the lowest annual gravel loss amongst all sites. In overall this highlights the positive impact of material compliance to the recommended material plasticity and grading requirements, and that compliance to the latter does resist losing gravel material at a high rate.. Since P355 is classified as having G8 quality, the latter findings also highlight that even if gravel material is of lower quality but if its aggregate distribution and plasticity requirements are met, its rate of gravel loss can still be low. Considering the presented data and Appendix 1-4 test results, GWC material of most sites had good aggregate grading and PI even though their quality was low i.e., G9.

4.3.1.1 Shale – humid

i. The GWC material of all three monitoring sections ravels and corrugates.

ii. The average oversize index is 10%, which is more than the recommended 5%.

iii. Shrinkage product – for all three monitoring sections, the shrinkage product (Sp) is below the minimum recommended value of 100.

iv. The grading co-efficient shows that 2/3 of the monitoring sections are within the recommended range of 16-34 and the other one is slightly below the minimum recommended value as per TRH 20 requirements.

v. The average CBR @ 95% Mod AASHTO and OMC is 11, which is less than the recommended value of 15.

vi. The average Maximum Dry Density @ 95% compaction is 2168 kg/m^3

vii. The average PI is 6.5.

viii. The GWC material complies with the G9 requirements in terms of Committee of State Road Authorities, 1985 (TRH 14, 1985).

4.3.1.2 Shale – dry sub-humid

i. The GWC material of all three monitoring sections ravels and corrugates.

ii. The average oversize index is 15%, which is more than the recommended 5%.

iii. The shrinkage product for all three monitoring sections is below the minimum recommended value of 100. The average Sp is 42.25.

iv. The grading co-efficient shows that 2/3 monitoring sections are within the recommended range of 16-34 and the other one is slightly below the minimum recommended value.

v. The average CBR @ 95% Mod AASHTO and OMC is 11, which is less than the recommended value of 15.

vi. The average Maximum Dry Density @ 95% compaction is 2175 kg/m³.
vii. The average PI is 12.
viii. The GWC material complies with the G9 requirements in terms of Committee of State Road Authorities, 1985 (TRH 14, 1985).

4.3.1.3 Dolerite – humid

i. The GWC material of two of the three monitoring sections ravels and corrugates. The remaining section is good.
ii. The average oversize index is 14%.
iii. The shrinkage product for two of the three monitoring sections is below the minimum recommended value of 100. the average Sp is 97.6
iv. The grading co-efficient shows two of the three monitoring sections are within the recommended range of 16-34 and the remaining one is below the minimum recommended value.
v. The average CBR @ 95% Mod AASHTO and OMC is 14, which is slightly less than the recommended value of 15.
vi. The average Maximum Dry Density @ 95% compaction is 1993.
vii. The average PI is 11.5.
viii. The GWC material complies with the G9 requirements in terms of Committee of State Road Authorities, 1985 (TRH 14, 1985).

4.3.1.4 Dolerite – dry sub-humid

i. The GWC material of two of the three monitoring sections ravels and corrugates. The remaining one is good
ii. The average oversize index is 15%, which is more than the maximum recommended value of 5%.
iii. The shrinkage product for two of the three monitoring sections is below the minimum recommended value of 100. the average Sp is 93.9.

iv. The grading co-efficient shows that all three monitoring sections are within the recommended grading co-efficient range of 16-34.

v. The average CBR @ 95% Mod AASHTO and OMC is 14, which is slightly less than the recommended value of 15.

vi. The average Maximum Dry Density @ 95% compaction is 2268.

vii. The average PI is 6.6.

viii. The GWC material complies with the G8 requirements in terms of Committee of State Road Authorities, 1985 (TRH 14, 1985).

4.4 Analysis and findings for validation of KZN-DoT's prioritisation methodology

4.4.1 Presentation of results

Figure 4.4 shows the average traffic counts under each priority rank (A-E) for both KZN-DOT's prioritisation model as well as the ones used by the researcher to validate the KZN-DoT model. Priority A represents the highest rank and E the lowest one:

