University of Southern Queensland

Faculty of Health, Engineering and Sciences

Low Volume Road Development and Maintenance

A dissertation submitted by

Timothy Raine

[redacted]

In fulfillment of the requirements of

ENP4111 – Professional Engineer Research Project

Towards the degree of

Bachelor of Engineering (Honours) (Civil)

Submitted November 2024

This page intentionally left blank

University of Southern Queensland

School of Engineering

ENP4111 Dissertation Project

(This is a 2-unit research project in Bachelor of Engineering Honours Program)

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Student Name: Timothy Raine

Student Number: [redacted]

[redacted]

Signature

4/11/2024

Date

Abstract

Throughout Australia, Low Volume Roads (LVR) encompass a large number of rural roads, connecting regional communities to each other and offering routes for mining equipment, raw materials to and from mines as well as local health and recreational services. Due to the relatively low average daily vehicle rate for these roads, federal, state and local funding is rather small if any as compared to larger, more occupied roadways.

The following research project aims to assess sample low volume roads and provide an insight into the economic viability and priority of repairs for the low volume road. This is to be tested through the development of research models to both determine whether a simple low volume road repair is more economic than a complete renovation of the section, as well as a model to effectively provide an accurate ranking of road segments required to be repaired and providing the most cost-effective repair technique for the required road characteristic. This was completed through the prolonged phase of research and analysis. The research project delivers on this with the development of a model to accurately outline the hierarchy of road segment repair with respect to road segment importance.

The results for this research project showcase the effectiveness of performing periodic maintenance strategies to segments of the road over that of complete reconstruction and rehabilitation of the roadway. This indicates the findings of neglecting roads for the duration of their design life is counterproductive and inefficient in the long-term planning schemes for low volume roads. These consistent inspections enable engineers to detect any signs of degradation or wear and tear, allowing for the most appropriate and cost-effective repair strategy or mitigation technique to be applied, leading to the road in most cases far exceeding the initial design life figure stated.

Utilising this approach, appropriate budget allocations can be introduced instead of the established practices currently being employed when discussing low volume roads. In addition to this, the adopted practice in this research paper supports the long-term economic growth of the region and if scheduled and maintained properly, can significantly reduce the level of disruption that the maintenance works would usually cause. Implementing these findings into the scheduling and budgetary responsibilities for low volume roads will assist agencies such as regional councils effectively manage these low volume roads with a higher level of efficiency as to ensure even in reduced budgetary conditions, these low volume roads will have appropriate funding and methodologies.

Acknowledgements

Special thanks to my project supervisor David Thorpe, for providing support and feedback on this project throughout this year long endeavour. Thank you for continually pointed me in the right direction.

Table of Contents

List of Tables

List of Figures

Glossary

AADT – Average Annual Daily Traffic.

Capacity – The maximum number of vehicles which can reasonably be expected to pass through an area of road during a specified time period.

CBR – California Bearing Ratio.

Cross Section – The profile of a road showing dimensions and shape.

Design Vehicle – A vehicle chosen to act as a control for operating conditions of the road.

GDP – Gross Domestic Product.

Infiltration – Movement of water from the surface level to the soil profile.

LVR – Low Volume Road.

OMC – Optimum Moisture Content.

Superelevation – On curved roads, the increase in crossfall to provide a one-way crossfall on the curve.

Table Drain – Drainage running along the side of the roadway.

Chapter 1: Introduction

1.1 Aim

The proposed research project aims to provide further insight and assess the condition of Low Volume Roads within rural or isolated areas by examining the economic, geotechnical and social implications of the Low Volume Roads within their communities. This data will then be used to provide recommendations for the process of upgrading LVR's at a cost-efficient rate with mechanically appropriate methods as compared to entirely reconstructing the road section, which would be difficult to accomplish due to the current budgeting status for LVR's. These LVR's are vitally important to the small communities they connect, proving them to be a significant step forward for civil engineers to effectively tackle in the coming future.

1.2 Background

Low Volume Roads encompasses a vast number of roads within rural or isolated areas within Australia, connecting small towns or communities, often traversing a series of harsh terrains that may become overly altered and impassable during extreme weather events. Low Volume Roads also often are used to transport raw materials from locations such as mines and deliver them to the required destination, as well as provide direct routes for emergency health services, travelling to and from schools and to nearby recreational amenities. These LVR's often receive significantly less funding from the government due to the overall AADT of the road, and therefore don't obtain the required upkeep they need to effectively perform the required task set. Low Volume Roads potentially range from sealed asphalt roads to unsealed gravel roads and earth formed roads with no additional construction materials, simply a compacted dirt track used for transportation.

This project will assess the economic, safety and geotechnical implications associated with the low volume road systems within rural communities, this will be accomplished through the assessment of previous literature and valuation of existing AADT data, construction/ management techniques and economic requirements necessary for such road management and repairs.

1.3 Issues

The main issues that this proposed research project will address include the following issues:

1. Economic Implications of low volume roads.
2. Effective Repair of pavement design for considered surface types.

1.4 Outcomes and Benefits

There are several expected outcomes and benefits that will be created through the completion of this project:

Outcomes:

- A greater understanding of LVR's pavement design and repair approaches.
- Further grasp on efficient practises for construction and maintenance of LVRs.
- Further understanding of cost-effective design principles for LVRs.
- Room for growth in the development of regional areas.

Benefits:

- Increased stimulation of Low Volume Road projects.
- Continuation of pavement maintenance techniques.
- Improved access for local schools, recreational areas, medical facilities and agricultural hubs.
- Increased job opportunities for Civil Engineers.
- Minimize environmental impact of low volume roads for the use of non-renewable resources.

Chapter 2: Literature Review

2.1 Established Knowledge

2.1.2 Financing Low Volume Roads

One of the largest issues facing the funding of Low Volume Roads is the challenge of securing a vast level of funding for projects. The majority of Australia's Low Volume Road network falls under to the purview of local government bodies and not an overarching control body of government. This means that the entirety of funding for these projects emanates from local collected taxes, federal road grants and state government road grants (McLean, 1995).

Below are tables outlining the total Road Related Expenditures for the annual timeframe as well as the Annual Road Fees and Charges Levied by the Australian government.

Table 1: **Road Related Expenditures for 2018-2019**

Financial year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	Other	Total Government	Total Public Sector
	$ million										
1998–99	5 957.1	2 899.9	4 472.4	774.3	1 452.7	350.1	179.8	38.7	4.7	16 129.7	16 004.4
1999–00	6 006.7	3 490.1	3 488.3	916.2	1 925.0	345.2	158.0	41.1	5.4	16 375.9	16 193.7
2000–01	6 543.6	3 178.4	4 036.2	904.5	1 808.0	313.2	160.5	99.2	4.1	17 047.9	16 866.0
2001–02	6 000.2	2 955.8	4 190.5	862.3	1 931.2	348.3	141.6	119.1	4.9	16 554.0	15 694.1
2002–03	5 790.0	3 719.1	5 411.8	875.2	1 453.4	371.8	154.5	112.7	3.7	17 892.2	16 903.2
2003–04	5 636.9	3 154.3	6 190.4	687.5	1 512.1	408.3	157.1	101.5	3.1	17 851.1	17 526.8
2004–05	5 795.9	3 417.2	5 612.7	852.7	1 734.7	488.6	160.6	93.5	3.6	18 159.6	17 619.4
2005–06	5 961.8	3 260.0	5 944.2	1 002.6	1 618.6	461.7	352.5	105.5	4.8	18 711.7	18 058.5
2006–07	6 022.8	3 524.6	6 869.9	933.1	2 006.7	428.7	371.8	126.1	8.1	20 291.9	19 745.3
2007–08	6 445.4	4 050.3	8 550.2	1 017.5	2 438.1	459.6	364.3	153.7	7.8	23 487.0	23 508.5
2008–09	7 124.1	4 570.2	7 328.1	1 256.8	2 485.2	477.6	463.4	161.4	5.1	23 871.9	23 864.9
2009–10	6 615.7	4 442.0	7 369.0	1 180.1	2 343.3	597.1	373.4	185.4	7.4	23 113.4	22 902.1
2010–11	6 809.5	4 433.7	7 627.0	1 134.7	2 166.3	622.8	376.2	210.2	7.1	23 387.6	23 064.4
2011–12	7 126.6	4 177.6	8 539.8	1 274.3	2 331.0	523.5	422.1	187.2	8.5	24 590.6	24 724.5
2012–13	7 376.5	3 522.2	9 068.6	1 434.7	2 885.2	494.6	279.0	190.9	7.8	25 259.6	24 885.4
2013–14	7 054.5	4 524.4	8 070.5	1 184.6	3 047.0	471.0	314.0	265.1	7.8	24 939.0	24 733.2
2014–15	7 766.8	4 029.1	6 456.0	1 073.9	2 975.3	541.8	348.1	166.7	8.4	23 366.0	22 845.3
2015–16	9 037.3	4 002.8	5 335.3	1 339.7	2 967.5	443.3	373.0	60.1	8.1	23 567.0	24 782.9
2016–17	8 483.5	6 102.6	6 082.9	1 782.7	3 081.3	586.0	457.9	165.8	9.4	26 752.1	28 170.2
2017–18	8 994.8	8 160.2	5 759.4	1 791.8	3 135.8	539.0	618.4	167.7	10.6	29 177.8	30 775.9
2018–19	9 356.9	7 106.4	5 688.0	1 602.9	3 306.0	659.5	606.0	210.0	0.3	28 535.9	28 891.8

Table 2: **Origin of Funding for Road Projects (Queensland)**

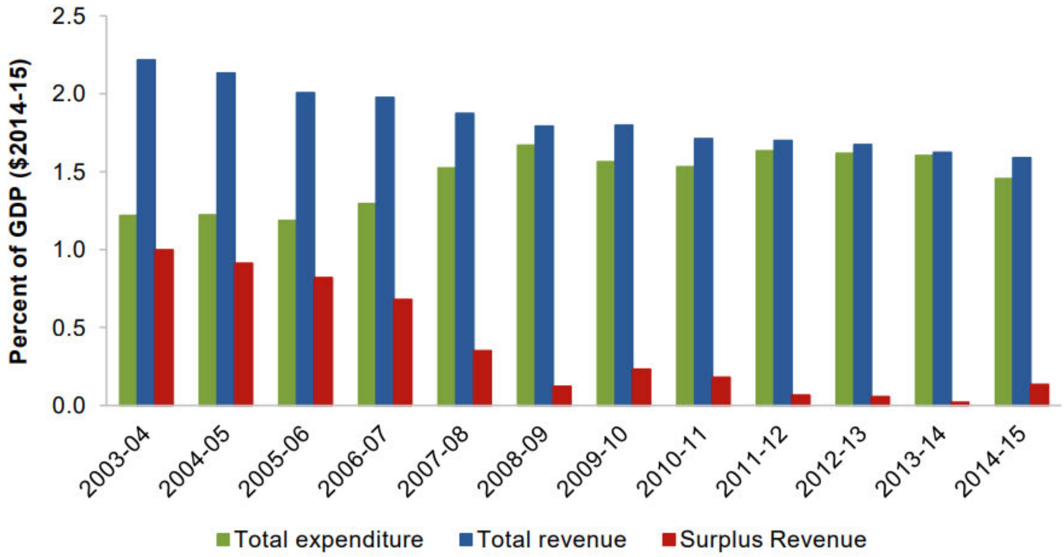
Financial year	State government expenditure – Origin of funding			Local government expenditure – Origin of funding				
	Common-wealth grants to state government	State from own sources	State gross	Direct common-wealth grants to local government	Indirect Common-wealth grants to local government via state government	State grants to local councils (excluding originating from common-wealth)	Local from own sources	Local gross
	$ million							
1998–99	588.3	2 827.0	3 415.3	0.0	119.0	488.1	1 057.1	1 545.2
1999–00	607.6	1 848.4	2 455.9	0.0	119.7	628.0	1 032.3	1 660.3
2000–01	523.3	2 595.0	3 118.3	69.3	118.1	721.0	848.7	1 639.0
2001–02	493.2	2 322.4	2 815.6	94.6	120.0	260.8	1 280.3	1 755.7
2002–03	494.1	3 181.9	3 676.0	60.0	123.8	291.3	1 675.9	2 150.9
2003–04	507.5	3 912.0	4 419.5	80.8	124.6	318.7	1 690.0	2 214.2
2004–05	507.7	3 977.4	4 485.0	62.7	123.8	333.5	1 065.0	1 585.0
2005–06	939.2	3 677.2	4 616.4	175.1	126.5	392.1	1 152.7	1 720.0
2006–07	690.8	4 812.0	5 502.8	192.6	127.5	416.3	1 174.5	1 911.0
2007–08	873.4	5 984.5	6 857.9	64.3	129.2	293.5	1 628.0	2 115.0
2008–09	2 113.4	3 302.4	5 415.8	124.5	168.2	467.0	1 787.8	2 547.4
2009–10	1 797.6	3 307.6	5 105.1	132.7	135.5	118.0	2 131.2	2 517.4
2010–11	750.3	4 578.5	5 328.8	169.4	141.7	503.3	2 128.8	2 801.6
2011–12	2 242.5	4 369.3	6 611.8	153.0	180.1	1 242.0	1 775.1	3 170.0
2012–13	703.5	6 781.3	7 484.8	76.0	138.7	1 679.8	1 507.8	3 263.6
2013–14	782.2	5 650.8	6 432.9	413.2	70.8	1 636.5	1 224.4	3 274.1
2014–15	928.1	4 120.8	5 049.0	292.7	212.0	1 378.2	1 114.3	2 785.2
2015–16	1 194.4	2 273.6	3 468.0	336.5	69.4	688.1	1 530.8	2 555.4
2016–17	1 601.6	2 542.7	4 144.3	247.9	207.2	586.4	1 690.6	2 524.9
2017–18	1 540.7	2 318.9	3 859.6	216.4	141.3	623.1	1 683.4	2 522.9
2018–19	1 221.0	2 596.0	3 817.0	84.2	143.1	729.0	1 786.8	2 600.0

Source: Sourced from BITRE 2020 *Yearbook 2020*: Australian Infrastructure Statistical Report

During 2018-19, the total encompassing road revenue collated was $28.8 billion with the largest return being gathered through means such as fuel excise, individuals taxes and charges and vehicle registration taxes and fees (Australian Government Productivity Commision, 2017) (Australian Government: Department of Infrastructure, Transport, Regional Development and Communications, 2020). With this revenue, throughout the same 2018-19 period, the Australian government spent $28.5 billion on roadwork projects nation-wide.

