University of Southern Queensland

Faculty of Heath, Engineering and Sciences

The Effect of Road Roughness on Traffic Speed and Road Safety

A dissertation submitted by

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Abstract

Road Safety is one of the most important issues for traffic authorities, as they attempt to reduce the frequency and severity of road crashes. This dissertation investigates the effect of Road Roughness on traffic speed and road safety in Southern Queensland, Australia. This research is important as it investigates the pavement variable of roughness, and considers its contribution to vehicle speed and crash rates. Using data collected by the Queensland Department of Transport and Main Roads, models were formed to depict the relationships between roughness, speed, crash rate and other road parameters. The model focused on a sample of roads in the 'Downs South West' region.

The models collectively indicated a strong relationship between higher crash rates and increased pavement roughness. Road segments with a crash history have a higher average roughness than non-crash segments. Crash rates involving light vehicles were more affected by increasing roughness than crashes involving heavy freight vehicles. When considering the five crash severity types, crashes resulting in hospitalisations and property damage had the strongest increase in crashes over a small increase in roughness. Regarding driver speed, there is 100% driver compliance on segments with roughness over 120counts/km NRM, with the 85^{th} percentile speed ranging from 5-15km/hr below the posted speed. The models presented similar conclusions to Australian and International research, but produce slightly different results from the two similar published investigations. Crash rates showed a steadily increasing linear relationship with increasing roughness and are slightly higher than Swedish results, however are well below the critical crash rate as specified in the MUTCD. This suggests that Queensland's road safety procedures are being implemented effectively.

These findings can be utilised by traffic authorities managing rural roads to create a safer road environment. Recommendations include ensuring regular road surface maintenance to provide low roughness (an IRI of 1.9m/km). Providing incentives to contractors for delivering a smooth pavement over the design life will ensure better pavement and construction quality. Prioritisation for maintenance of roads with lengths of roughness over 120 counts/km NRM may be suitable, with temporary speed reductions applied until works are completed. Prioritising maintenance on routes with lower volumes of heavy vehicles may also be suitable. Each of these recommendations can be implemented to ultimately improve the safety on the road network, through efficient funding prioritisation and understanding the effects of pavement roughness.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Limitations of Use

Candidates Certification

I certify that the ideas and experiential work, results, analysis 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.

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Student Number: U1016950

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Signature

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Date

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Table of Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations

AADT - Annual Average Daily Traffic

ARMIS - A road management information system

ARRB – Australian Road Research Board

ATLM - Audio Tactile Line Marking

CAMs – Chevron Alignment Markers

Ch. - Chainage

CHR – Channelised Right Turn Treatment

DCA - Definitions for Coding Accidents

DTMR – Department of Transport and Main Roads

DVR – Digital Video Road

HV - Heavy Vehicles

IRI – International Roughness Index

LCS – Limiting Curve Speed

MUTCD – Manual of Uniform Traffic Devices

NAASRA – National Association of Australia State Road Authorities

NRM- NAASRA Roughness meter

RPDM – Road Planning and Design Manual

RPM – Raised Pavement Markers

STE- Smooth Travel Exposure

TARS- Traffic Analysis and Reporting System

V85 – 85^{th} percentile speed

Vpd- Vehicles per day

VKT – Vehicle Kilometres Travelled

Chapter 1: Introduction

1.1 Introduction

Every day drivers, pedestrians and cyclists are faced with the hazards of the road network. As a society, we must work to limit the risks that the transportation industry and the community encounter when making their way to work, school or to visit friends and family. Transport authorities are working with communities, to provide a safer travel network, through road, rail and water safety. In Australia, vehicle travel on roads is the most popular form of transportation. Road safety is governed by three aspects: the road, the driving environment and the driver. While it is difficult to control specific conditions (e.g. weather), transport authorities can influence road and driver safety, and how each interacts with the conditions. Driver safety is targeted through licencing laws, road rules, vehicle safety improvements and driver campaigns. Road safety includes having a combination of safe road parameters including the geometry, sight distance, seal width, overtaking opportunities, pavement quality and surface conditions etc. It is in the public's interest for Transport authorities to improve the conditions of the road network to ensure a high safety standard is provided to the community.

One such component of the road network is the road surface conditions. The defects and deterioration of the pavement decreases the road safety for drivers. Road roughness is a method to quantify this deterioration of the pavement. Roughness is the most widely used pavement condition indicator, as it is affordable data to capture, it reflects road user's costs and is widely accepted as the most relevant measure of pavement behaviour (Hunt 2002, p.9). However, investigating the road network parameters (e.g. pavement) is not enough, research into the way that this parameter interacts with drivers and the environment is very important. In Australia, driver's behaviour is governed by the road rules. One of the most frequently enforced rules is the speed limit, due to the distinct relationship between travel speed and crash frequency and severity. This dissertation investigates the effect that pavement roughness has on driver behaviour, particularly speed and other safety factors.

Driver safety is regulated by the authorities through the enforcement of road rules. These rules ensure that the general road users can safely travel to their destination, in a timely and low risk manner. Parameters such as legal vehicle speed, direction of manoeuvre and right of way are defined through state enforced road rules. In Australia, drivers' speed is often monitored through stationary speed cameras or through the police force (using speed radars). This is due to the increased safety risks involved in speeding. In this investigation, crash rate and traffic speeds are analysed, to quantify driver behaviour.

This investigation will be based on the southern region of Queensland, Australia. Standards and procedures of Australian and Queensland road authorities will be used throughout this investigation. Currently, there have been limited studies on these relationships around the world, and no studies have been identified as having been completed in Queensland.