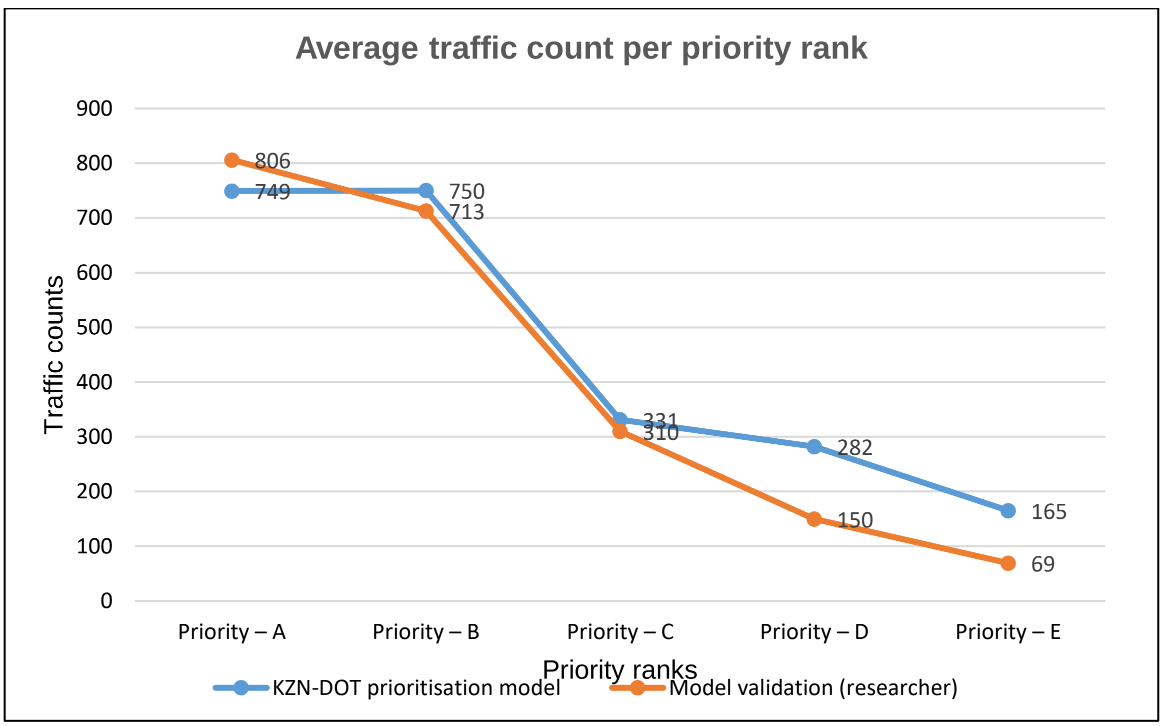

Figure 4.4 Average traffic counts under each priority rank.

Table 4.8 was drawn by the researcher to show the differences between the methodology used by KZN-DoT when prioritising gravel roads upgrade and the one used by the researcher in validating the KZN-DoT's prioritisation methodology. The researcher collated data from KZN-DoT's prioritisation model and arranged it as shown in Table 4.8. Information collected includes the number of provincial gravel roads that were considered by KZN-DoT when prioritising, the traffic count data used, as well as the traffic baseline that KZN-DoT used to select roads to prioritise. In validating KZN-DoT's prioritisation methodology, the researcher selected all gravel roads within the study area whereas the KZN-DoT model only considered gravel roads with a traffic count of 200 and more. The traffic data that was used by the researcher was taken from the KZN-DoT's Road asset management data file. In Table 4.8 the phrase 'enhanced model' refers to the KZN-DoT's model validation that was carried out by the researcher.

Table 4.8 Project selection methodologies for KZN-DoT's and enhanced model

Prioritisation Approach: Differences in KZN-DoT and enhanced model		
Comments	**KZN-DoT model**	**KZN-DoT Model validation**
1. Total no. of KZ222 provincial roads considered on the model	82	118
2. Traffic baseline considered in selecting the segments to be compared	200vpd	No baseline used. All gravel roads were prioritised
3. Average traffic count when not considering PCE adjustment:		
Very high priority – A	749	806
High priority – B	750	713
Medium priority – C	331	310
Low priority – D	282	150
Very low priority – E	165	69
4. Average traffic count when considering PCE adjustment:		
Very high priority – A	NA	1183
High priority – B	NA	1124
Medium priority – C	NA	383
Low priority – D	NA	183
Very low priority – E	NA	90

Table 4.9 shows the KZN-DoT's gravel roads ranked in the order of their priorities. Priorities shown in Table 4.9 are KZN-DoT's project priorities.

Table 4.9 Priorities of the KZN-DoT model

No.	Priority A Top 5%	Priority B 5-20%	Priority C 20-40%	Priority D 40-70%	Priority E >70%
1	P130 (3)	P390(1)	P165 (2)	P165 (1)	P145(1)
2	P526	D1129(5)	P28-2 (2)	P130(1)	D17 (1)
3	P9	D292(1)	P130 (2)	D369 (2)	D17 (2)
4	no data	D292 (2)	P165 (3)	P144 (1)	D507
5	no data	P548 (1)	P28-2 (1)	P144 (4)	D794
6	no data	P143	D1129(4)	P133 (3)	D369 (1)
7	no data	no data	D1129(2)	P132	P145(4)
8	no data	no data	D1129(1)	D2069	P144 (2)
9	no data	no data	D1129(3)	P134(3)	P144 (3)
10	no data	no data	P133 (1)	D16	D710
11	no data	no data	D709	P133(5)	D406
12	no data	no data	D293(3)	D174	P134(2)
13	no data	no data	D290 (2)	D293 (1)	P134(4)
14	no data	no data	P548(2)	D815	D369 (3)
15	no data	no data	no data	D290 (1)	P134(1)
16	no data	no data	no data	no data	P162
17	no data	no data	no data	no data	P133(4)
18	no data	no data	no data	no data	D534
19	no data	no data	no data	no data	D814
20	no data	no data	no data	no data	D2345
21	no data	no data	no data	no data	D18(1)
22	no data	no data	no data	no data	D18(2)
23	no data	no data	no data	no data	D182
24	no data	no data	no data	no data	D287
25	no data	no data	no data	no data	P133(2)
26	no data	no data	no data	no data	P145(2)
27	no data	no data	no data	no data	D293(2)