Fuel excise charges relate to sales tax that is levied at the people by the Australian Government for buying fuel from a bowser. The current fuel excise being enforced upon Australian motorists is levelled at 48.8 cents per litre of fuel purchased at service stations (Australian Automobile Association, 2022). There are certain exemptions for these fuel excises, with some examples being vehicles related to the industries of agricultural and mining practises receiving tax credits as well as owners of electric vehicles would not be charged a fuel excise as they don't require fossil fuels to function.

Figure 1: Road Revenues and Expenditures



Source: Sourced from BITRE 2016 *Yearbook 2016*: Australian Infrastructure Statistical Report

The graph above shows the ratio of Total Expenditure, Total Revenue and the calculated Surplus Revenue in proportion to the gross domestic product. In recent years, the road revenue collected has been steadily decreasing, whilst the overall expenditure on roads has seen a rise in recent years, with relevant data beginning in the financial year 2003-04.

With this data in mind, it can be stated that if the current trend of road revenue and expenditure rates continue into the future, the economic aspects of transport management and roadway funding must be reformed or altered. It must also be stated that diligent research and measures should be taken in order to rehabilitate these road attributes in the most cost-effective manner possible, whether that be systematically patch fixing the areas as the issues appear or factoring in degradation in the long-term and deciding to completely rebuild the road section with much more stable materials. This idea is what the remainder of the research paper will be based upon.

Throughout the industry, there are multiple definitions of what truly defines a low volume road. As an example, McLean (1995) states that low volume road is a road that carries less than 400 vehicles per day, whereas other sources such as Faiz (2012) utilise an AADT of 100 vehicles per day as their definition. As this definition is considered a loose approximation, for the purposes of this research, a value of 800 vehicles per day will be accepted as the maximum threshold for what constitutes a low volume road.

The capital costings of basic road repairs should be outlined and presented as values that may be adopted as approximated figures for required expenditure for a fault. Using the Depart of Transport and Main Roads cost-benefit analysis document, the consistent yearly maintenance for an unsealed road with an AADT of 125 vehicles and an annual traffic growth of 1% linearly is $20,000 yearly for the 12 km section length (Department of Transport and Main Roads, 2011). This is relatively low due to the ungraded, unpaved nature of the road, though the road needs to be consistently repaired and reformed in leu of a formed, sealed road, in which very little annual repairs would be required until major faults appear within the foundations of the pavement, many years down the line. This is the basis for the research to be conducted, utilising low volume road datum in order to make/ develop a simplified model to determine the most efficient and economically sound way to systematically repair and maintain the rural low volume road systems.

2.1.3 Repair of Roadway Designs

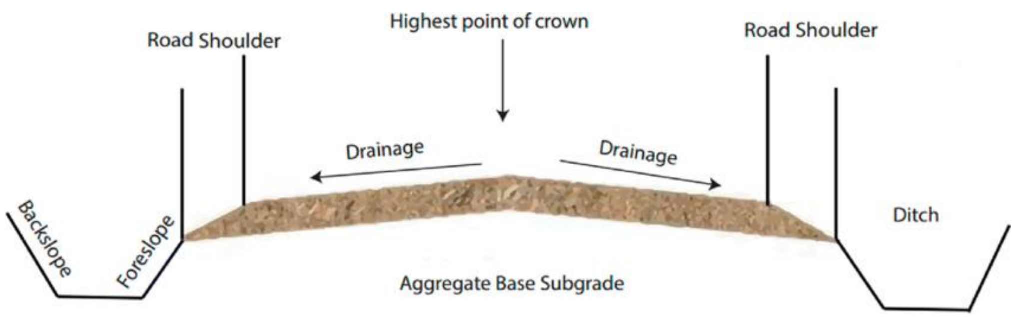
The definition of a low volume road has various definitions usually concerning where in the world it is being discussed. As outlined above, for this project, the definition of a low volume road will be taken as a roadway in which the average daily traffic is equal to or less than 1000 vehicles per day.

The principal features of roadway repair that will need to be discussed within the context of the maintenance project include the following:

- Roadside Conditions
- Drainage
- Surface Conditions
- Sub-surface Conditions

(Saeed, Nyberg, & Moudud, 2022)

Figure 2: Average Cross-Section of a Gravel or Earth-formed roadway.



Source: Sourced from Gravel Road Classification using Transfer Learning, 2022

The figure above depicts the average cross-section of an earth-formed or gravel roadway, outlining the major features and requirements of a maintenance project for this specific type of roadway.

The overall purpose of maintenance for a low volume road should be to reduce the number of routine checks and maintenance required throughout its lifetime and only provide systematic periodic maintenance repairing and conditioning of large-scale components of the low volume road. Routine or regulated maintenance for earth-formed roadways include activities most often broken up into three main groups, those being:

- Roadside based maintenance
    - Eroded or deteriorating road shoulder.
    - Grass beginning to grow over road shoulder.
    - Bushland or trees encroaching on road shoulder.

- Drainage
    - Slope of Roadside Eroded
    - Possible Culvert or Drainage Under Road Blocked
    - Camber of Road not draining off of Roadway

- Road Surface
    - Potential Potholes
    - Potential Rutted Roadway

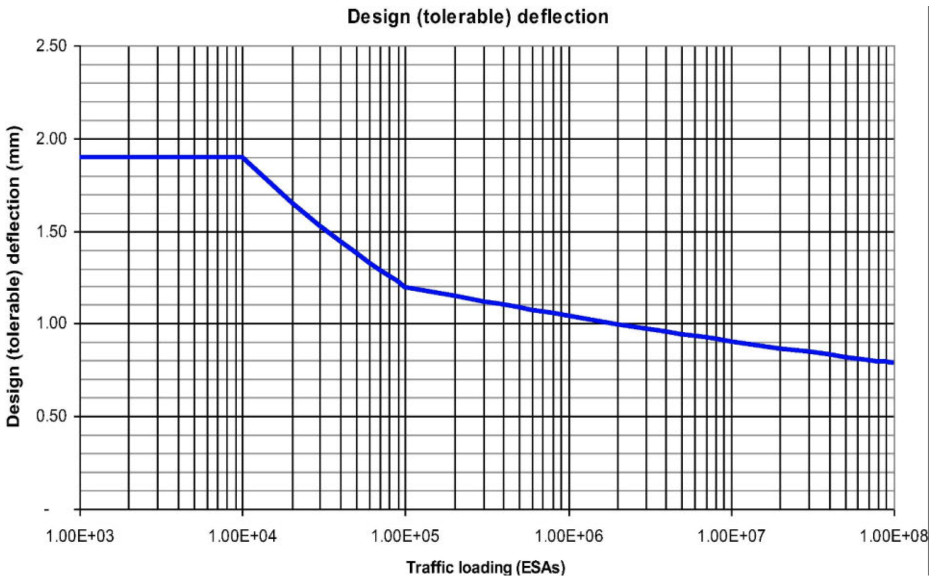
(Low Volume Road Maintenance Booklet, 2013)

Periodic maintenance refers to the repairs or maintenance that may only be required after several years of service use. This mostly refers to asphalted and paved roads as the majority of repairs relate to the resurfacing and occasional spot repair work for the roadway. Unsealed, earth formed roadways can have resurfacing methods after years of service, though the cost of materials, machinery and labour to complete the process would far exceed the expected budget for low volume roadway maintenance.

There are certain objectives that a maintenance project must address to be considered successful. Skidding is the process in which a vehicles wheel traction is lost on the road surface and is most commonly attributed with altered or unstable road surface conditions as well as the drivers' behaviours behind the wheel. This is why skid resistance is an essential test to be conducted when assessing a roadways useability. The other objectives that need to be met relate to the corrugations and rutting that may occur over time in an unpaved earth formed road. Corrugations and rutting are ridges that are formed through the displacement of any loose material, which in the context of low volumes roads is a majority of the material present in the design (CementConcrete, 2021). Over time, these ridges develop into a more pronounced settlement of mass, mimicking the washboard effect with the formed corrugated masses (Brosnan, 2023).

Another key area that management and repair techniques must address are the outward effects of flooding and the deterioration of the surface conditions for the pavement. The impacts of flooding have a large-scale impression on the structural state of the pavement in a low volume road. A study by (Chai, Chowdhury, Martin, & Sultana, 2016) outlined the way in which they determine relative pavement design life after a flooding event. They did this through utilisation of the Department of Main Roads chart for tolerable deflection and using the ESA value (Equivalent Standard Axles) in order to quantify into approximated timeframe until which the subgrade will deteriorate enough to require intervention. In the case of unformed roads, it is quite similar as an inundation of rain leads to the surface conditions very quickly deteriorating and forming things such as rutting stretches or the release of a portion of the segment causing things such as degrading to a point in which intervention is then required. A figure outlining the tolerable design deflections for road traffic loadings is shown in figure 3 below.

Figure 3: Tolerable Design Deflection for Roads.



Source: Sourced from Department of Transport and Main Roads 2007.

Water filtration or entry into the subgrade is also of grace importance to this research project and of the low volume roads in question as it has significant effects in the road's overall serviceability, impacting both its performance over time, as well as its structural integrity. Infiltration into the pavement can be caused due to several factors, those most prominently being from things such as the surface runoff, poor drainage conditions within the road, the use of unsuitable materials with porous and permeable properties or the presence of cracks and fissures forming within the pavement surface. If one of these imperfections occurs within the pavement, the water content will move through the soil and aggregates present in the base and subgrade, this is dependent on the type of soil present in the area. The main two types of soil present in any given Australian environment are either sandy soils or clayey soils. It should be noted that sandy soils are much more permeable when compared to the other soil types and will allow for a water content to flow through much more quickly. The secondary typical soil type in Australia is that of clayey soils as pointed out above. This type of soil has as significantly lower permeability when compared to sandy soils and can therefore retain water levels for longer periods of time, which can leave to several non-advantageous properties within the soil that will lead to diminished structural and loading capacity. Prolonged infiltration will lead to the overall saturation of the soil. Saturation of a soil will lead to various impacts affecting the strength and serviceability of the soil (Dhruvin Jasoliya, 2024). These impacts are most notably a loss of bearing capacity, an increase in the overall deformation that are presented within a pavement surface and an increase in the overall timeline for deterioration within the pavement.

Within the world of soil mechanics, the bearing capacity of a soil indicates the apparent ability of the soil to support a vertical load placed upon it without causing extensive issues or failure within the pavement. The overall factors influencing soil bearing capacity are the soil cohesion, internal friction angles and overall level of compaction present within the soil. With the introduction of water to the area, the pore water pressure will increase, causing a reduction in the frictional resistance and interlocking between the particles within the subgrade (G.Shanmugam, 2018). This in turn leads to a decrease in effective stress, reducing the soils shear bearing capacity.

Soil deformation follows the principles set by the theory of consolidation and elastic-plastic behaviours. Due to the aforementioned reduction in shear strength, a soil with a completely saturated subgrade will yield and showcase a higher level of plastic deformation when loaded with the consistent trafficking of vehicles that is required of a roadway. The most common forms of deformation within a plastically deforming road are the rutting and wash boarding of the roadway, both serious forms of deterioration that needs consistent repair.

The apparent acceleration and material weathering can occur when the there is an apparent lessening in binder between particles, whether that be within the subgrade, base or within the binder used to seal the surface of the pavement. With the introduction of water into these layers, the adhesion is irreparably altered and will causing stripping, leading to the profile deteriorating and the breaking down of the surface layer or base. This stripping is most commonly associated with the potholes and rutting that occurs on the surface layer.

Understanding these maintenance issues, and their relevance to established material properties and soil mechanics help in devising the appropriate mitigation strategies to retain the low volume roads performance and specified design life.