1.2 The Problem

In 2013 the Queensland Government Department of Transport and Main Roads (DTMR) commenced a state wide review of the speed limits of a hundred roads throughout the state. This review was based on public survey, crash statistics and local knowledge (Queensland Government 2014b). The current speed limits for these roads were reviewed in accordance with the Manual of Uniform Traffic Devices (MUTCD), in particular part 4 which covers speed controls. Due to the widespread reviews on speed limits of the state's road network, the MUTCD part 4 was also reviewed. This highlighted a range of topics which required further research or discussion. One topic which was raised by the review and by regional DTMR engineers was the effect of surface roughness upon the review of speed limits. The MUTCD only provides roughness limits for a 110km/hr design speed, and the question was raised if these limits were suitable on lower speed environments. The review highlighted that at a point, the pavement deterioration would require a reduced speed limit (usually temporary, pending pavement repairs). This research aims to investigate this correlation between increased road roughness and speed limits. The effect this has on road safety is also investigated.

Prioritisation of funding is another challenging decision which the Queensland Department of Transport and Main Roads engineers and planners face regularly. Being a public service, there is always high competition for funds between each department, and within DTMR for which projects are more urgent. This research into the effect of roughness on speed and safety will identify ways to more efficiently prioritise funding, particularly for pavement repair and reseal projects.

1.3 Downs South West Region Network

The Downs South West region is an administrative area defined by the Department of Transport and Main Roads. It is situated in the southern end of Queensland, Australia. Figure 2 is a map of the region, which highlights the national and state road network. This region covers 399,515km^2 which is approximately 23% of Queensland (Queensland Government 2013a, p.3).

In the Downs South West region, a typical road is a single carriageway with 2 x 3.5m lanes and shoulders of approximately 1m. The clearzone is usually grassed, and trees and services are usually also located within the road reserve, as seen in Figure 1 below, on the Warrego Highway.

Figure 1: A typical road (Warrego Highway, 18E) (QDTMR 2014a)

Figure 2: Map of the Downs South West Region (Queensland Government 2013a, p.2)

1.4 Research Objectives

The following is the defined scope of this investigation into the effect of road roughness on traffic speed and safety:

1. Research the topic of pavement roughness. This includes recording roughness, the parameters which effect roughness and the relationship of roughness between crash rate and speed.

2. Investigate the factors which influence speeds and road safety. Research the current methods in which roughness is treated by speed reviews, the relationship between speeding and crash rate, and the treatments used to improve road safety.

3. Attain traffic speed, pavement roughness and crash data on all declared roads in South-East Queensland. Ten to twenty appropriate roads will be selected for modelling (DTMR data).

4. From the crash history, calculate the crash rate. Investigate the roughness on the roads selected in relation to the crash rate and speed data. When investigating crash data consider heavy vehicles effect and investigate crash data by crash severity type.

5. Complete a case study analysis on roads of interest, and investigate the effect of external factors. Utilise site visits to accurately assess current road conditions.

6. Determine a roughness level where the operating speed is impacted. Analyse the effects of reducing/ changing posted speeds and methods of improving safety where high crash rates occur.

7. Produce results and evaluate all findings, and present these in a graphical or tabular format (as appropriate).

8. Complete an academic dissertation providing conclusions and recommendations on the relationship between pavement roughness, speed compliance and road safety.

The literature review in Chapter 2 will investigate objectives 1 and 2. The methodology in Chapter 3 describes how objectives 3, 4, 5 and 6 will be achieved. Chapter 4: Roughness Models and Chapter 5: Roughness Case Studies and Financial Model, address objective 4, 5, 6 and 7 through models and discussion. Chapter 6 evaluates the results found in chapters 4 and 5, and summarises the findings. Chapter 7 states the conclusions and recommendations found. Each Chapter within this dissertation creates an academic dissertation on the relationship between road roughness, speed and safety (objective 8).

Chapter 2: Literature Review – Pavement Roughness

2.1 Introduction

Through investigating both Australian and international sources, the literature review highlights pavement roughness, vehicle speed and road safety, and how each of these parameters are interrelated. Section 2.2 highlights pavement roughness definitions, causes and effects, and the current studies between roughness in speed and safety. The different types of speed are defined in section 2.3, along with the factors which may cause speeds to change. Methods to improve road safety and the current costs of crashes to society are also defined in section 2.4. These sections define the parameters used in this research and provide background to the models within this dissertation

Figure 3: Rough Road Surface (California Department of Transportation 2014)

2.2 Roughness

Austroads (an organisation of Australian and New Zealand road transport and traffic authority) defines roughness as the deviations or irregularities from the intended longitudinal profile (true planar surface) of the pavement surface (Austroads 2007). This definition is widely accepted and mirrors the definitions used by other road authorities around the globe. Roughness measures surface irregularities with wavelengths between 0.5m and 50m in the longitudinal profile. Roughness is measured by recording the movement in the rear axle relative to the sprung mass (vehicle mass supported by suspension) during travel at a constant speed.