Table 4.10 shows the KZN-DoT's gravel roads ranked in the order of their priorities. Priorities shown in Table 4.10 are priorities from the enhanced model, the one used to validation KZN-DoT's priorities.

Table 4.10 Priorities of the enhanced model

No.	Priority A Top 5%	Priority B 5-20%	Priority C 20-40%	Priority D 40-70%	Priority E >70%
1	P130 (3)	P390(1)	L2698	P134(2)	L1472
2	P165 (2)	P165 (1)	D17 (2)	D174	L1927
3	P28-2 (2)	P145(1)	P144 (4)	P134(4)	D183(1)
4	P130 (2)	P130(1)	P367	D369 (3)	L1464
5	P165 (3)	D1129(5)	D369 (1)	P134(1)	D494
6	P526	P9	D507	P133(4)	D183(2)
7	no data	P28-2 (1)	D794	P162	L75
8	no data	D1129(4)	P133 (3)	D293 (1)	L2698
9	no data	D1129(2)	P144 (2)	D534	D745
10	no data	D1129(1)	P144 (3)	D814	L1891
11	no data	D1129(3)	P143	P163 (2) N	P366
12	no data	D292(1)	D290 (2)	D18(2)	D361
13	no data	D292 (2)	P548(2)	D18(1)	D533
14	no data	P548 (1)	D2069	D815	D2245
15	no data	P133 (1)	L805	D290 (1)	L2539
16	no data	P144 (1)	P134(3)	L805	D765
17	no data	D369(2)	P145(4)	D544 (2)	L1942
18	no data	P144 (1)	D16	P163 (1)	D2377
19	no data	no data	P133(5)	P133(2)	D244
20	no data	no data	D709	D287	L3135
21	no data	no data	D710	D293(2)	D768
22	no data	no data	D293(3)	D734	L2839
23	no data	no data	D406	P145(2)	D2078
24	no data	no data	P132	D515	D830
25	no data	no data	no data	D2477	D793
26	no data	no data	no data	D544 (1)	D707
27	no data	no data	no data	D16	L1477
28	no data	no data	no data	P145(3)	D574
29	no data	no data	no data	L733	L312
30	no data	no data	no data	D2345	D735
31	no data	no data	no data	L1928	D156
32	no data	no data	no data	D546	L3394
33	no data	no data	no data	D2077	L1520
34	no data	no data	no data	D666	D795
35	no data	no data	no data	D182	L3000

Table 4.11 presents enhanced model's priorities after adjusting traffic counts by PCE. The impact made by adjusting traffic counts by PCE is discussed on item 4.5.2

Table 4.11 Adjusted traffic counts' effect

No.	Priority A Top 5%	Priority B 5-20%	Priority C 20-40%	Priority D 40-70%	Priority E >70%
1	P130 (3)	P390(1)	L2698	P134(2)	D183(1)
2	P165 (2)	P165 (1)	D17 (2)	D174	L1927
3	P28-2 (2)	P145(1)	P144 (4)	P134(4)	L1472
4	P130 (2)	P130(1)	P367	D369 (3)	L1464
5	P165 (3)	D1129(5)	D507	P134(1)	D494
6	P526	P9	D794	P162	D183(2)
7	no data	P28-2 (1)	D369 (1)	P133(4)	L75
8	no data	D1129(4)	P145(4)	D293 (1)	L2698
9	no data	D1129(2)	P133 (3)	D534	D745
10	no data	D1129(1)	P144 (2)	P163 (2) N	D533
11	no data	D1129(3)	P144 (3)	D814	D361
12	no data	D292(1)	D710	D2345	P366
13	no data	D292 (2)	P143	D815	L1891
14	no data	P548 (1)	D709	D18(1)	D765
15	no data	D369 (2)	D293(3)	D18(2)	L2539
16	no data	D17 (1)	D290 (2)	L805	D2245
17	no data	P133 (1)	P548(2)	D290 (1)	D2377
18	no data	P144 (1)	D406	P163 (1)	L1942
19	no data	no data	P132	D182	D244
20	no data	no data	D2069	D544 (2)	L2839
21	no data	no data	L805	D287	D768
22	no data	no data	P134(3)	P133(2)	L3135
23	no data	no data	D16	P145(2)	D2078
24	no data	no data	P133(5)	D734	D830
25	no data	no data	no data	D293(2)	D793
26	no data	no data	no data	D515	L1477
27	no data	no data	no data	D2477	D707
28	no data	no data	no data	D544 (1)	D574
29	no data	no data	no data	D16	D156
30	no data	no data	no data	P145(3)	D735
31	no data	no data	no data	L733	L312
32	no data	no data	no data	L1928	L3000
33	no data	no data	no data	D546	D795
34	no data	no data	no data	D2077	L1520
35	no data	no data	no data	D666	L3394