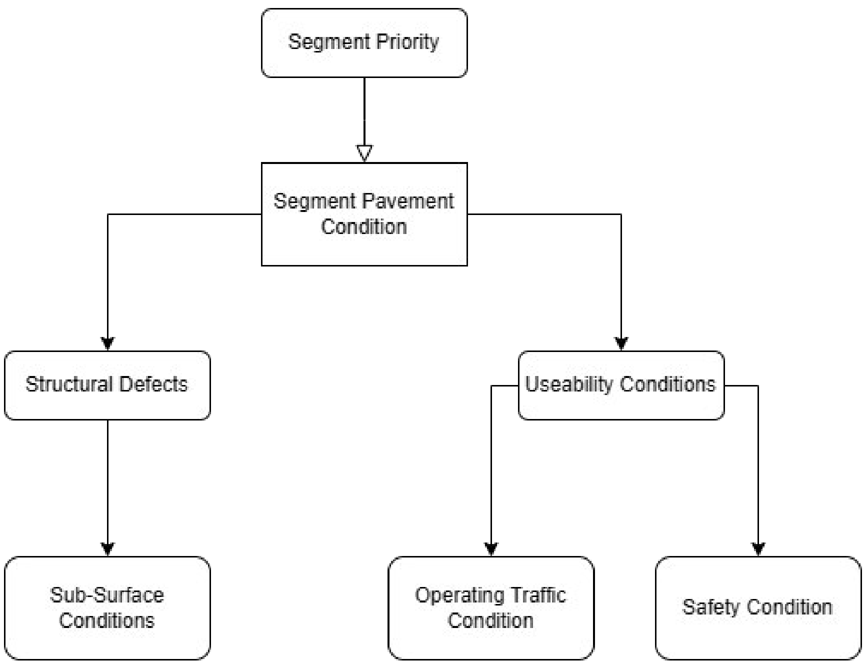
Chapter 3: Methodology

3.1 Project Parameters

3.1.1 Scope

The overall scope of the research project can be simplified down to the development of a model to accurately and time efficiently outline the hierarchy of road segment repair with respect to road segment importance. In order to accomplish this, first a structure of the maintenance priorities of the suggested road segments was created. The initial research stage will collect data based on relevant subsurface conditions of the low volume road, as well as existing traffic conditions and the relative safety conditions of the road.

Figure 4: Hierarchy of importance for project.



There will be two separate roads that will be analysed for the purposes of this research paper, one being an earth-formed, graded road – Road A, and the other being a formed and paved road – Road B. It was decided to use two roads instead of one in order to provide context of the model for various types of low volume roads, not just the unformed versions of the low volume roads. Standard road data will be collated and analysed before any of the following model development shall occur.

Road A (Graded Gravel Road):

Road A has been chosen to be Banff Lane in the Atkinson region and is apart of the Somerset region council jurisdiction. A photo of the roadway is shown in image 1 below.

.

Figure 5: GeoGlobe image of Banff Lane.

Road B (Formed and Paved Road):

Road B has been chosen to be Coominya-Connection Road in the Coominya region and is apart of the Somerset region council jurisdiction. A photo of the roadway is shown in image 2 below.

Figure 6: GeoGlobe image of Coominya Connection Road.

Within this phase, using GIS and satellite images the roads to be analysed will be split up into chainage blocks over a set run distance of each road. This will ensure a wide range of conditions to discuss and a provide the model will sufficient data in order to provide the most effective information in summary.

Using these comparisons, a set of conclusions could then be drawn discussing both the success of the model and be used as a base for further analysis and work to be conducted in the field of low volume roads. These constraints will operate as the underlying restrictions and factors, that will act as a quality assurance for the project going forward.

3.2 Project Components

The initial project phase to be conducted is the creation and development of a simple mathematical model in order to accurately decipher the economic and operating priority or importance of each individual section of the low volume road being analysed. The basis of this model is to be designed so that it is a function of a series of user inputted values as well as empirical values assigned to certain elements within relation to technical aspects of the road design and condition in order to provide simplicity of use whilst still maintaining the accuracy of the model.

The foundation of the model would be the user inputted variables for the condition of the road throughout the section, with an associated scaling factor for each road condition. The scaling factor for each road condition are to be assigned through the user assigning a value to the factor on a scale from 0.0 - 100, with the value of 0.0 being regarded as inconsequential or no repairs required, and 100 being large-scale repairs needed or road is untravellable in current conditions.

The basic form of the model is presented below in equation 1.

$$SP_n = \sum_{x=1}^{a} (FI_x \times L_x) \tag{1}$$

Where:

SP_n = Segment Priority

FI_x =Factor Index

L_x = Loading of Factor

a = Number of Factor

x = Factor

The factor index is a calculated approximation of a value assigned for each individual segment based upon the present conditions with that specific segment. The loading of a factor is a predetermined value in which will give the factor index some sort of weighting when compared to the other factors being considered.

Operating traffic conditions is the first of the factor indexes that is to be calculated. This would affect the model outlining section priority due to the overall level of consistent operational traffic that passes through the specified road segment. This is due to the effective load exerted through the regulated traffic operation on the low volume road, which will in turn affect the priority rankings for segment repairs of the project. Due to the extremely low traffic volumes of the two roads selected, the values for this factor index will most likely not change values throughout the stretch of the road.

The operating traffic index factor will be displayed as:

$$OT_n$$

Where:

OT = Operating traffic conditions index factor

n = Road segment number

Safety conditions and a safety index are the secondary factor that is to be calculated through data collection. This is the primary factor for all surface level deteriorations in the pavement and will cause the most drastic range of values throughout the segmented road. These surface level deteriorations will include items mentioned above such has rutting, corrugations, pothole formation and drainage related issues such as silting or flooding of the road.

The safety conditions index factor will be displayed as:

$$SC_n$$

Where:

SC = Safety conditions index factor

n = Road segment number

The next factor to be considered is the relative level of significance that the connecting road is responsible for. This relates to the level of infrastructure that the road is responsible for connecting to other regions with items such as local medical centres, agricultural production centres or other important locations that would be crucial to those in which the road serves.

The proportional significance index factor will be displayed as:

$$RI_n$$

Where:

RI = Proportional significance index factor

n = Road segment number

The sub-surface conditions are the next section of this research project. They will mainly focus on collecting simple data points about the integrity of the subsurface layers of the roadway. These include the established soil type found within the of the roadway, soil moisture content of certain areas within the suggested road segment and finally noting all previous geotechnical features found within the site area such as nearby drainage channels or sinkholes in which would negatively affect the surrounding soil profiles and structural integrity. These factors being collated in this research project form the basic fundamentals of soil structural integrity and may be expanded upon in future iterations of the concept.

The sub-surface index factor will be displayed as:

$$SS_n$$

Where:

SS = Sub-surface conditions index factor

n = Road segment number

Finally, the last factor that will be considered for the project is the overall area in which the damage has occurred. This value is of vital importance as it outlines the overall vicinity in which the repairs will have to take place.

The Damaged Area index factor will be displayed as:

$$DA_n$$

Where:

DA = Damaged Area index factor

n = Road segment number

3.3 Limitations

Throughout the data collection process, there are several limitations to the progress of this research project. The main series of limitations that will be exerted on the project throughout completion are the monetary, time, and scope aspects of completing the project, as well as onsite data collection issues.

Due to the nature of the research project and timeline presented due to university deadlines, there is an inherent time constraint placed upon the creation of this research project or more specifically the collection of the data in a timely manner. In order to counteract this, the project has been meticulously planned and scheduled in order to provide as much time as possible for data to be accurately collected and analysed for the precise presentation of data.

The secondary limitation is that of the monetary limitations placed upon the research papers. Due to the number of students all completing research papers, there is an inevitable limitation placed upon the amount of financial support each student could receive in order to complete their respective research goals. In order to combat this, the project outlined utilises processes and datapoints in which sufficient levels of data can be accrued whilst still utilising the least amount of financial support by the university.

Furthermore, with these inherent time restrictions, there is a limitation of scope that has been applied to this research paper. Due to the factors touched on above, there are certain other factors that cause a narrowing of focus such as interdisciplinary constraints and exclusion of variables. Interdisciplinary constraints in this project mainly refers to items such as geotechnical considerations within the road base or surrounding environment of the low volume roads in question that have limited the overall scope in which the research can be conducted in order to effectively provide accurate data within the given timeframe.

Lastly, the final foremost limitation cast upon the research project are the relevant data collection issues that may occur onsite during collection. These limitations include surrounding conditions of the area, inclement weather conditions and the wildlife of the surrounding area may cause a restraining or slowing of data collection that may adversely affect the results and analysis of the next stages of the project. These issues are discussed within the risk assessment below and have relevant controls outlined in how to most effectively extinguish these restraints.

3.3 Project Planning

3.3.1 Resources Required

Table 3: Equipment Requirements for Project

Item	Quantity	Source	Cost	Comment
Laptop	1	Student	Nil	Already Owned
Microsoft Word	1	Uni	Nil	Already Owned
Microsoft Excel	1	Uni	Nil	Already Owned
Vehicle	1	Student	Nil	Already Owned
Soil Containers	5	Student	Nil	Already Owned
Camera	1	Student	Nil	Already Owned
Queensland Globe		Student	Nil	Free Service

3.3.2 Quality Assurances

The quality assurances assigned to the proposed project are the measures and checks to be implemented in order to safeguard the authenticity of the project data collection and analysis through the inclusion of the following:

- Road Data will be collected 3 times to avoid incorrect data or outliers.
- All input data will be evaluated to ensure consistency across the board.
- Constant checking and validation the evolution of the developing model.
- All defects and suspected outliers will be identified in testing and model development.

3.4 Safety and Risk Assessment

NUMBER	RISK DESCRIPTION	TREND	CURRENT	RESIDUAL
4656	Journal Paper - Research Paper A & B		Low	Low

DOCUMENTS REFERENCED

RISK OWNER	RISK IDENTIFIED ON	LAST REVIEWED ON	NEXT SCHEDULED REVIEW
Tim Raine	09/05/2024	09/05/2024	09/05/2025

RISK FACTOR(S)	EXISTING CONTROL(S)	PROPOSED CONTROL(S)	OWNER	DUE DATE
Working in temperatures over 35 degrees	**Control:** Wear appropriate clothes and gear	**Control:** Take work breaks, carry water, fatigue management policy		
Working in Close Proximity to a Road	**Control:** Wear appropriate Hi-Visibility jacket	**No Control:**		
Eye Strain from Laptop	**Control:** Take breaks after prolonged exposure.	**Control:** Wear blue-light filtering glasses		

Uneven or rocky terrain causing slips, tripping, falls and scratches	**Control:** Wear appropriate footwear	**No Control:**
Inclement Weather Conditions	**Control:** Postpone data collection till inclement weather subsides	**No Control:**
Dust Inhalation caused by loose materials	**Control:** Wear appropriate face-wear to prohibit dust inhalation	**No Control:**
Use of equipment may cause cuts and bruises	**Control:** Proper briefing of equipment in how to use equipment safely	**No Control:**
Animals causing biting, stings and physical injury or trauma	**Control:** Appropriate work gear to be worn	**Control:** Vehicle is fitted with a sonic device to deter wild animals **Control:** First Aid Kit in vehicle

Chapter 4: Results and Discussion

4.1 Summarised Field Notes for Paved Road

Section 1 (Chainage 0-250):

Chainage 0 of this road is a T-intersection joining a small rural town to the neighbouring larger scale cities and townships within the region. The pavement is covered with approximately 18 potholes of varying sizes. This also shows the deterioration of the subgrade and subbase of the pavement. Further down the section there is evidence of rutting beginning to occur, also displaying sub surface deterioration within the section. The drainage channel running along each side of the roadway is not shaped for proper drainage and requires extensive excavation to appropriately allow for flow. This end of the low volume road sees the least number of heavy vehicles on the trafficable surface.

Section 2 (Chainage 250 -500):

Within this segment, the main issues presented are the encroaching materials slowing protruding through the shoulders of the roadway and the moderate degree of fatigue cracking that is forming throughout the area. There were also signs of root cracking beginning to appear at a very minute area due to a large tree quite close to the road. It should be noted there was no overhand of branches over the road, just the roots acting underground within the subgrade. Edge failure has occurred. This is most likely due to the small dam in relatively close proximity to the road overflowing into the table drain seeping through the side batter and causing saturation of the subgrade and damage to the surface pavement. This segment services local stockyards in which heavy vehicles are consistently being trafficked and used in ways which may lead to pavement degradation or failure over time.

Section 3,4 & 5 (Chainage 500 – 1250):

These sections are relatively stable in their appearance, showing no outwards signs of any degradation or edge failure. The subsurface conditions of these areas can be assumed as stable as there is very little settling of material or indentations present within the surface profile. This cannot be confirmed however without extensive subgrade testing, exceeding the scope of this research project. These segment service local stockyards, farms and in which heavy vehicles are consistently being trafficked and used in ways which may lead to pavement degradation or failure over time, though there is enough evidence to suggest nothing has occurred yet.

Section 6 (Chainage 1250 – 1500):

This section showed failure of the pavement edge running along the extent of the roadway section. This most likely due to the creek that exists approximately 40m into the section. Through inspections, it is evident that this creek carries a large amount of material and deposits it within the pipe culvert running underneath the roadway, causing the culvert to become silted up and slowing the potential flow rate causing a pooling of water and debris on the side of the road. This seepage into the subgrade and base of the road causes an instability within the pavement, leading to the cracking and separation of the surface layer from the base of the road.