Figure 4 highlights the factors which effect roughness in unbound granular pavements. It highlights the complexity of pavement roughness. It is evident that the range of variables effecting roughness include (Hunt 2002):

- Pavement type and structure (including age)
- Seal age
- Resurfacing and routine maintenance
- Quality and strength of the Base, Subbase and Subgrade
- Location of the Water table
- Drainage
- Environmental impacts such as rain, both during construction and throughout the life of the pavement, weather and temperature.
- Quality of the gravel, particularly strength, source of rock, depth and permeability.
- Nature of the soil i.e. reactive/non-reactive soils
- Current and predicted traffic volumes and loadings.
- Quality of construction methods (including materials used and maintenance techniques)

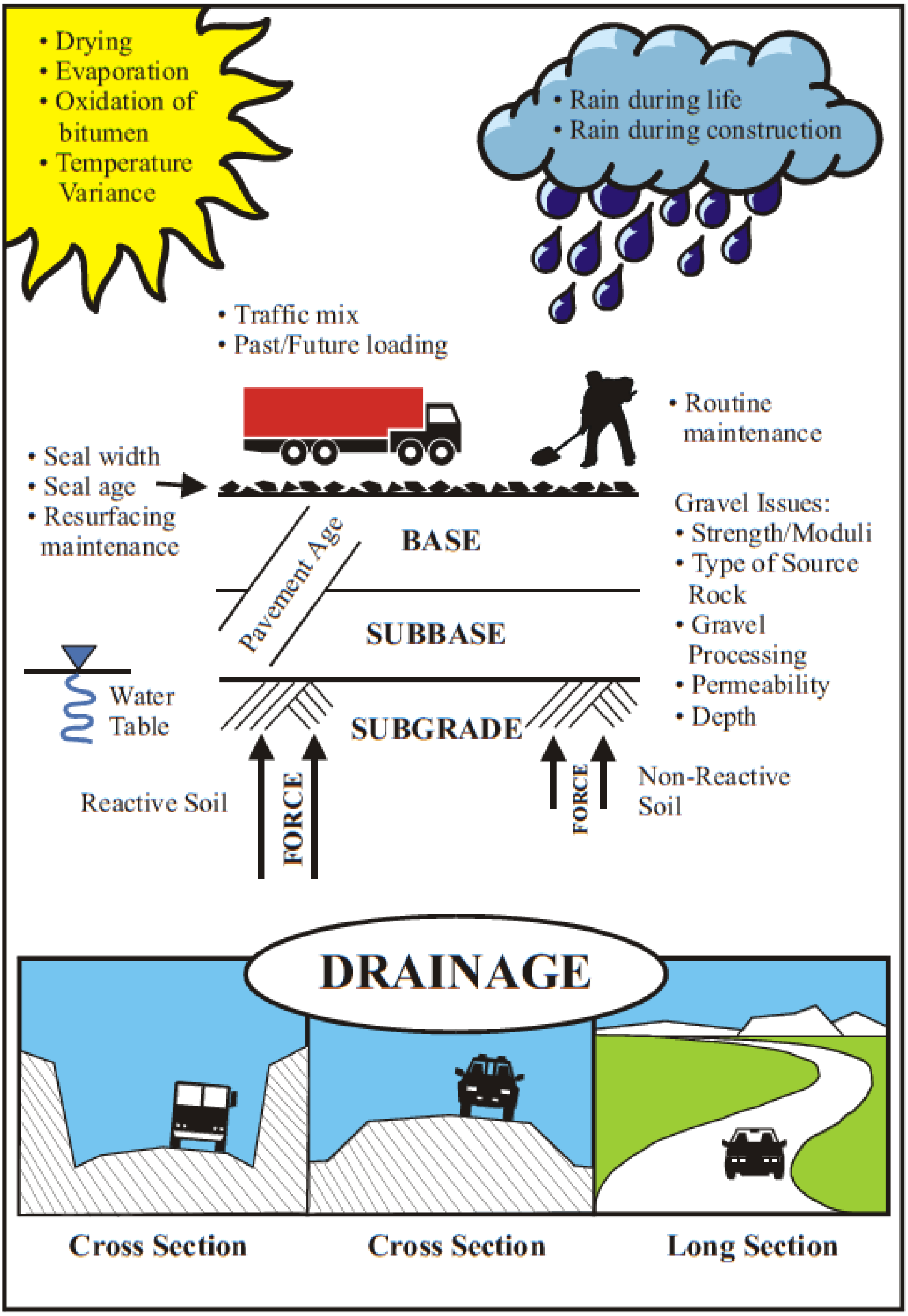

Figure 4: Influential factors on Pavement Quality (Hunt 2002, p.13)

Roughness is used in conjunction with the terms ‘ride comfort,’ ‘ride-ability,’ ‘smoothness,’ and ‘evenness’ (Austroads 2007). Roughness is perceived by most traffic authorities as the best indication of ride-quality of the road network. There are many ways to quantify roughness. Austroads endorses the International Roughness Index (IRI) as the reporting unit for Australasia. IRI is the most widely adopted standard, however it is not used in most of Europe and parts of the United States (Austroads 2007).

Some other quantities of roughness include (Al-Rousan, T & Asi, I 2010, p.1):

- Present Serviceability Rating (PSR)
- Present Serviceability index (PSI)
- Ride Number (RN)
- Riding Comfort Index (RCI): the Canadian version of the PSI, which ranges on a scale of 0 to 10 (Chandra 2004, p.360).
- NAASRA (National Association of Australia State Road Authorities) roughness meter counts (NRM) are being phased out (as NAASRA preceded Austroads as Australia’s national road authority), however it is still used by some Australian road authorities. This method of quantifying roughness has high correlation with IRI results, and is therefore easily comparable (Austroads 2007).

Austroads highlights the measures of roughness that are used in the Australasia region in Table 1. The IRI averaging method using profile-based profilometers are the Austroads supported method for measuring roughness. Other methods include the NAASRA roughness counts (NRM) which were an older method of determining roughness, and other profile-based methods.