Presented on Table 4.12 are the enhanced model's priorities with the Public Transport Route (PTR) factor considered. Although the PTR was listed as one of KZN-DoT's prioritisation factors, but it was never considered during their gravel road upgrade prioritisation, and a need to check its effect on priorities was identified by the researcher. This research found that most of PTR were already paved and very few were still gravel surfaced at the time of validating KZN-DoT's prioritisation model. Those few that are still unpaved are under priority A-B, and no major movement from one priority group to the other was noted on project priorities because of considering PTR.

Table 4.12 Priorities influenced by Public Transport Route on priorities.

No.	Priority A Top 5%	Priority B 5-20%	Priority C 20-40%	Priority D 40-70%	Priority E >70%
1	P130 (3)	P165 (1)	L2698	D16	D183(1)
2	P165 (2)	P390(1)	D17 (2)	P134(1)	L1927
3	P28-2 (2)	P130(1)	P145(4)	P133(5)	L1472
4	P130 (2)	D1129(5)	P144 (4)	P163 (2) N	L1464
5	P165 (3)	P145(1)	P367	D174	D494
6	P526	P9	D507	P163 (1)	D183(2)
7	no data	D1129(4)	D794	D369 (3)	L75
8	no data	P28-2 (1)	D369 (1)	P162	L2698
9	no data	D1129(2)	P133 (3)	P133(4)	D745
10	no data	D1129(1)	P144 (2)	D293 (1)	D533
11	no data	D1129(3)	P144 (3)	D534	D361
12	no data	D292(1)	D710	D814	P366
13	no data	D292 (2)	P143	D2345	L1891
14	no data	P548 (1)	D406	D815	D765
15	no data	D369 (2)	D709	D18(1)	L2539
16	no data	D17 (1)	D293(3)	D18(2)	D2245
17	no data	P133 (1)	D290 (2)	L805	D2377
18	no data	P144 (1)	P548(2)	D290 (1)	L1942
19	no data	no data	P134(3)	D182	D244
20	no data	no data	P132	D544 (2)	L2839
21	no data	no data	D2069	D287	D768
22	no data	no data	P134(2)	P133(2)	L3135
23	no data	no data	P134(4)	P145(3)	D2078
24	no data	no data	L805	P145(2)	D830
25	no data	no data	no data	D734	D793
26	no data	no data	no data	D293(2)	L1477
27	no data	no data	no data	D515	D707
28	no data	no data	no data	D2477	D574
29	no data	no data	no data	D544 (1)	D156
30	no data	no data	no data	D16	D735
31	no data	no data	no data	L733	L312
32	no data	no data	no data	L1928	L3000
33	no data	no data	no data	D546	D795
34	no data	no data	no data	D2077	L1520
35	no data	no data	no data	D666	L3394

4.4.2 Discussion of research findings

i. No huge differences were noted in terms of the average traffic count found in priority C-A category list of both prioritisation strategies. Refer to figure 4.4.

ii. Adjustment of traffic counts by applying PCE values had no major impact on roads listed under priority A-B, and the effects of adjusting traffic counts affected priority C-E category. Adjusting traffic counts by PCE values resulted in some of the gravel road segments that previously had traffic counts lower than the set traffic baseline for project selection to holding higher ranks on the final project priority list than some of those that previously met the selection criteria prior to the adjustment of the traffic counts. However, when comparing priorities of KZN-DoT and enhanced model without adjusting traffic counts, for priority A category, two similar gravel roads are appearing on both models. The difference is that KZN-DoT had three roads listed under priority A whereas on the enhanced one there are six roads listed under priority A. This could be because of considering all roads under study area and not using traffic baseline to select roads for prioritisation. For priority B most of road's priorities are the same but there are more roads appearing on the enhanced model than on the KZN-DoT's one. From priority C-E road priorities differ significantly, and again the reason to this could be the difference in road selection criteria used on respective models.

iii. Some of the gravel road segments with a high traffic count ended up being lower on the priority ranks. Some of the low-order gravel roads hold higher ranks on the project priority list than higher-order gravel roads. KZN-DoT needs to assess and reclassify some gravel roads based on their present functionality. From figure 4.4 it is observed that traffic counts increase in the order of priority groups, and this proves the significance of considering traffic as a critical factor.