Section 7 & 8 (Chainage 1500 – 1750):

Section 7 & 8 have very little damage present upon an inspection. Throughout the entirety of the section, there were no visible indentations, sagging stretches of road and potholing, indicating no subgrade or surface damages. The only mentionable items are the table drains running alongside the roads. These drains could utilise an excavation to return them to an appropriate batter slope and channel shape for optimum flow from the road.

Section 9 & 10 (Chainage 2000- 2500):

These segments of the road are servicing a large-scale abattoir and food processing facility. Due to this constant trafficking of heavy vehicles, these sections have developed severe potholing and rutting in approximately 15m zones throughout the areas. Section 9 has a much sparser dispersion of these rutting points and potholing zones when compared to section 10. Section 10 is connected to a T-junction with connections to a main road leading to a moderately sized country township. The drainage within these sections requires immediate excavation and shaping. This end of the road is at significantly lower elevation than the rest of the road. It should be noted that the area in which this paved road is located was affected by a recent flood in 2022. Within this flood, due to conditions and relative falls of the road, these sections would be the most adversely affected, leading to the copious amounts of sub surface damages present in both sections. Insitu stabilisation is recommended.

4.2 Collation of Data (Paved Road)

Weightings for the respective factors that are being considered is a vitally important stage of the project, and the values for weighting were determined through a mix of literature review and stakeholder input from a council technical officer. The literature review was conducted in order to determine which factors have the most impact on degradation and safety conditions of the road.

The weightings for the factors are as follows:

Table 4: Weighting of Factors

Factor	Weighting (%)
Operating Traffic Conditions	10
Safety Conditions	30
Proportional Significance	10
Sub-surface Conditions	20
Damaged Area	30

Operating Traffic Conditions

Using these field notes, index values can be assigned to each individual segment. The values for these indexes were classified through the grouping shown below. These values were determined through literature review and stakeholder interviews. The values were selected due to the simplicity of separation that could occur onsite during a small-scale traffic study estimation. For the case of operating traffic conditions, the values are:

Table 5: Operating Traffic Conditions Index Groupings

Operating Traffic Conditions	Index
No Heavy Traffic	0
Very Little Regular Frequency of Heavy Traffic	20
Little Regular Frequency of Heavy Traffic	40
Regular Frequency of Heavy Traffic	60
High Frequency of Heavy Traffic	80
Consistent Heavy Traffic	100

Therefore, the weighted importance values for each road segment factoring operating traffic conditions are:

Table 6: Operating Traffic Importance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-250m	15	0.1	1.5
2	250m-500m	30	0.1	3
3	500m-750m	30	0.1	3
4	750m-1000m	30	0.1	3
5	1000m-1250m	30	0.1	3
6	1250m-1500m	25	0.1	2.5
7	1500m-1750m	25	0.1	2.5
8	1750m-2000m	25	0.1	2.5
9	2000m-2250m	85	0.1	8.5
10	2250m-2500m	85	0.1	8.5

Safety Conditions

For the case of roadway safety conditions, the value groupings are as follows. These values for indexes were selected to effectively separate the road conditions. For example, small scale cracking would result in a significantly smaller bracket than that of shoving occurring within a section. These values selected accurately and easily separate these for analytical use.

Table 7: Safety Conditions Index Groupings

Relative Conditions	Index
No adverse conditions requiring rehabilitation	0
Slight surface level damages (Beginning of Deterioration)	20
Moderate level of damages (May Cause Damage to Vehicles)	40
Severe Conditions (Complete Deterioration)	60
Extremely Hazardous Conditions (Will Cause Severe Damage to Vehicles)	80
Critical Failure - (Immediate action to be taken)	100

Therefore, the weighted importance values for each road segment factoring segment safety conditions as follows:

Table 8: Safety Conditions Importance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-250m	95	0.3	28.5
2	250m-500m	44	0.3	13.2
3	500m-750m	14	0.3	4.2
4	750m-1000m	11	0.3	3.3
5	1000m-1250m	11	0.3	3.3
6	1250m-1500m	35	0.3	10.5
7	1500m-1750m	9	0.3	2.7
8	1750m-2000m	24	0.3	7.2
9	2000m-2250m	50	0.3	15
10	2250m-2500m	75	0.3	22.5

Proportional Significance

For the case of segment proportional significance, the value groupings are as follows. These values for indexes were selected to effectively separate the segments into the brackets of importance that the segment effectively services. For example, a section that has no driveways or entrances to stockyards will have a lower level of significance than a segment that services an agricultural facility or a type of make-shift worker carpark. These values selected accurately and easily separate these into brackets for ease of analytical use.

Table 9: Proportional Significance Index Groupings

Proportional Significance	Index
No Importance	0
Very Little Importance	20
Little Importance	40
Important	60
Very Important	80
Vital Importance	100

Therefore, the weighted importance values for each road segment factoring proportional significance are:

Table 10: Proportional Significance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-250m	85	0.1	8.5
2	250m-500m	76	0.1	7.6
3	500m-750m	58	0.1	5.8
4	750m-1000m	58	0.1	5.8
5	1000m-1250m	55	0.1	5.5
6	1250m-1500m	60	0.1	6
7	1500m-1750m	66	0.1	6.6
8	1750m-2000m	81	0.1	8.1
9	2000m-2250m	95	0.1	9.5
10	2250m-2500m	95	0.1	9.5

Sub-surface conditions

For the case of sub-surface conditions, the index value groupings are as follows. These values were selected through stake holder engagement and utilising the onsite surface conditions to effectively estimate the conditions of the sub-surface.

Table 11: Sub-surface conditions Index Groupings

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-250m	90	0.2	18
2	250m-500m	88	0.2	17.6
3	500m-750m	4	0.2	0.8
4	750m-1000m	2	0.2	0.4
5	1000m-1250m	4	0.2	0.8
6	1250m-1500m	31	0.2	6.2
7	1500m-1750m	3	0.2	0.6
8	1750m-2000m	14	0.2	2.8
9	2000m-2250m	2	0.2	0.4
10	2250m-2500m	15	0.2	3

Therefore, the weighted importance values for each road segment factoring sub-surfacing conditions are:

Table 12: Sub-surface Importance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-250m	90	0.3	27
2	250m-500m	88	0.3	26.4
3	500m-750m	4	0.3	1.2
4	750m-1000m	2	0.3	0.6
5	1000m-1250m	4	0.3	1.2
6	1250m-1500m	31	0.3	9.3
7	1500m-1750m	3	0.3	0.9
8	1750m-2000m	14	0.3	4.2
9	2000m-2250m	2	0.3	0.6
10	2250m-2500m	15	0.3	4.5

Damaged Area

For the case of affected damaged area, the index value groupings are shown below. These values were determined through literature review and stakeholder interviews. The values were selected due to the simplicity of separation that could occur onsite during a small-scale survey.

Table 11: Damaged Area Index Groupings

Area	Index
$0m^2$	0
$<10m^2$	20
$10m^2<x<50m^2$	40
$50m^2<x<100m^2$	60
$100m^2<x<200m^2$	80
$>200m^2$	100

Therefore, the weighted importance values for each road segment factoring the damaged area within each segment are:

Table 12: Damaged Area Importance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-250m	65	0.2	13
2	250m-500m	41	0.2	8.2
3	500m-750m	26	0.2	5.2
4	750m-1000m	24	0.2	4.8
5	1000m-1250m	25	0.2	5
6	1250m-1500m	40	0.2	8
7	1500m-1750m	16	0.2	3.2
8	1750m-2000m	21	0.2	4.2
9	2000m-2250m	32	0.2	6.4
10	2250m-2500m	71	0.2	14.2

4.3 Paved Roads Results Table

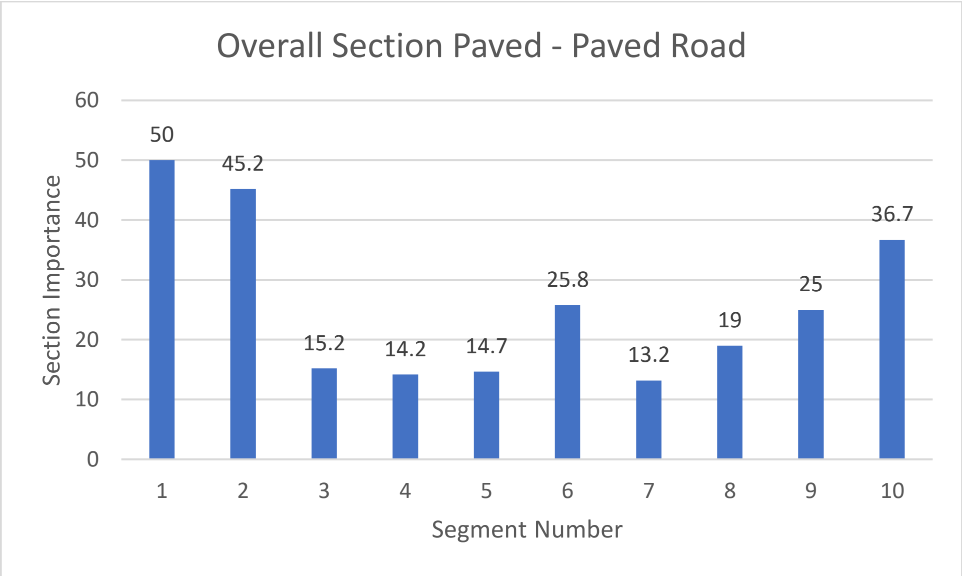
The importance values are scaled from 0-100, 0 being least important, 100 being of vital importance to initiate repair. The following table and graph are an additive approach for the section values. Tables and graphs for individual factors of segments are shown in Appendix A.

The overall results for the paved road survey are then as follows:

Table 15: Paved Road Survey Overall Section Value and Priority Rankings

Section Number	Operating Traffic Index	Proportional Significance Index	Subsurface Conditions	Damaged Area Index	Overall Section Value	Priority Ranking
1	1.5	8.5	27	13	50	1
2	3	7.6	26.4	8.2	45.2	2
3	3	5.8	1.2	5.2	15.2	7
4	3	5.8	0.6	4.8	14.2	9
5	3	5.5	1.2	5	14.7	8
6	2.5	6	9.3	8	25.8	4
7	2.5	6.6	0.9	3.2	13.2	10
8	2.5	8.1	4.2	4.2	19	6
9	8.5	9.5	0.6	6.4	25	5
10	8.5	9.5	4.5	14.2	36.7	3

Figure 7: Overall Section Values for Paved Road



4.4 Summarised Field Notes for Formed Gravel Road

Section 1 (Chainage 0 -50):

Section 1 is a curved gravel section that leads towards a small creek section located within section 2 of the respective road segments. Throughout the inspection, there were various issues that were discovered that have impacts on the overall health of the road. Firstly, there is no apparent change in superelevation for the curved section of the road as well as not having any evident crown in the centre of the road, meaning little to no change in slope throughout the cross section of the road. Without an appropriate fall stemming from the crown of the road, drainage issues will become prevalent as rainfall has no predetermined exit off the roadway, causing increased levels of saturation and subgrade deterioration in the future. Furthermore, at the time the inspection was conducted, other than the cross-section issues, there were very little present surface conditions other than a relatively small amount of material accumulating within the centre of the roadway and approximately three metres of road that is beginning to showcase signs of rutting on the left-hand shoulder. Again, this is just the beginning of the deformation and presents very little definite issues in terms of road useability, though the act of managing these initial issues form the basis of a proposed maintenance schedule that could only be formed through thorough and time efficient inspections such as the one conducted for this research project.

Section 2 (Chainage 50-100):

This section has an active creek running underneath a small section the road base, through a series of box culverts that is currently sitting upon a concrete base below the water surface. At the time of recording, the entirety of this crossing section was under the surface level of water, posing great risks to motorists needing to pass through the area. It was evident that most of the initial roadway had been stripped away by the waterflow and requires significant repairs in order to make the crossing acceptably safe and future proof for upcoming extreme weather events. In order to accomplish this, the existing crossing would need to be demolished and rebuilt entirely. The crossing would need to be raised to the existing level of the roadway, with an approximate rise of half a metre to maintain a level road base across the entire distance. In the absence of updated AADT data for the low volume road, using the presence of nearby farm and cattle yards, the percentage of heavy vehicles can be interpolated causing for the design of the crossing to take this into account. This includes selecting the appropriate culvert shape and diameter, whether that be a series of box culverts or pipes and their respective sizes. This information can only be obtained through extensive surveying and hydraulics testing on the affected area, which would greatly impact the costings for the repair of the section. Other than this small crossing, the section presents very little deformations other than a small segment (less than a square metre) of rippling beginning to form at the start of the recorded section. This is a small surface condition that could be easily managed with a light grading of the road and could potentially be folded into a proposed periodic maintenance schedule that will be discussed later in the report.

Section 3 (Chainage 100-150):

Section 3 had approximately the same area of damages as section 1, mainly consisting of small indentations or slight corrugations in the surface material. As stated previously, these corrugations on unpaved, formed roads are a result of a series of vehicles travelling as such as speed so that when the vehicles travel over a certain imperfection in the road, it causes the vehicles to slight bounce and land on certain point, causing a ridge to form. These ridges are relatively minor in their current state, though actions should be taken as soon as possible so as not allow for major long-term damages to the road and vehicles traveling on it in the future. These corrugations are most effectively mitigated through the use of a road grader and multi tyred roller in order to reshape the surface and compact it back into its original shape with a tighter, more interlocked surface layer.