Roughness values are used by the transport industry to monitor road condition, prioritise projects within a network, assess the suitability of roads for the uses and predict the cost of travel

Table 1: Measurements of Roughness in the Australasia Region (Austroads 2007 p.37)

Measuring device	Mechanical response-type	Profile-based profilometers Profile readings are taken at approximately 50 mm centres along the profile being surveyed		
Name of measure	**NAASRA Roughness Counts**	**Single Wheelpath IRIqc**	**IRI averaging**	**Profile averaging**
Reporting units	Counts/km	m/km	m/km	m/km
Symbol (complete)	NRM	Single Wheelpath IRI_{qc}	Lane IRI_{qc}	Lane IRI_{hc}
Common symbol	NRM	Single Wheelpath IRI_{qc}	IRI	Lane IRI_{hc}
Description	The cumulative total relative upward physical displacement between axle and body of a standard vehicle operating at a standard speed (1 NRM corresponds to a relative upward physical displacement of 15.2 mm)	International Roughness Index calculated for each 100 m segment by applying a mathematical model of a quarter-car to a single longitudinal profile	The Single Wheelpath IRI_{qc} for each wheelpath for each 100 m segment is computed independently and then averaged to produce Lane IRI_{qc}	The point-to-point average of the two wheelpath profiles is determined and the quarter-car mathematical model is applied to this average profile to simulate a 'half-car' model, i.e. Lane IRI_{hc}
Favoured by Austroads	Traditional measure, being phased out	No	Yes	No
Used in HDM-4 products	No	No	Yes	No
Used by ARRB in calibrating NAASRA roughness meters	Not applicable	No	Yes	No (was used until mid 1990s)
Conversion to NRM (Prem 1989)	Not applicable	NRM = - 3.47 - 0.557 (Single Wheelpath IRI_{qc})^2 + 27.50 x (Single Wheelpath IRI_{qc})	NRM = – 1.27 + 26.49 x Lane IRI_{qc}	NRM = – 1.95 + 33.67 x Lane IRI_{hc}
Correlation (r^2) (Prem 1989)	Not applicable	0.955	0.990	0.994
Typical relative value in Australia (Prem 1989)	Not applicable	Not applicable	Lane IRI_{qc} = 1.27 Lane IRI_{hc}	Lane IRI_{hc} = 0.79 Lane IRI_{qc}

Physical Characteristics

A range of surface defects contribute to pavement roughness. In flexible pavements (granular materials with bituminous surface), roughness is increased by a combination of localised depressions, ruts, potholes, patches, corrugations, shoving, delamination/ debonding, stripping, cracking or unevenness from the installation of services. In rigid pavements (those which contain Portland cement), roughness is higher in pavements which have stepping/faulting, rocking, pumping, spalling, patches, slab curling (temperature induced) or unevenness from the installation of services (Austroads 2007). Other factors which increase the roughness include localised factors such as intersections, roundabouts, railway crossings, bridge abutments etc. These defects are often caused by moisture penetrating the surface causing failure, lack of strength, unsuitable materials or the breakdown of the materials over time.

Cost of Roughness to society

These irregularities in the road surface effect vehicle efficiency, road safety and social and economic facets of society. An increase in road roughness affects the dynamics of a moving vehicle and increases the wear of parts, loss of tyre friction and produces greater operating costs due to travelling at decreased speeds (See Figure 2) (Chandra 2004, p.360). The total direct vehicle operating costs increase by 4 to 5 percent per unit increase of IRI. When incorporating the increased travel time costs, the increase in costs per IRI is 3% for cars and 5.5% for trucks (Foley & McLean, 1998). As the amplitude and frequency of roughness increases, the coefficient of friction (between the tyre and the road surface) decreases by up to 80%, during low speed braking (Cenek P, Davies R & Jamieson 2012, p.1). The vehicle rolling resistance increases with each unit of IRI by about 3 to 6% (Foley & McLean, 1998). Increased roughness also increases the risk of accidents, and therefore has a negative socioeconomic impact to the community. Roughness deteriorates ride comfort, dynamic loading, surface drainage and impacts the safety and performance of the road network. The economic cost to businesses and consumers increases as the roughness increases, due to the operational and maintenance costs to vehicles. The cost to improve road pavements is usually minimal compared to the ongoing operational costs to society (Chandra 2004, p.360). Therefore, there are many benefits for road authorities to maintain low roughness levels on road infrastructure. The benefits of low roughness values include greater road comfort and safety, and decreased vehicle operational costs (including less fuel consumption), tire wear, maintenance costs, vehicle depreciation, and pavement maintenance expenditure (Al-Rousan, T & Asi, I 2010, p.1).

Figure 5 highlights the greater operational costs which result from increased roughness. It can be seen for IRI 3 and higher, the vehicle operating costs increase. Between an IRI 3 and 5 there is an increase in operational cost of about 5% for cars and 10% for cars.