iv. With reference to figure 4.4, Priority C is regarded as a medium priority category. Projects which are listed under Priority C – A can be programmed for gravel road upgrade. An average traffic count found under Priority C under both models is 300vpd. Considering priority groups and their order of importance, an average traffic count found under Priority C justifies the need to upgrade a gravel roads to paved standard. However, to reach final conclusions, each gravel road forming part of the top priority list should be further assessed for their economic viability in terms of both options, paving versus keeping them as gravel roads. The decision on the extent of the gravel road network to pave each year would be determined by available budget.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Based on the outcomes of this research, it can be concluded that the performance of a gravel road is indeed sensitive to traffic volume, climate, and the GWC material deployed on it. Then, based on that, the road authorities should consider carrying out long-term surveys on their gravel road network to understand each gravel road's performance, predict their deterioration pattern and plan for their maintenance and upgrading timeously. Assessment of an appropriate time to upgrade a gravel road to paved should commence at a project level whereby each gravel road's deterioration pattern can be predicted proactively to plan for future maintenance needs and costs of upgrading each gravel road.

The onus is left with the KZN-DoT and other stakeholders to decide on their preferred tool or system to use for the economic analysis of upgrading a gravel road or retaining it unpaved and on how they tailor their existing prioritisation methodologies to incorporate a system of carrying out economic analysis.

Based on predicted gravel losses as presented on chapter 4, it can be concluded that the re-gravelling frequencies of the KwaZulu-Natal provincial gravel roads with shale or dolerite gravel wearing courses vary between 6-8 years, 4-5 years and 3-4 years for traffic within the ranges of 200-400 vpd, 400-600 vpd and greater than 600 vpd, respectively.

The following are recommendations which are in line with research questions and objectives:

i. To be ascertain of when to upgrade a gravel road, outcomes of the GL study and re-gravelling maintenance records as well as carrying out of economic analysis should give an indication of when to upgrade each gravel road. The timing of upgrading gravel road cannot be the same for all gravel roads.

ii. In terms of additional required factors, KZN-DoT should consider developing or adopting a well-suited economic analysis model to check economic viability of upgrading their gravel roads during prioritisation stage. It is recommended that when economic analysis is performed gravel roads' maintenance and capital costs be compared with the seal type that is most viable for that road. It is also recommended that the traffic composition be considered as a factor by adjusting traffic counts by PCE values and this will assist in establishing fair comparisons when selecting gravel roads for upgrade prioritisation.

iii. The traffic baseline used by the KZN-DoT for gravel road selection is theoretical correct based on the reviewed literature. However, a traffic baseline that justifies the upgrading of gravel roads to paved cannot be the same for all roads since their upgrading costs cannot be the same due to the variation of factors like founding materials and the availability of suitable material within a reasonable radius of each road. In addition, it would be ideal and fair to do economic analysis of each unpaved road meeting the criteria separately, meaning not using an average costing approach but rather an applicable project-specific cost estimate for the upgrading and maintenance of each road being assessed. This will allow for fair comparisons of both options.

iv. It is recommended that the traffic baseline change slightly to accommodate gravel roads with traffic volumes from 100 vpd based on the KZN-DoT's model validation's finding that some of the gravel roads that had traffic counts of 100 vpd and more made it through to higher priority rankings.

v. Based on the findings and results the KZN-DoT's prioritisation methodology is ideal; however, it needs enhancement on certain areas as per the above recommendations.

vi. Recommendation for future research is that a GL study be conducted on other dominant GWC materials which were not considered for this study i.e., sandstone and granite to understand their deterioration in terms of GL.