Section 4 & 5 (Chainage 150-250):

Section 4 and section 5 are both in relatively pristine conditions with only a few very minor upgrades requires to properly maintain the existing roadway. This is most likely due to the positioning of the section being far out of the reach of the creek, both in distance and elevation, limiting the degradation and saturation that these sections could be exposed to. During the inspection, the only real issues found are the drainage channels on either side the road being quite shallow and could potentially prove troubling for the health of the road during an extreme weather event. The batter on either side of the road has accumulated an amount of gravel and other materials have settled within the channel at the base of the batter causing to relatively level out. This accumulation of material also has affected the concrete piping running underneath the occupant’s driveways and cattle grids, causing them to become silted up and slowing the rate their capable of carrying. For these segments, the only maintenance requirement to be specified is to excavate and reshape the drainage channels and desilt the pipes, which is relatively inexpensive repair method and is not immediately important to perform to maintain the existing roadways.

4.5 Collation of Data (Formed Gravel Road)

Operating Traffic Conditions

Using these field notes, index values can be assigned to each individual segment. The values for these indexes were classified through the grouping shown below. These values were determined through literature review and stakeholder interviews. The values were selected due to the simplicity of separation that could occur onsite during a small-scale traffic study estimation. For the case of operating traffic conditions, the values are:

Table 16: Operating Traffic Conditions Index Groupings

Relative Importance	**Index**
No Heavy Traffic	0
Very Little Regular Frequency of Heavy Traffic	20
Little Regular Frequency of Heavy Traffic	40
Regular Frequency of Heavy Traffic	60
High Frequency of Heavy Traffic	80
Consistent Heavy Traffic	100

Therefore, the weighted importance values for each road segment factoring operating traffic conditions are:

Table 17: Operating Traffic Importance Values

Section Number	**Road Segment Chainage**	**Index**	**Assigned Weighting**	**Importance**
1	0m-50m	25	0.1	2.5
2	50m-100m	25	0.1	2.5
3	100m-150m	50	0.1	5
4	150m-200m	40	0.1	4
5	200m-250m	50	0.1	5

Safety Conditions

For the case of roadway safety conditions, the value groupings are shown below. These values for indexes were selected to effectively separate the road conditions. For example, small scale cracking would result in a significantly smaller bracket than that of shoving or wash boarding occurring within a section. These values selected accurately and easily separate these for analytical use.

Table 18: Safety Conditions Index Groupings

Relative Conditions	Index
No adverse conditions requiring rehabilitation	0
Slight surface level damages (Beginning of Deterioration)	20
Moderate level of damages (May Cause Damage to Vehicles)	40
Severe Conditions (Complete Deterioration)	60
Extremely Hazardous Conditions (Will Cause Severe Damage to Vehicles)	80
Critical Failure - (Immediate action to be taken)	100

Therefore, the weighted importance values for each road segment factoring segment safety conditions are:

Table 19: Safety Conditions Importance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-50m	54	0.3	16.2
2	50m-100m	98	0.3	29.4
3	100m-150m	46	0.3	13.8
4	150m-200m	20	0.3	6
5	200m-250m	15	0.3	4.5

Proportional Significance

For the case of segment relative importance, the value groupings are shown below. These values for indexes were selected to effectively separate the segments into the brackets of importance that the segment effectively services. For example, a section that has no driveways or entrances to stockyards will have a lower level of significance than a segment that services an agricultural facility or a type of make-shift worker carpark. These values selected accurately and easily separate these into brackets for ease of analytical use.

Table 20: Relative Importance Index Groupings

Relative Importance	Index
No Importance	0
Very Little Importance	20
Little Importance	40
Important	60
Very Important	80
Vital Importance	100

Therefore, the weighted importance values for each road segment factoring relative importance are:

Table 21: Proportional Significance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-50m	11	0.1	1.1
2	50m-100m	15	0.1	1.5
3	100m-150m	20	0.1	2
4	150m-200m	55	0.1	5.5
5	200m-250m	60	0.1	6

Damaged Area

For the case of affected damaged area, the index value groupings are shown below. These values were determined through literature review and stakeholder interviews. The values were selected due to the simplicity of separation that could occur onsite during a small-scale survey.

Table 22: Damaged Area Index Groupings

Area	Index
$0m^2$	0
$<10m^2$	20
$10m^2<x<20m^2$	40
$20m^2<x<50m^2$	60
$50m^2<x<100m^2$	80
$>100m^2$	100

Therefore, the weighted importance values for each road segment factoring the damaged area within each segment are:

Table 23: Damaged Area Importance Values

Section Number	Road Segment Chainage	Index	Assigned Weighting	Importance
1	0m-50m	24	0.2	4.8
2	50m-100m	85	0.2	17
3	100m-150m	28	0.2	5.6
4	150m-200m	9	0.2	1.8
5	200m-250m	5	0.2	1

4.6 Unsealed Road Results Table

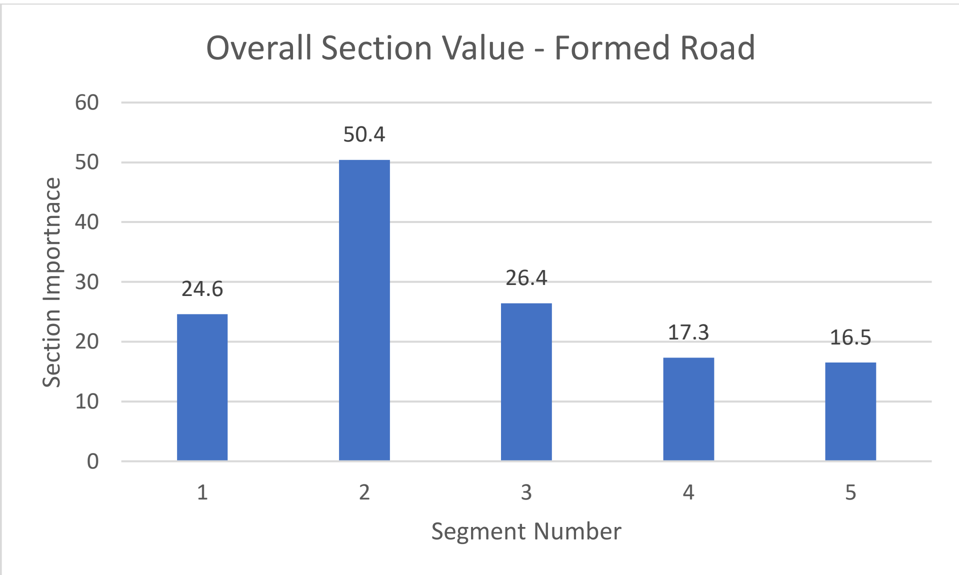
The importance values are scaled from 0-100, 0 being least important, 100 being of vital importance to initiate repair. The following table and graph are an additive approach for the section values. Tables and graphs for individual factors of segments are shown in Appendix B.

The overall results for the formed gravel road survey are then as follows:

Table 24: Paved Road Survey Overall Section Importance and Priority Rankings

Section Number	Operating Traffic Index	Safety Conditions	Proportional Significance Index	Damaged Area Index	Overall Section Importance	Priority Ranking
1	2.5	16.2	1.1	4.8	24.6	3
2	2.5	29.4	1.5	17	50.4	1
3	5	13.8	2	5.6	26.4	2
4	4	6	5.5	1.8	17.3	4
5	5	4.5	6	1	16.5	5

Figure 8: Overall Section Value for Formed Road



4.7 Cost Benefit Analysis Values

For the development of a basic cost- benefit analysis, relative values for certain regulatory and onsite needs of the project.

Certain stages that ensue costings for a road rehabilitation project are:

- The design or redesign of a roadway cross section, seal or drainage component.
- Materials to be utilised in the project, being primarily road bases and gravels.
- The costs of onboarding contractors or internal labourers to carry out the scope of works.
- The costs of traffic controllers whilst the works are being undertaken.

These values are to be approximated based upon realistic quotations for each individual costings, though the values to be used are not exactly accurate as they would be if an agency such as a regional council was to undertake this cost benefit analysis. Therefore, the approximated costings are shown in table 24 below.

Table 25: Example of Approximate Costings for Construction Activities and Requirements.

Activity	**Approximated Costings**
Design/ Survey	$10,000 per kilometre
Material	$120 per cubic metre
Contractors / General Labourer	$400 per labourer per day
Traffic Control + Equipment	$350 per traffic controller per day
Miscellaneous Maintenance Costs	$5,000 per year

Secondly, the machinery used within a civil project of this nature will undoubtedly factor into a cost benefit analysis system. For the development of a basic cost- benefit analysis, relative values for certain machinery needs within the project.

Certain machinery that is required to carry out works such as these are:

- Road grader, especially for the maintenance of gravel formed roads.
- A stabiliser unit, for the process of in situ stabilisation and recycling of materials.
- Front end loader for the movement of excess materials.
- Excavator for clearing and grubbing of materials.

These values are to be approximated based upon realistic quotations for each individual costings, though the values to be used are not exactly accurate as they would be if an agency such as a regional council was to undertake this cost benefit analysis. Therefore, the approximated costings are shown in table 25 below.

Table 26: Example of Approximate Costings for Construction Machinery.

Machinery	Approximated Costings
Road Grader	$ 2500 per kilometre
In Siu Stabilization (lime stabiliser)	$ 75,000 per kilometre
Front End Loader	$ 3000 per day
Excavator	$ 2500 per day
Multi Wheeled Roller	$1000 per day

Using this data as well as the summarised field notes outlined above, cost benefit analyses can then be drawn for each of the roads being discussed.

Paved Road – Long term repairs:

With the use of the field notes, it can be stated that to effectively repair a majority of the paved road in question, in situ stabilisation or boxing out and replacing the pavement as well as the reconstruction of drainage components is the critical method to undertake. Boxing out and replacement of the pavement consists of removing material down to the subgrade, reforming, strengthening and re-laying of the pavement. Using stakeholder interviews as a gauge, an approximated time frame for construction activities could be created.

Approximately 85 days of construction:

30 days for excavation

20 days for subgrade preparation

30 days for pavement replacement

5 days for quality assurance checks, reinstituting line marking and signage

Total cost of project:

- Design / Surveying of area = $20,000
- 30 days of excavator and front-end loader = $165,000
- 20 days of rolling, addition of materials to subgrade and shaping of the subgrade = $188,000
- 30 days of pavement replacement and compaction = $680,000
- Labour Costs (Assuming a crew of 10) = $340,000
- Traffic Control Costs (Assuming 2 controllers) = $59,500

Total approximate cost of project = $1,452,500

Completed over approximately 85 days with an assumed crew of 10 people.

Assuming design life of 10 years.

It should be noted that this calculation is based on the underlying assumption that the entirety of the road is to be boxed out and replaced with appropriate material, instead of selecting stretches of road with relatively unaffected surfaces and subgrades to remain. If this method is to be considered the approximate costing the project would reduce significantly to a value most likely between $700,000 and $1,000,00.

Paved Road – Periodic maintenance and repairs:

If the method of construction is to repair periodically and maintain a consistent level of performance, this would reduce the number of crew members required for each individual job. This method would also factor in the segment priority and area of damaged pavement in order to significantly reduce the work load required for each maintenance activity.

Segments 1 and 2 have the highest priority within the road system and will be selected for repair in this analysis. Segment 1 will require extensive work, mainly that of complete pavement replacement due to the extensive level of damages noted and discussed previously. Segment 2 requires an arborist to clear the tree beginning to obstruct the roadway and damage the pavement, as well as stabilising the shoulder of the road for the length of the damaged area.

Segment 1:

Approximately 15 days of construction:

5 days for excavation

2 days for subgrade preparation

7 days for pavement replacement

1 day for quality assurance checks, reinstituting line marking and signage

Total cost of project:

- Design / Surveying of area = $2,500
- 5 days of excavator and front-end loader = $27,500
- 2 days of rolling, addition of materials to subgrade and shaping of the subgrade = $25,800
- 7 days of pavement replacement and compaction = $54,800
- Labour Costs (Assuming a crew of 5) = $60,000
- Traffic Control Costs (Assuming 2 controllers) = $24,500
- Yearly miscellaneous maintenance costs to the road = $5,000

Total approximate cost of project = $ 195,100

Completed over approximately 15 days with an assumed crew of 10 people.

After initial repairs, cumulative costs to maintain after 10 years = $50,000

For all segments of the road, cumulative costs to perform small scale repairs and maintenance are approximately $500,000 for a set 10-year block. This only takes into account the maintenance and upkeep costs, excluding the initial costs to repair to the sections.

Segment 2:

Approximately 7 days of construction:

1 day for clearing and grubbing

5 days for excavation and recycling of pavement and stabilisation with lime

1 day for quality assurance checks, reinstituting line marking and signage

Total cost of project:

- Design / Surveying of area = $2,500
- 1 day of clearing a grubbing = $4,000
- 5 days for pavement excavation, recycling and lime stabilisation of damaged area = $61,375
- Labour Costs = $28,000
- Traffic Control Costs (Assuming 2 controllers) = $11,000
- Yearly miscellaneous maintenance costs to the road = $5,000

Total approximate cost of project with additional admin costings and unforeseen variations = $ 106,875

Completed over approximately 7 days with an assumed crew of 10 people.