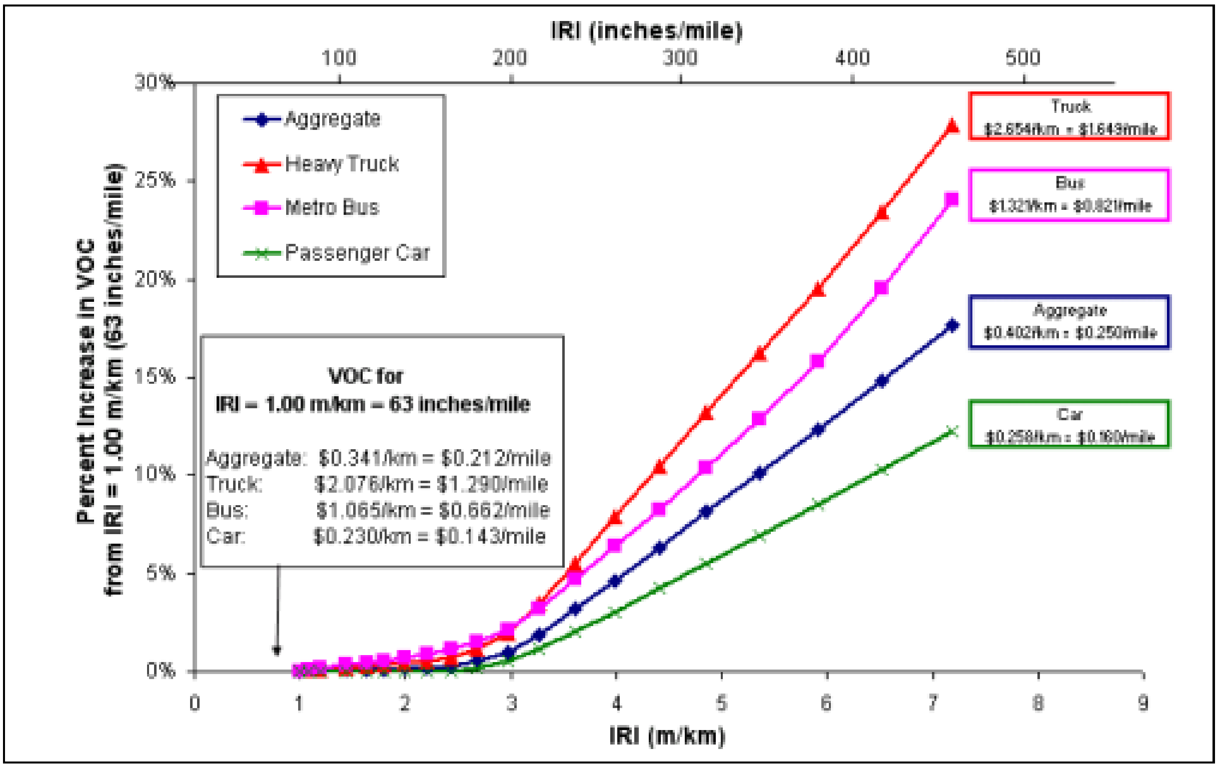

Figure 5: Percentage increase in operation costs dependant on roughness (Al-Rousan, T & Asi, I 2010, p.3)

In the USA, incentives or penalties are provided to contractors who provide a high level of smoothness. This both provides beneficial quality control, but may impact the structural integrity of the road. An IRI of 0.96 – 1.26m/km for new roads equates to no incentive or penalty. Lower IRI earn up to a 10% incentive (IRI <0.8m/km), and IRI's higher than 1.89m/km require replacement (Mannering & Shafizadah 2002).

Austroads suggests that a maintenance response may be to undertake surface regulation for pavement lengths with roughness in excess of IRI 4.2m/km (110NRM counts/km) (Austroads 2007).

2.2.1 International Roughness Index (IRI)

The International Roughness Index (IRI) is a scale for roughness based on the simulated response of a generic vehicle to the pavement roughness in a single wheel path of the road surface (Al-Rousan, T & Asi, I 2010, p.5). Initiated by the World Bank in 1986, the IRI is a profile-based statistic which is used around the world as a cost-effective index for gathering and comparing pavement smoothness, based on the response of a typical motor vehicle (Chou et al. 2006). Typical IRI values range from 0 to 5m/km (317in/mil), with higher values used for rougher pavement surfaces (Mannering & Shafizadah 2002). This scale of roughness is adopted by the World Road Association (PIARC), Austroads (the road authority for Australia and New Zealand) and many other transportation authorities around the globe.

Roughness is usually measured in a car travelling at 80km/hr. Therefore, high roughness readings at roundabouts, small local streets, and low speed environments, may not be reflective of the perceived roughness, as the public are travelling less than 80km/hr (Austroads 2007). Road networks are usually surveyed in one direction only, and in the lane with the heaviest traffic as a minimum (usually the left lane). According to Austroads standards, heavily trafficked arterial roads should be surveyed each year, while low trafficked local roads only required surveying every 5 years (Austroads 2007).

Roughness Values

Roughness values range from zero into the positive numbers. IRI is linearly proportional to roughness, and an IRI of 0.0 means that the profile is perfectly flat or smooth. Typically there is no upper limit to roughness however IRI's of 8m/km or higher are usually only possible at reduced speeds or particularly rough surfaces (American Concrete Pavement Association 2002). Figure 6 highlights the IRI scale and where speed limits and pavement quality fit into the scale. It defines damaged pavements, as those with at IRI between 4 and 11. This scale also limits the speed to 80km/hr at an IRI of 6 (Al-Rousan & Asi, 2010, p.5). Table 2 also highlights the range of normal IRI values at an 80km/hr speed, showing that lower values are desirable, while higher vales reflect poor surface quality.