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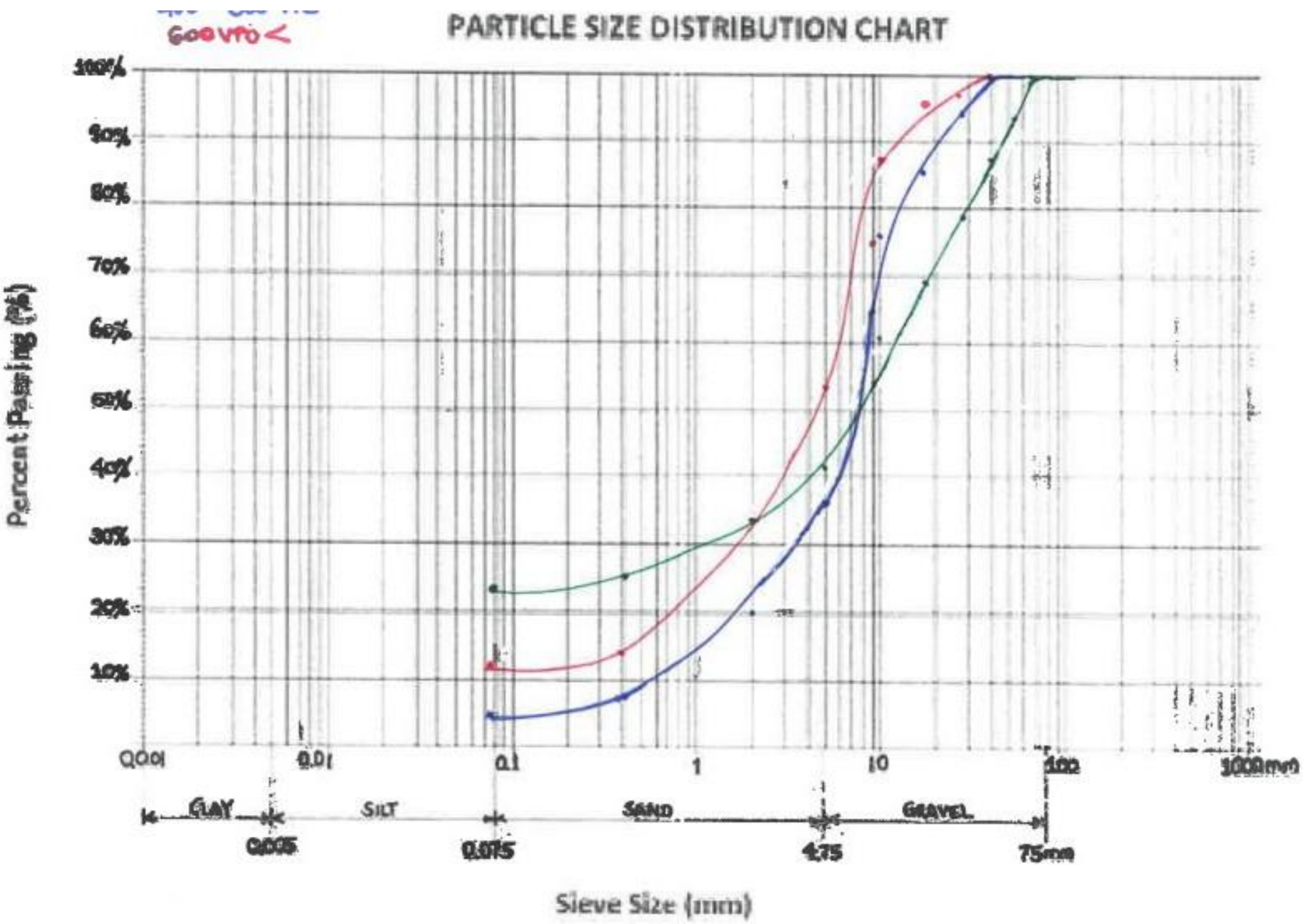
APPENDICES

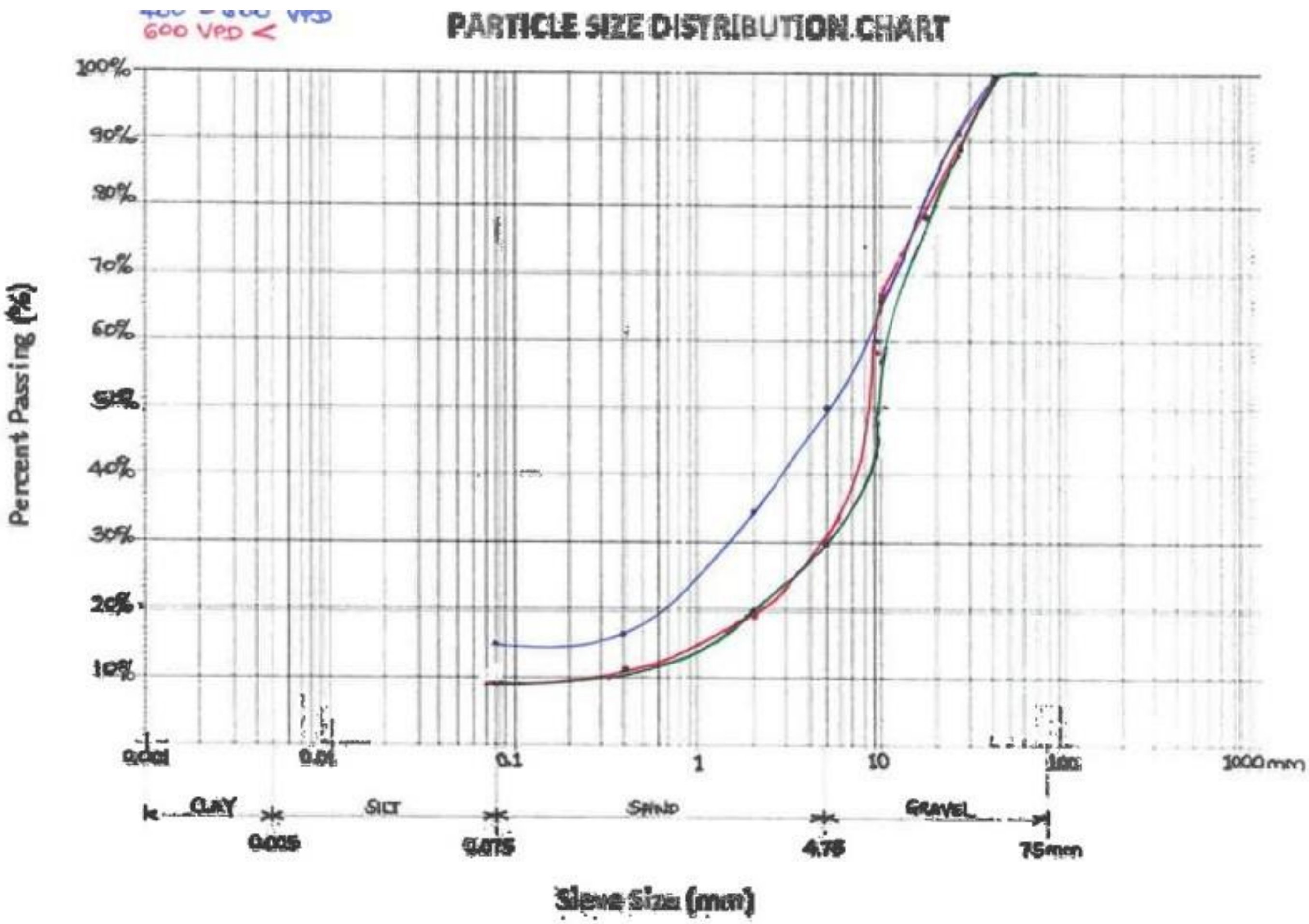
Appendix 1 Grading analysis results – shale in humid