After initial repairs, an assumed cumulative cost to maintain after 10 years = $ 50,000

For all segments of the road, cumulative costs to perform small scale repairs and maintenance are approximately $250,000 for a set 10-year block. This only takes into account the maintenance and upkeep costs, excluding the initial costs to repair to the sections.

Table 27: Costings for all section of paved road for initial rehabilitation

Section No.	Approximate cost for initial rehabilitation
1	$ 195,100
2	$ 106,875
3	$ 54,200
4	$ 51,350
5	$ 39,100
6	$ 80,895
7	$ 41,450
8	$ 55,050
9	$ 69,400
10	$ 187,540
Total	**$ 880,960**

The value calculated above is within the region of costings assumed for the replacement of the pavement assuming the design takes into account the pavement area not requiring repair or replacement, that value being approximately $700,000 to $1,000,000. However, for the purposes of this cost benefit analysis, the initial value for the complete rehabilitation of the pavement must be used as a worst-case scenario. This represents a major limitation of this cost benefit analysis due to the limited scope of geotechnical works that could be completed within the timeframe.

Therefore, after a period of 10 years, it can be stated that for the paved road, it would cost approximately $1,130,960 with the initial rehabilitation and periodic maintenance activities with variations. This is compared to the $1,452,500 that was calculated for the complete reconstruction of the pavement, subgrade and other construction items mainly being drainage structures.

4.8 Utilisation and Discussion of Results

With these sets of data collated, the results can then be dissected and discussed in detail before conclusions can be drawn. The above results tables (tables 14 and 23) as well as figures 5 and 6 illustrate the prioritised order in which the relative segments of the road have been arranged. As stated above, the higher the value within these forms, the greater the risk of damages occurring to both the surface of the roadway as well as any potential traffic utilising it. The results also demonstrate various optimisation techniques that can be applied in the future of low volume road repair and maintenance procedures.

The main purpose of the aforementioned results is to construct an approximate cost benefit analysis of the roadway in order to determine if small scale repairs are more cost and time efficient than that of major projects and reconstructions with the constraints of low volume road financing. With the collation of these results, an approximated cost-benefit analysis was created in order to differentiate whether the road would benefit from consistent small-scale repairs and upkeep or major repairs after a certain design life period, in this case, the design period being 10 years. The results obtained outline the following costings data for the paved roadway section:

- For complete reconstruction of the low volume road: **$1,452,500**
- For initial limited rehabilitation with periodic monitoring and maintenance: **$1,130,960**

This shows definitive evidence of the periodic maintenance technique costing less for the paved road in question with the assumptions and constraints that have been put in place for the purposes of this research project. This may not always be the case however, as the constraints placed upon the cost benefit analysis will alter based upon multiple factors, the most important being the funding available to the agency allowing for the maintenance activities and the changing rates of machinery hire and contractor tender pricings for the project. It should also be reiterated that the complete reconstruction value is based upon a worst case scenario estimate and will be subject of change with the addition of further geotechnical research.

The key findings of this research project also provide a basis for the development of schedules and strategies with the intention of providing a more periodic inspection timeframe for regions, in which inspectors would note any items that may be an early warning sign to point towards the beginnings of wear and tear for the specified roadway. The results also point out a required need for the development of preventative management and maintenance procedures, with the intended purpose of preserving the road as much as possible leading to an extended lifespan of the roadway. The most appropriate way of creating this management procedures is to allow for inspections such as the one conducted in this research project, which an added emphasis on the road marked with appropriate indicators most commonly associated with the overall road usage, the volume of traffic for the road and other environmental factors for the road. These factors would most commonly include items such as the AADT, percentage of heavy vehicles and those in regions in which weather conditions will play a large part in the act of roadway degradation.

These findings can also be utilised in order to enhance already established decision making matrixes and tools that are currently being employed but the councils. Due to the relatively low budget that is afforded to low volume roads when compared to that of main roads or high AADT roads in any given area, there seemingly aren't very many established decision-making tools specifically for these types of roads. This is also due to the inherent lack of information held on these lower priority roads, stifling any potentially informed decision making. This can be altered however, as conducting these scheduled, regulated inspections provides valuable data detailing in a broad sense, the performance and relative condition of the road over a set period of time. Using this data, formal decisions based upon proven information regarding the designated design life of the road can be carried out. This will eventually prove the road to be cost efficient, spending relatively small amounts of revenue periodically, that neglecting the road for the majority of its design life as discussed previously.

Furthermore, to this point, consistent inspections and tracking of these minor maintenance activities allow for a service record that can be effectively used as milestones tracking the overall performance and trends of that particular road. This would allow for engineers and project managers to change maintenance schedules and activities freely based upon a roads track record and performance data, adjusting the program strategy as needed.

The next discussion points to be reviewed is the overall reduction in disruption that would occur for the overall motorists that actively use that low volume road consistently through the reduction in complete road closures and effective scheduling of works targeted at minor maintenance. With the periodic monitoring of the road, all maintenance work can be conducted without having to create temporary roadways for traffic to filter around, drastically increasing the overall budget required for the project to be completed. The secondary way in which this reduces disruption to the motorists using the road, is that it limits the length of continuous time in which the process of completely closing off the road so that works can occur significantly when compared to that of a large-scale rehabilitation project. This however should be tempered with the knowledge that only certain low volume roads would require complete road closures as compared to single lane closures with traffic management plans.

Looking to the future, an inspection and cost benefit analysis such this could be potentially integrated into a long-term infrastructure and development plan for its respective region. Integrating this into long term infrastructure plans could in theory align with the agency's numerous development goals for a specific region, with an emphasis on points such as promoting local economic growth or enhancing the interconnectivity of a steadily growing population within a more rural community. This will in turn provide the agency in charge, whether that be a local or regional government, a critical impact on the overall resource or budget allocation for low volume road infrastructure.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

To summarise, this research project aimed to provide the relative costs and benefits associated with the maintenance strategies regarding low volume roads within a rural setting. This report provides a thorough framework for agencies such as regional councils to utilise as a decision making matrix, when budget allocations allow for repairs of these often over-looked division of rural infrastructure.

Throughout this project there were certain key findings that were discovered through the use of extensive research, on site investigations and rigorous testing and modelling. The overall key findings for this research project are a periodic inspection and construction maintenance, with the added monetary inclusion of initial rehabilitation costs and consistent ongoing maintenance costs presented itself as a more affordable alternative to that of consistently neglecting a road for the duration of its design life, then performing what is essentially a complete road replacement and reconstruction project.

These results highlight an emphasis on the importance of consistent and regular inspections of these low volume roads. Regular inspections performed on these roads help identify early stage signs of the roads wear and tear becoming prominent, allowing for relatively cost effective intervention procedures and preventative steps. This can allow for the low volume road to effectively push past the expected and designed life span of the road, further saving the agency a significantly large sum of money that would otherwise have to be spent on complete rehabilitation or reconstruction of entire sections of road.

Furthermore, the effects for the future resource and budget allocation of the agency in charge of these low volume roads cannot be understated. Integrating the cost benefit analysis as well as routine periodic inspections into a specified structural framework for maintenance activities and repairs, will lead to long-term economic growth in addition to the given development of connectivity and minimal disruption to the surrounding area and communities that utilise these roads. As companies and agencies face consistently tightening budgetary conditions, the act of applying the finding within this research project allow for the optimisation of management processes regarding the low volume roads.

5.2 Future Recommendations of Research

Looking to future, there are several steps that can be taken within the context of this research project to further innovate and provide cost effective measures for low volume road infrastructure.

The first step that could be taken is to incorporate useful technologies into the data collection stage of the project. The introduction of items such as drones and sensory integration may modernize the process in which low volume roads are managed, with these technologies covering vast distances quickly and providing the agency with a brief snap shot of the physical conditions of the road, before going to investigate the subsurface conditions with the use of sensory equipment. The overall time efficiency provided by these emerging technologies cannot be understated and would provide an excellent extension into this research project, implementing technologies such as these in the cost benefit analysis undertaken.

The secondary point that could fleshed out within newer iterations of this project is to integrate further social and economic impacts of the area. The social aspects of these low volume roads cannot be understated when in the context of the small rural communities that they service, as well as the multitude of farming and agricultural centres that rely on these roads for the livelihood of these same communities. With this in mind, a more detailed report regarding the social and economic interactions and requirements for these regional communities should be gathered and utilised to the fullest when discussing the maintenance needs for the low volume roads. These pieces of social and economic data can then be used to further solidify the foundation on which the project is built upon, taking in the relative needs of the community when designing maintenance strategies and schedules.

The next recommended implementation for this research project is perform similar case studies on other low volume roads in the region. This could be done in order to develop a sense of uniformity among the strategies for maintenance and provide invaluable insight into the different approaches and solutions that can be used to main low volume roads. Case studies such as these span items including previous successful projects within the region to international practices and approaches that could potentially be adopted by domestic agencies in the efforts of streamlining or advancing internal practices and strategies. With the use of these case studies, engineers can identify the most effective strategy for the situation, understand the various social, economic and environmental impacts of each approach and become able to swiftly adapt these strategies outlined a tailor them towards the necessary conditions and constraints of the low volume road in question.

Furthermore, another example of recommendations for this research project is to further evolve the cost modelling procedure. Incorporating this into the research project will assist in the budgetary and resource allocation stages of the projects. With the inclusion of an evolved cost modelling procedure, information such as design life costs, construction costs as well as any potential monetary savings can be collated to provide a more informed decision for any stakeholders in the project to take under advisement and maintain a more economically viable strategy.

Moving forward, the environmental impacts of a project should also be considered. The assessment of environmental impacts, especially for low volume roads is an important stage of rehabilitation due to the surrounding regional needs of the community. Environmental factors such as soil erosion, disruptions to vegetation and water runoff provide a vital and comprehensive understanding of the surrounding ecosystem and how the low volume roads construction, rehabilitation or repairs will affect it. With this in mind, engineers can effectively develop a series of strategies aimed at limiting these impacts on the environment.

This page intentionally left blank

References

Australian Automobile Association. (2022, August). *How Fuel Excise Pays for our Roads.* Retrieved September 28, 2023, from Australian Automobile Association: https://www.aaa.asn.au/fuel-excise-explained/

Australian Government Productivity Commision. (2017). *Funding And Investment for Better Roads.* Retrieved Sepetember 25, 2023, from https://www.pc.gov.au/inquiries/completed/productivity-review/report/productivity-review-supporting9.pdf

Australian Government: Department of Infrastructure, Transport, Regional Development and Communications. (2020). *Yearbook 2020: Australian Infrastructure 2020.* Retrieved September 26, 2023, from https://www.bitre.gov.au/sites/default/files/documents/bitre_aus_infrastructure_yearbook_2020.pdf

Brosnan, L. (2023). *Corrugations in Soil.* Retrieved September 29, 2023, from https://www.conplant.com.au/news/corrugations-in-soil/#:~:text=Compaction%20rollers%20are%20used%20in,windswept%20sands%20in%20a%20desert.

CementConcrete. (2021). *Repair and Maintenance of Earth Roads, Gravel Roads, W.B.M. Roads, Bituminous Roads.* Retrieved September 29, 2023, from https://cementconcrete.org/transportation/repair-maintenance-earth-gravel-wbm-bituminous-roads/3028/

Chai, G., Chowdhury, S., Martin, T., & Sultana, M. (2016). Deterioration of flood affected Queensland roads – An investigative study. *International Journal of Pavement Research and Technology, 9*(6), 1-15.

De Ceunynck, T., Ponders, E., Daniels, S., Hermans, E., Brijs, T., & Wets, G. (2013). *Road Safety Differences between Priority-Controlled Intersections and Right-Hand Priority Intersections: Behavioral Analysis of Vehicle–Vehicle Interactions.* Retrieved October 5, 2023, from https://journals.sagepub.com/doi/abs/10.3141/2365-06

Department of Transport and Main Roads. (2011). *Cost-Benefit Analysis Appendices.* Retrieved March 27, 2024

Department of Transport and Main Roads. (2019). *2018-2019 Annual Report.* Queensland Government, Department of Transport and Main Roads. Queensland Government. Retrieved September 26, 2023, from file:///C:/Users/Tim_R/Downloads/TMR-2018-19-Annual-Report.pdf

Dhruvin Jasoliya, A. U. (2024). A review of soil modeling for numerical simulations of soil-tire/agricultural tools interaction. *Journal of Terramechanics*, 41-64.

Faiz, A. (2012). The Promise of Rural Roads Review of the Role of Low-Volume Roads in Rural Connectivity, Poverty Reduction, Crisis Management, and Livability. *Transportation Research Circular, 97*(8515), 52.

Franzen, T., & Thorpe, D. (2016). *Sustainable Development and Management of Low Volume Road Networks in Australia.* Retrieved March 27, 2024, from https://research.usq.edu.au/download/8096c4c58527bd4ff2fd7e93927b3b880bf8867d09282e582e5990b9574f4067/750632/Sustainable%20Development%20and%20Management%20of%20Low%20Volume%20Road%20Networks%20in%20Australia%20as%20Submitted.pdf

G.Shanmugam. (2018). The Role of Excess Pore-Water Pressure. *Reference Module in Earth Systems and Enviromental Science*.