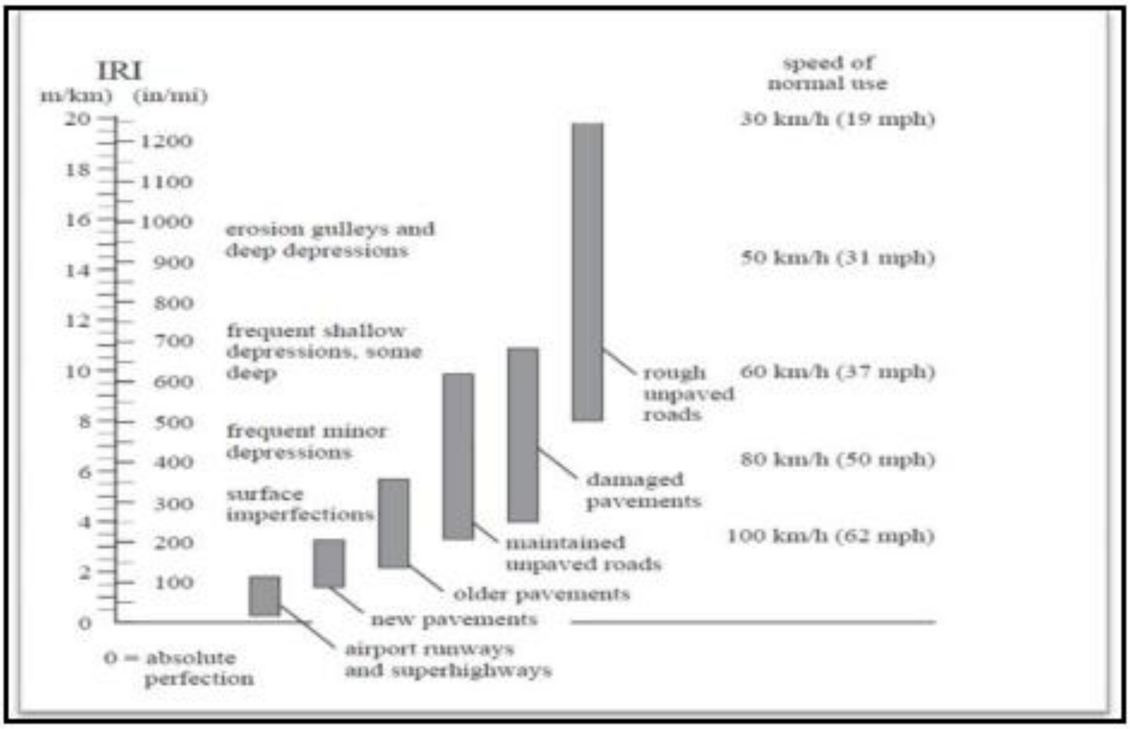

Figure 6: IRI roughness on different roads (Al-Rousan, T & Asi, I 2010, p.5)

Table 2: Ranges of IRI's (Al-Rousan & Asi, 2010, p.8) (Based on 80km/hr)

	Roughness Level
Below 2.0	Excellent
2.0 – 3.99	Good
4.0 – 5.99	Fair
6.0 – 10.0	Poor
Above 10.0	Bad

Austroads highlights maximum desirable roughness values on new roads and indicative values to investigate pavement quality. On highways and main road with a 100km/hr posted speed limit, the maximum desirable IRI on new roads is 1.9. On existing highways (100km/hr) investigations should be carried out on roads with IRI's over 5.3 or 4.2 for sections greater than 500m. This is evident in Table 3.

Table 3: Maximum IRI levels for new and existing roads (Austroads 2007, p.18)

Road function	Typical maximum desirable roughness for new construction or rehabilitation (length 500 m)	Indicative investigation levels for roughness (IRI m/km)	
		Isolated areas	Length > 500 m
Freeways and other high-class facilities	1.6	4.2	3.5
Highways and main roads (100 km/h)	1.9	5.3*	4.2
Highways and main roads (< 80 km/h)	1.9	6.1	5.3
Other local sealed roads	No limits defined †	No limits defined†	No limits defined†

When measuring roughness of a road segment, the longitudinal profile is initially measured and then a mathematical model of the response of a hypothetical vehicle is generated, using a profilometer and the quarter-car stimulation (Austroads 2007). Austroads states that roughness should be reported as Lane IRI_{qc} (usually IRI (m/km), which represents the roughness of a traffic lane within a section of road using the quarter-car model. This is determined by averaging two individual single wheel path IRI_{qc} values. The half car model is not used. However, ARRB (Australian Road Research Board) found that the quarter-car model (IRI averaging model) provides a slightly worse correlation between IRI and NRM data, than the half- car model (profile averaging), which is more complex.

The IRI is recorded for each 100m segment and lane roughness is recorded to not more than 2 decimal places. Decisions based on roughness, should be based on roughness to not more than one decimal place (Austroads 2007). This is an appropriate level of accuracy given the test procedures. Locations of significant road features (bridges, intersections etc.) are included in roughness results, with the lane surveyed, the direction and speed of the travel and the date and weather conditions. This data may be used to explain unusual IRI values. External factors such as road works, congestion, wet areas, water over road, or obstacles on road, may make the results invalid (Austroads 2007). Inconsistencies with IRI results are caused by bias, random error and/or calibration issues between testing devices. Bias occurs due the profiler's characteristics in measuring the pavement surface (American Concrete Pavement Association 2002).

The quarter-car model (Austroads approved) uses the following equation to calculate IRI:

$$\text{Lane } IRI_{qc} = \frac{\text{Single wheel path } IRI_{qc} \text{ (inner)} + \text{Single wheel path } IRI_{qc} \text{ (outer)}}{2}$$

Compared with the formula for NAASRA roughness meter (an older reporting unit) for ride quality:

$$\text{NAASRA roughness (counts/km)} = 26.49 \times IRI_{qc} \text{ (m/km)} - 1.27$$

(Austroads 2007, p.8)

Appendix B highlights the approximate conversion between IRI (quarter car model) and NRM.

NAASRA roughness is no longer considered an appropriate method to determine roughness; however it is still used by many road authorities. The Queensland DTMR still uses NRM as its main reporting unit.

The DTMR 20 year vision for roughness values highlights a relationship between roughness and AADT (Queensland Government 2010, p.7). The 5 year milestone (2015) is for 94% of roads to meet the following standards. Roughness should not be greater than the values highlights in table 4.