200-400 vpd 400-600 vpd >600 vpd



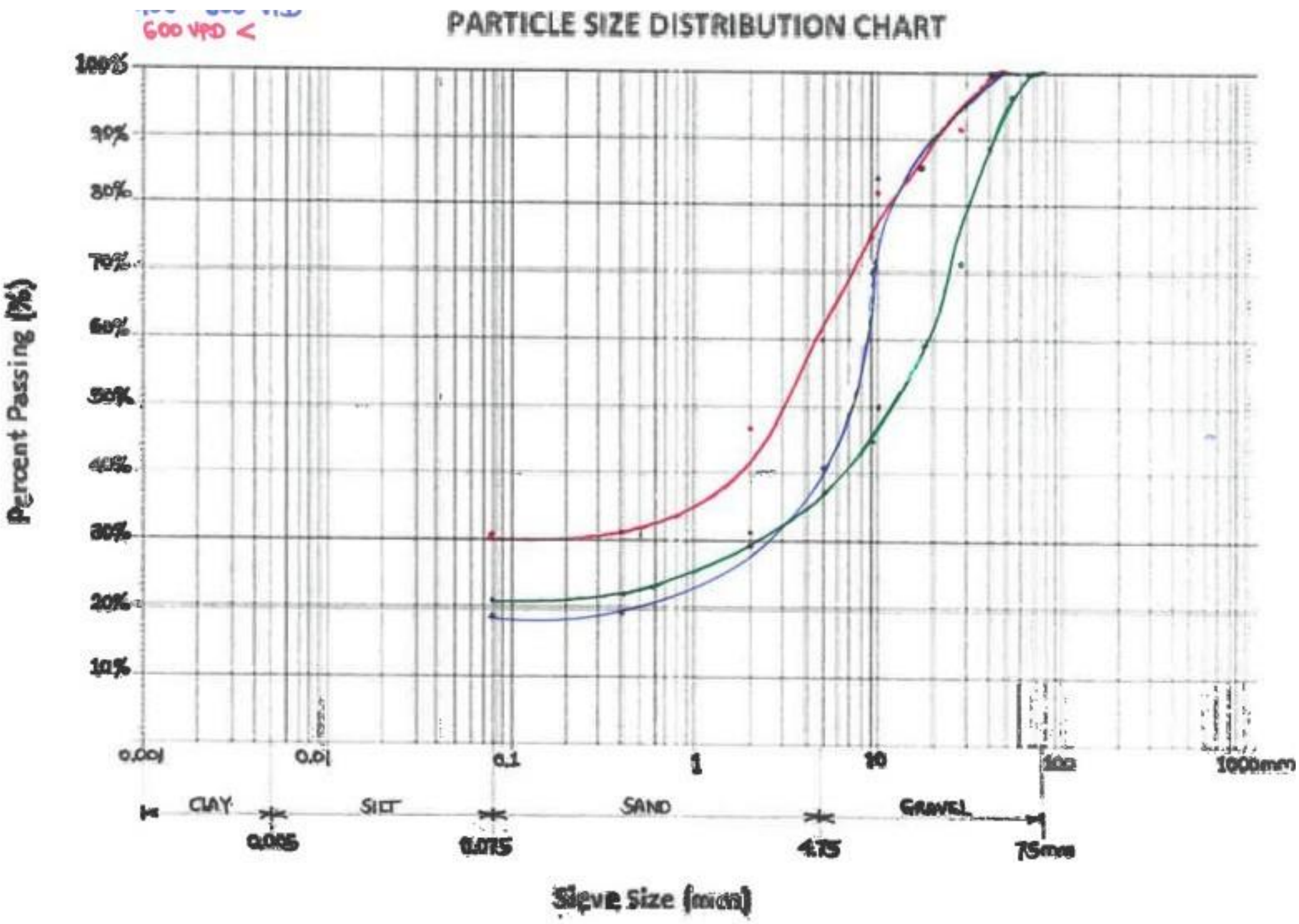
Appendix 2 Grading analysis results – shale in dry sub-humid