K, N. S. (2021). *Different Types of Bitumen, their properties and Uses.* Retrieved August 15, 2023, from https://theconstructor.org/transportation/types-of-bitumen-properties-uses/15709/

Liphardt, A., Radziszewski, P., & Krol, J. (2021). Homogeneity and Viscoelastic Behaviour of Bitumen Film in Asphalt Mixtures Containing RAP. *MDPI, 14*(4355), 1-14.

Low Volume Road Maintenance Booklet. (2013). Retrieved September 28, 2023, from https://assets.publishing.service.gov.uk/media/57a08a3b40f0b649740004c6/AFCAP-SUD085-Low-Volume-Road-Maintenance-Manual-South-Sudan.pdf

McLean, J. (1995). *Low-Volume Roads in Australia.* Retrieved Spetember 25, 2023, from https://onlinepubs.trb.org/Onlinepubs/TRCircular/446/446-008.pdf

Norman Walzer, D. C. (n.d.). *Financing and Maintaining Low-Volume Roads in the Midwestern United States.* Retrieved September 25, 2023, from https://onlinepubs.trb.org/Onlinepubs/trr/1987/1106v1/1106v1-002.pdf

Saeed, N., Nyberg, R., & Moudud, A. (2022). *Gravel Road Classification based on loose gravel using transfer learning.* Retrieved September 29, 2023, from https://www.researchgate.net/figure/Cross-section-structure-of-gravel_fig1_365301950

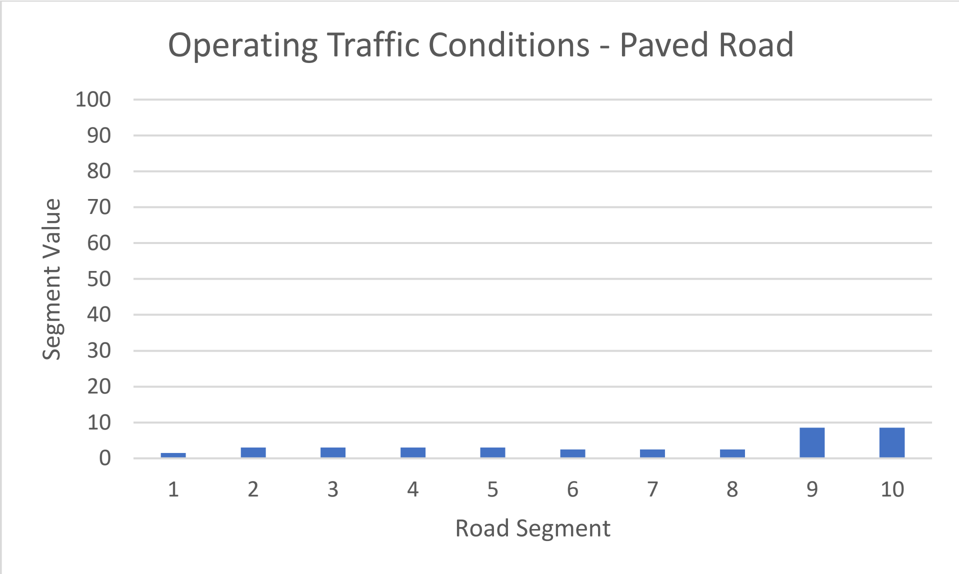
South African Transport and Communications Commission. (2003). *Guideline - Low Volume Sealed Roads.* Retrieved October 3, 2023, from https://www.ssatp.org/sites/ssatp/files/pdfs/Toolkits/LVSR-Guideline-FullText[1]_0.pdf

Zaniewski, J., & Orobio, A. (2012). Using the mechanistic-empirical pavement design guide for material selection. *Sci-Elo, 1*(64), 1-5.

Appendix A

Operating Traffic Conditions for Paved Road

Figure 9: Operating Traffic Conditions for Paved Road



Above is accurately scaled to the weighting factor, below is scaled to one tenth of the actual size.

Figure 10: Operating Traffic Conditions for Paved Road (Scaled)

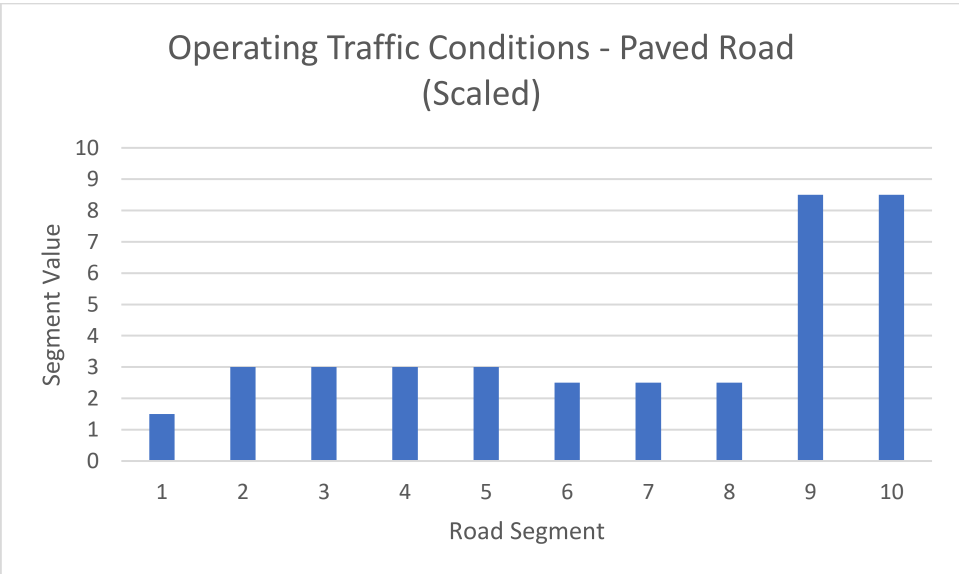


Figure 11: Safety Conditions for Paved Road

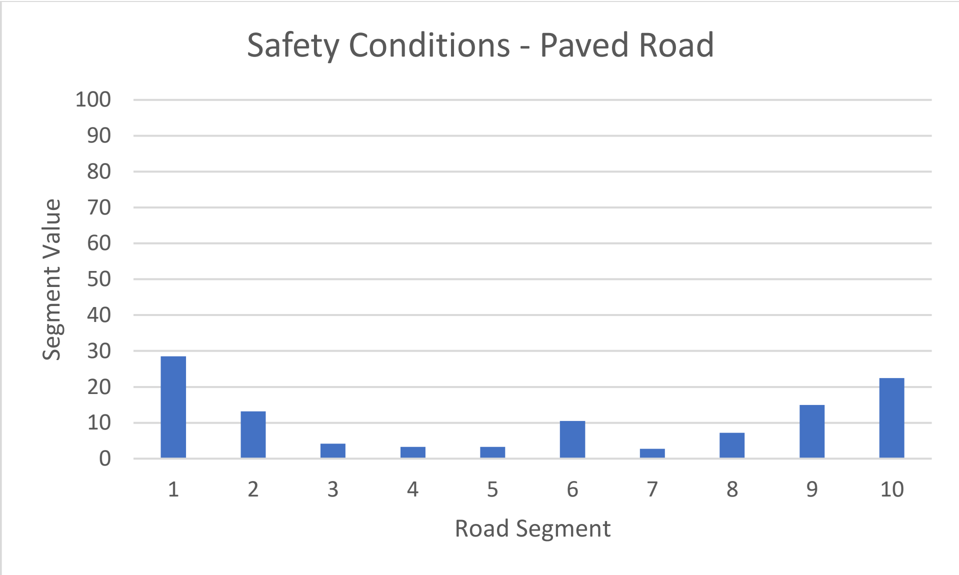
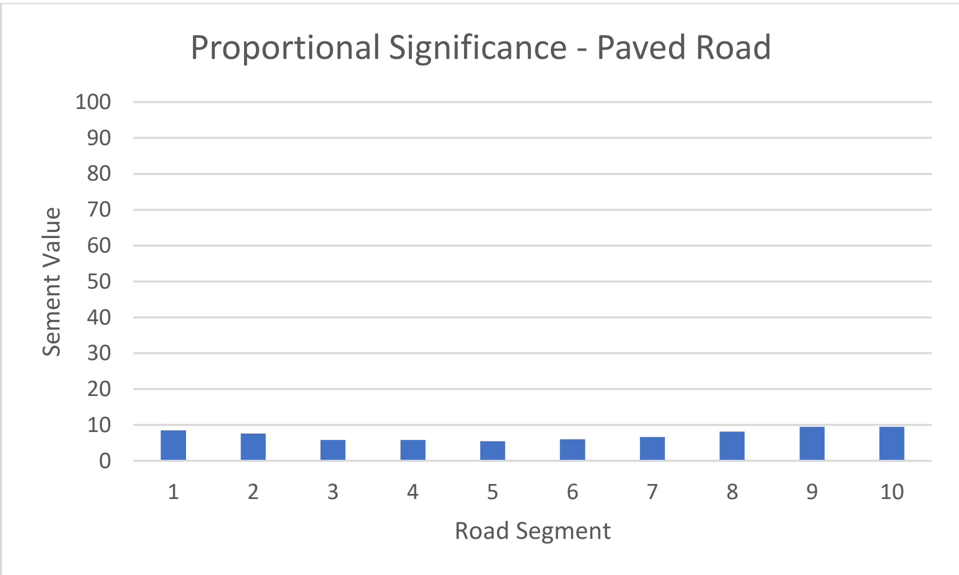


Figure 12: Proportional Significance for Paved Road



Above is accurately scaled to the weighting factor, below is scaled to one tenth of the actual size.

Figure 13: Proportional Significance for Paved Road (Scaled)