Table 4: Queensland's 20 year vision for roughness (Queensland Government 2010, p.7)

AADT	IRI	NRM
0-200	6	160
201-500	6	160
501-1000	5	130
1001-10 000	4	110
>10 001	3.5	90

Quarter Car Model

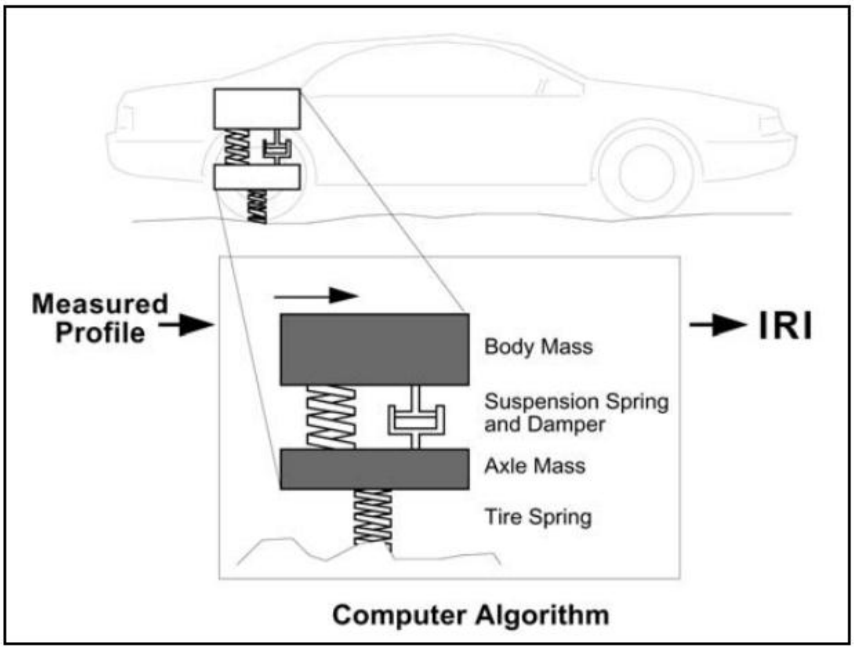

Figure 7: The Quarter Car Model (American Concrete Pavement Association 2002)

Figure 7 is a schematic of how the quarter car model works. It is calculated at one wheel, or one quarter of the car. The model incorporates the tire (represented as a spring in the model), the axle mass (supported by the tyre), the suspension spring and damper and the body mass (only that supported by the tire). Figure 8 shows another model of the IRIqc.

The NAASRA roughness count is measured in counts/km, where 1 count is equivalent to 15.2mm of accumulated vehicle movement between the sprung and unsprung body mass (Hunt & Bunker, 2004 p.3).

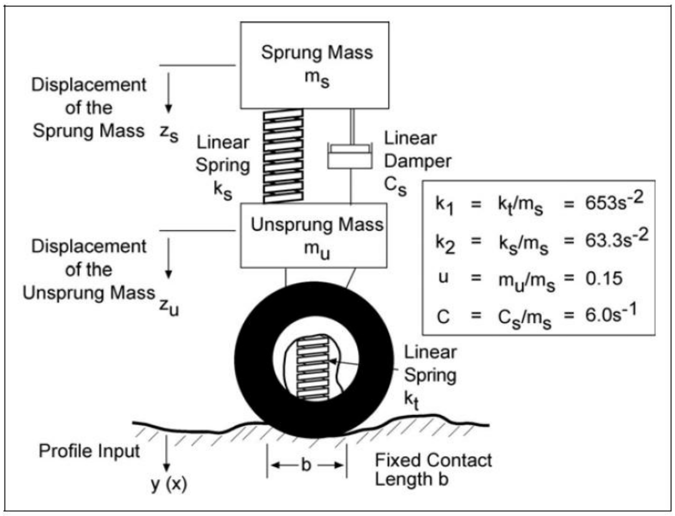

Figure 8: A Simulation of IRI quarter-car model (Austroads 2007 p.39)

Measuring Roughness

There are a range of methods used to measure IRI. These include (Pavement Interactive 2007):

- Rod and Level Survey- unfeasible for large projects
- Dipstick Profiler- used for small quantities of data
- Profilographs- used on construction inspections, not feasible for network data collection.
- Response type road roughness meters (RTRRMs) - suitable for large scale network modelling as device installed onto a vehicle.
- Profiling Devices- Most popular device for roughness data collection and used of network scale collections.

Figure 5 highlights some of the data collection devices for roughness, their properties and extent of their use.

Table 5: Methods to collect roughness data (Pavement Interactive 2007)

Roughness Data Collection Device	Principle of Measurement	Relative Initial Cost	Relative Data Collection Cost (Network)	Relative Degree of Accuracy	Approximate Decade of Development	Extent of Current Use	Projected Extent of Use
Dipstick	Direct Differential Measurement	Low	Impractical	Very High	1980s	Limited, Used for Calibration	Same as Current Use
Profilographs	Direct Profile Recordation	Low	Impractical	Medium	1960s	Extensive for Const. Acceptance	Same as Current Use
BPR Roughometer	Device Response	Low	Low	Medium	1940s	Limited	None
Mays Meter	Vehicle Response	Low	Low	Medium	1960s	Extensive	Decreasing Continuously
South Dakota Road Profiler	Direct Profile Recordation	Medium	Low	High	1980s	Growing	Rapidly Increasing
Contact Profiling Device	Direct Profile Recordation	High	Medium	Very High	1970s	Limited	Decreasing
Non-Contact Profiling Device	Direct Profile Recordation	High	Medium	Very High	1980s	Medium	Increasing Continuously

Profiling Devices

While they are fairly expensive and complex, profiling devices are the most accurate and scaled method of data collection of surface roughness. There are three main types including the straight edge, low speed systems and inertial reference systems (which uses a contact, or non-contact sensor system) (Pavement Interactive 2007).