200-400 vpd 400-600 vpd >600 vpd



Appendix 3 Grading analysis results – dolerite in humid

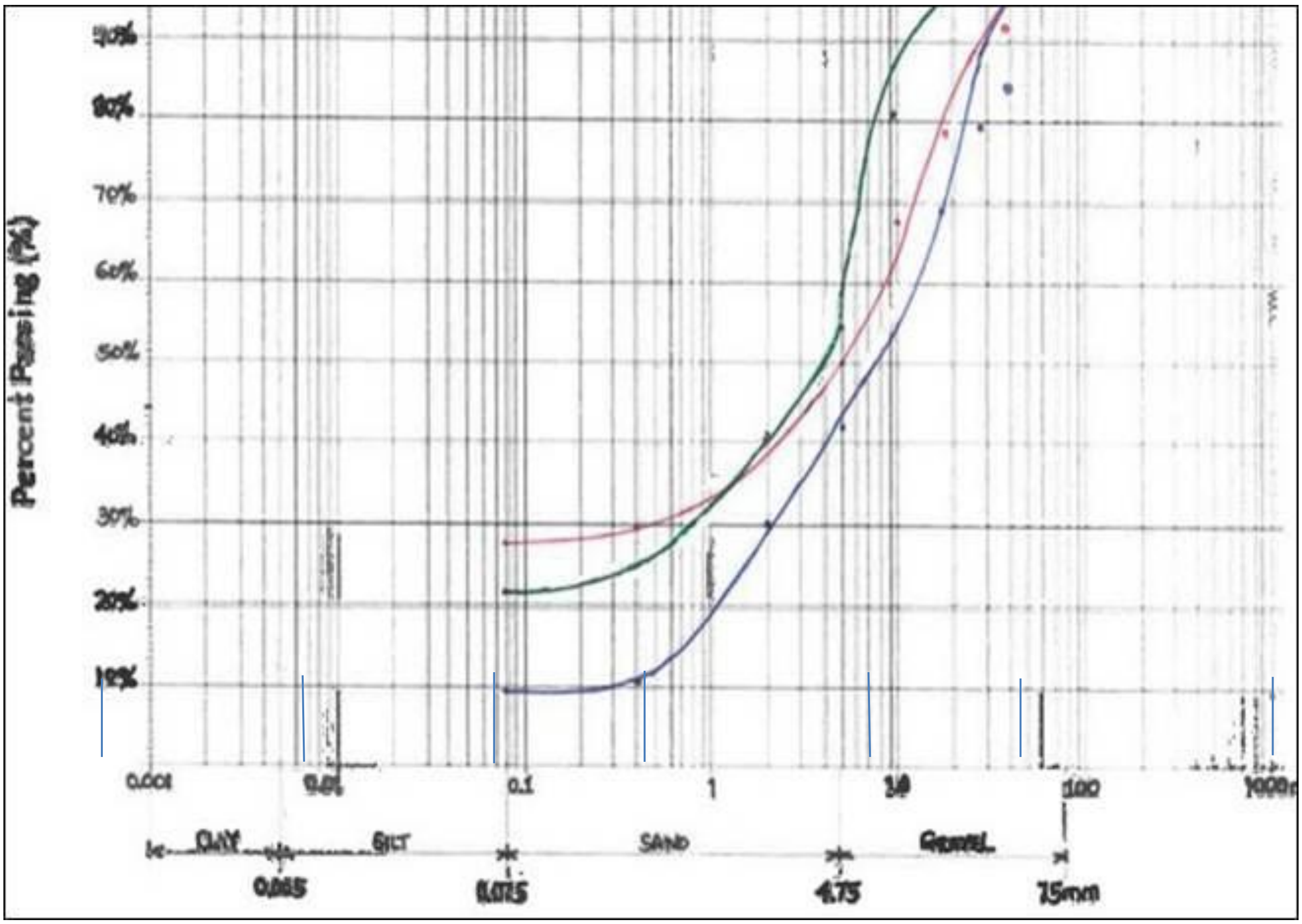
200-400 vpd 400-600 vpd >600 vpd



Appendix 4 Grading analysis results – dolerite in dry sub-humid

200-400 vpd 400-600 vpd >600 vpd

PARTICLE SIZE DISTRIBUTION



Appendix 5 Proof of editing

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