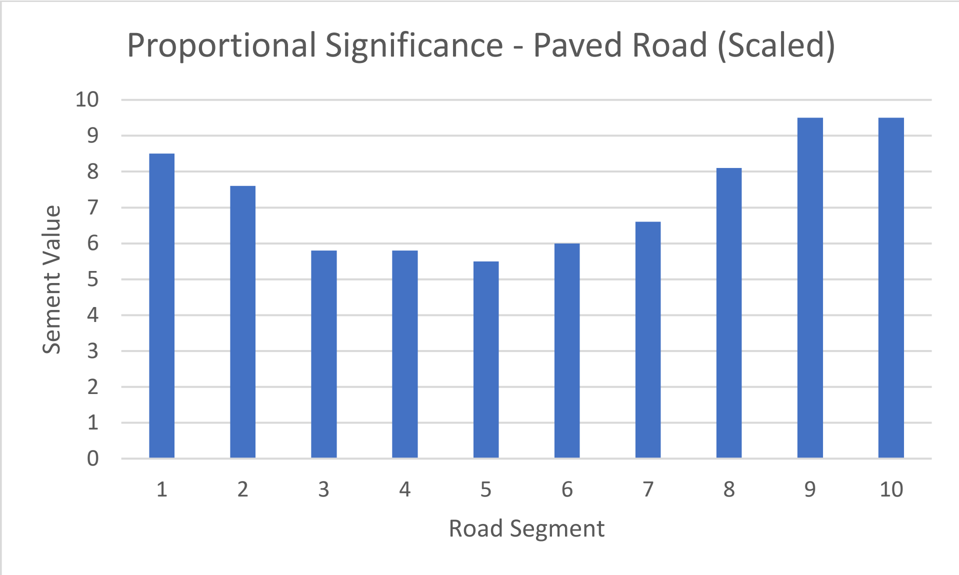


Figure 14: Sub-surface conditions for Paved Road

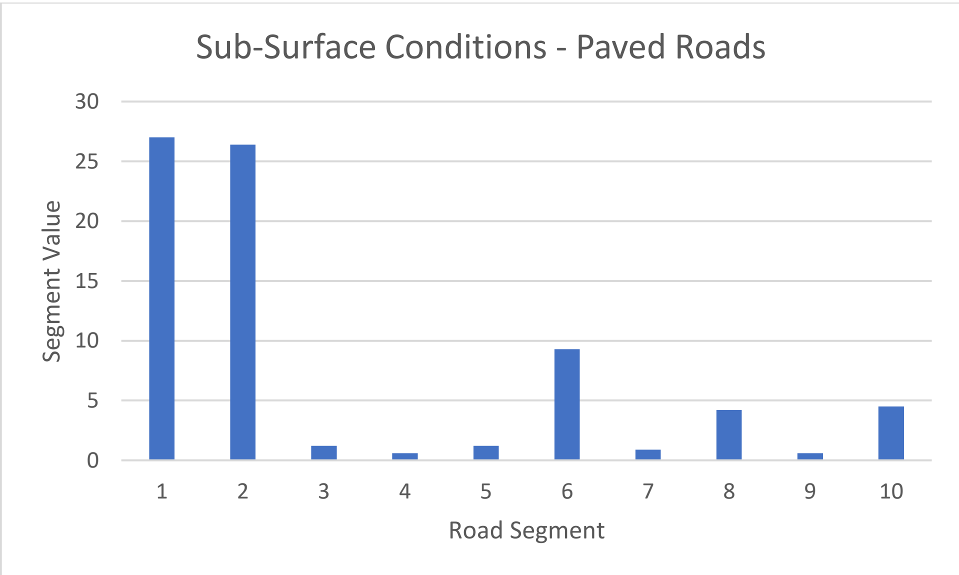
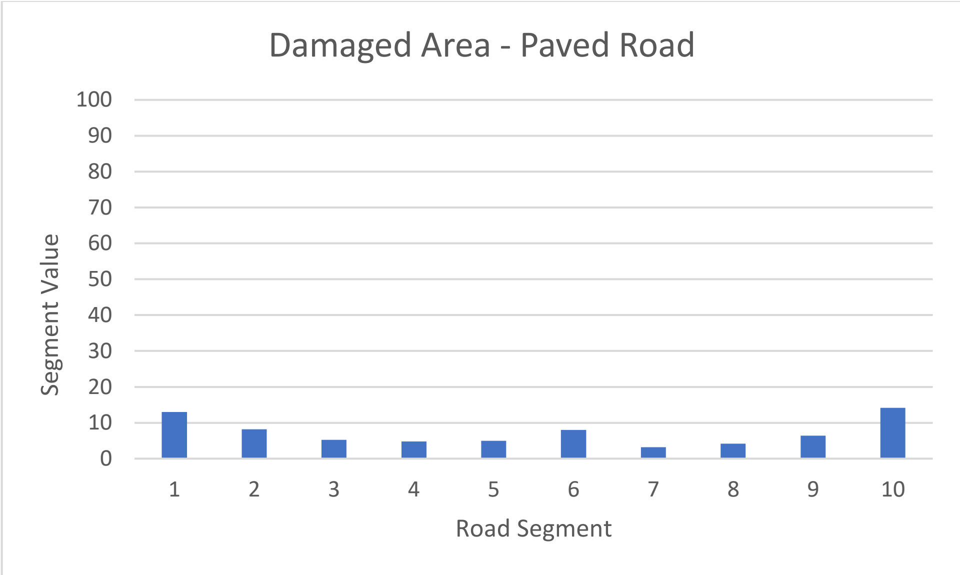
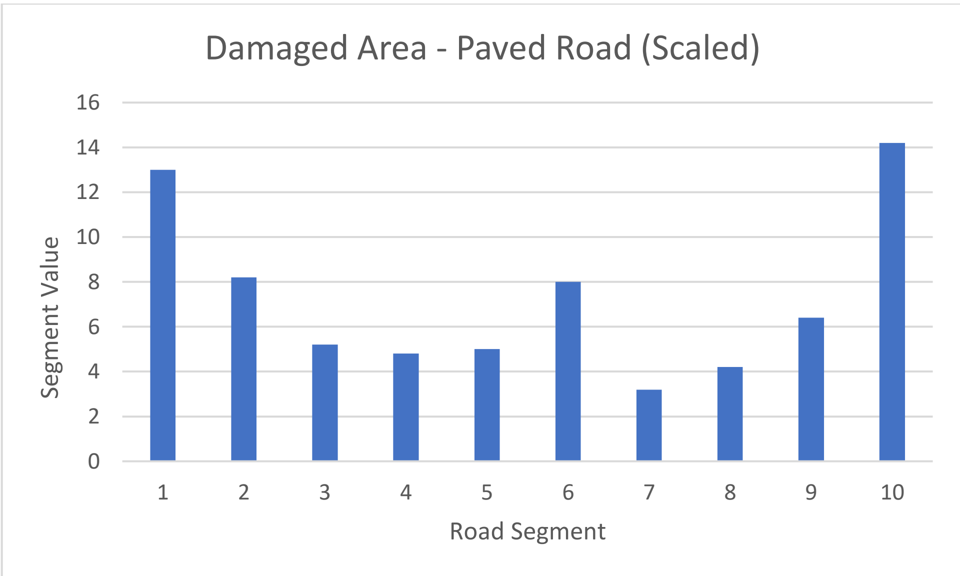


Figure 15: Damaged Areas for Paved Road



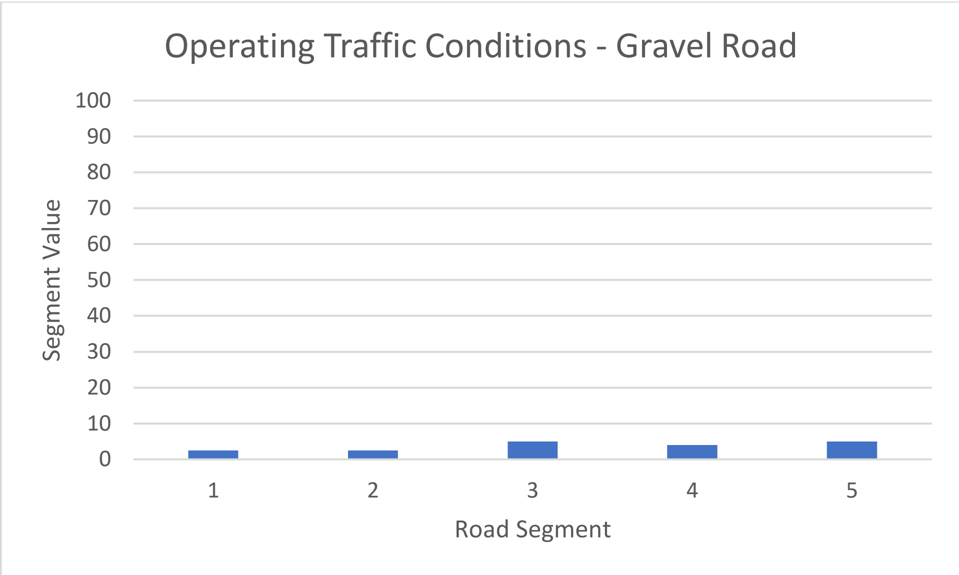
Above is accurately scaled to the weighting factor, below is scaled to one tenth of the actual size.

Figure 16: Damaged Areas for Paved Road (Scaled)



Appendix B

Figure 17: Operating Traffic Conditions for Gravel Road



Above is accurately scaled to the weighting factor, below is scaled to one tenth of the actual size.

Figure 18: Operating Traffic Conditions for Gravel Road (Scaled)

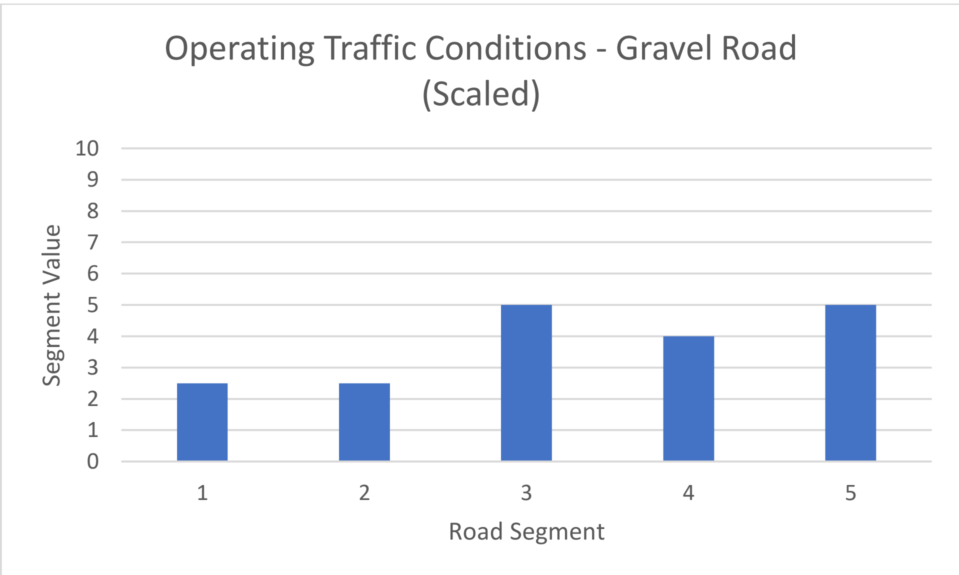


Figure 19: Safety Conditions for Gravel Road

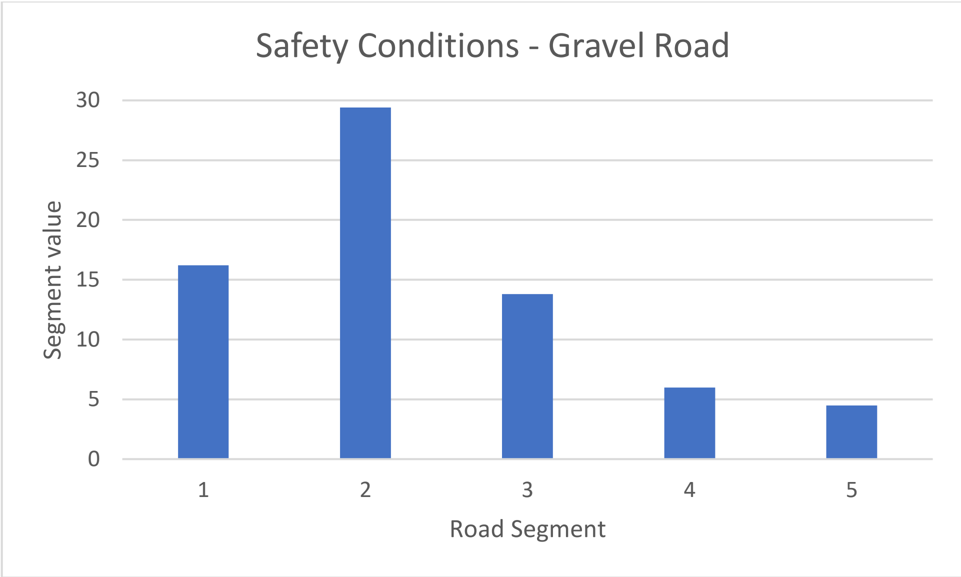


Figure 20: Proportional Significance for Gravel Road

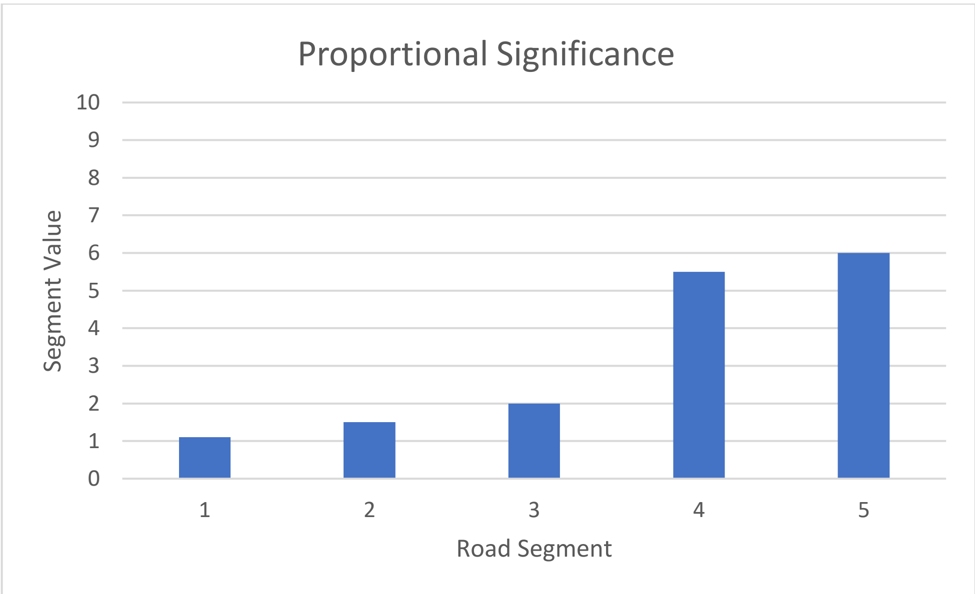
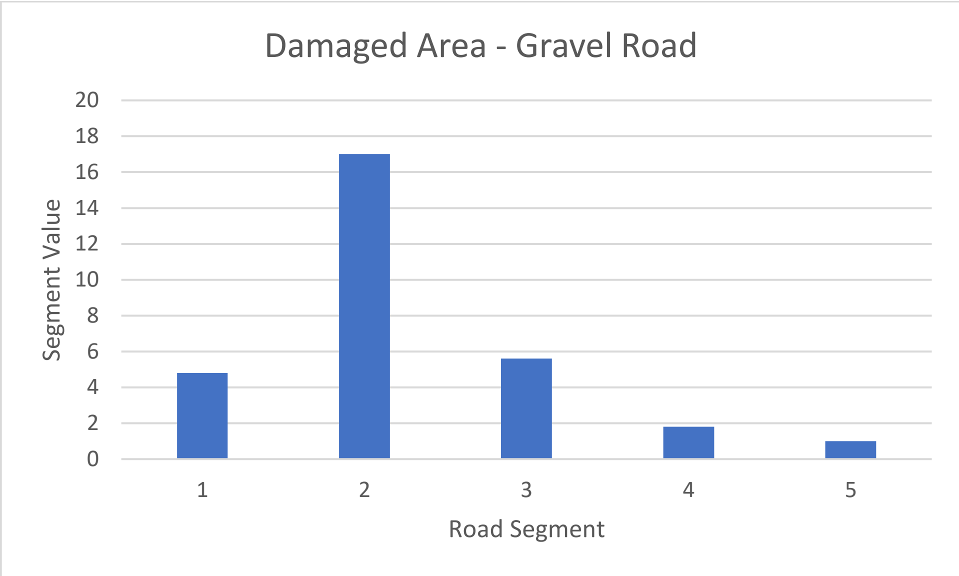


Figure 21: Damaged Area for Gravel Road



This page intentionally left blank