The Queensland Department of Transport and Main Roads gain pavement information including roughness through the use of a laser profilometer survey vehicle. This vehicle is supplied by ARRB, and features two rear mounted scanning lasers, and four front mounted 78 kHz lasers (Baran & Krichan n.d. p.1). The rear lasers measure the road profile and rutting, while the front lasers record roughness and texture depth. Raw data is extracted at 10m intervals. The longitudinal profile is recorded at 50mm intervals which are used to compute IRI for the quarter car model and the NAASRA roughness meter counts/km (Baran & Krichan n.d. p.1).

2.2.2 Smooth Travel Exposure (STE) and Methods of Analysis

When analysing roughness, a statistical approach is adopted. Statistics methods such as maximum, minimum, median, inter-quartile range, mean and standard deviation can be used on the road segment, and can be investigated over time (Austroads 2007). Graphs such as histograms and cumulative distribution curves are suitable to represent the data (Austroads 2007).

An Austroads National Performance indicator used for roughness is the Smooth Travel Exposure (STE), which measures the ride quality of the road pavement by considering the traffic volumes. This is used for roads with IRI roughness less than or equal to 4.2 and 5.3m/km (or NRM readings of 110 and 140 counts/km), and is only used for sealed roads.

STE = 100 x Tnf/TvC

STE = 100 x the year's travel measured in vehicle km travelled (VKT) on roads which meet the targeted condition / the year's travel measured in VKTs for the entire network being reported.

Method of STE:

1. Determine length of network (km) which has av. Roughness < 4.2m/m and/or <5.3m/km.
2. Determine annual kilometres travelled = AADT x segment length x 365
3. Sum total annual km travelled on segments with Roughness < 4.2m/m, and separately sum segments with roughness <5.3m/km.
4. Calculate $STE_{4.2}$ = step 3/step 2, $STE_{5.3}$ = step 3/step 2, for 4.2 and 5.3m/km respectively. (Austroads 2007)

Another advanced analysis technique is using the Power Spectral Density Function, which filters from the profile the different sinusoidal or wave shapes which may give insight into specific vehicular responses (Austroads 2007).

2.2.3 Relationship between Roughness and Safety

Swedish research has found that while ruts have little effect on safety (may even slightly improve safety in some situations), that with increased IRI values there is a clear increase in accident rates (Ihs 2004, p.1). The increase of accident rates with increased IRI was greater in the winter months than in the summer (meets 5% significant level). Additionally, the accident ratio increased with IRI for all traffic flow classes, as seen in Figure 9 (Ihs 2004, p.3). This graph shows a linear regression of crash rate calculated per 100 million axle pair kilometres. The effect of roughness on accidents is the same on all accident types (property damage, minor injury, medical treatment, hospitalisation, fatality). However, an increased IRI had the greatest effect on single-vehicle accidents, compared to multi-vehicle accidents (Ihs 2004, p.4).

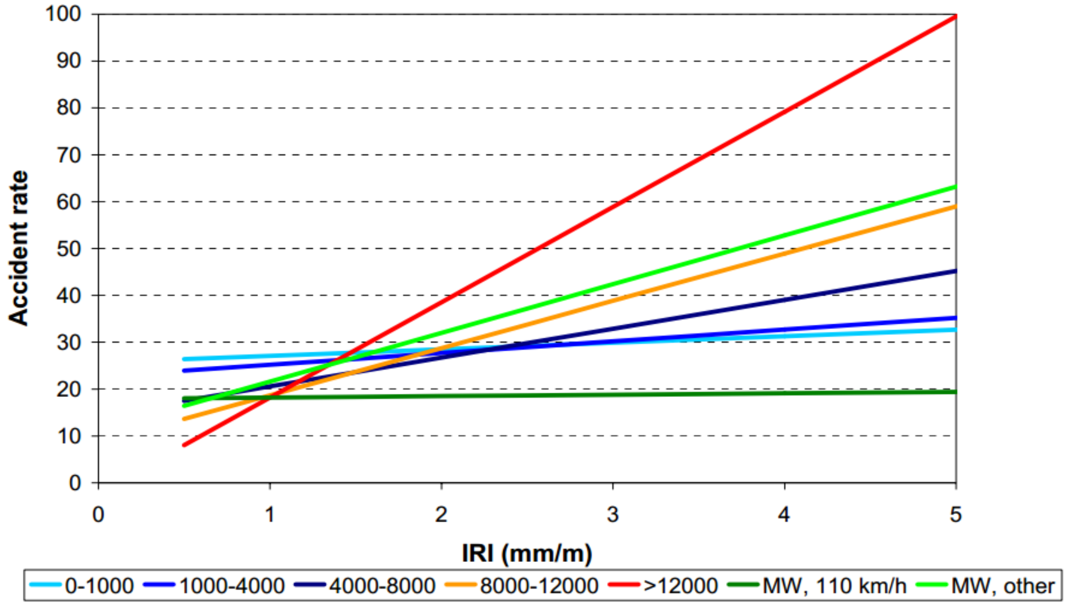

Figure 1 Results from linear regression with accident rate (number of accidents per 100 million axle pair kilometres) as dependent and IRI as independent variables, for different traffic flow classes and the whole year.

Figure 9: Effect of IRI on accident rates (Ihs 2004, p.3).

It can be seen in Figure 9 that as the IRI increases the accident rate increases for all AADT classes. For traffic volumes higher than 8000 there is a substantial increase in the accident rate for IRI's of 4 and 5. This large relationship may be impacted by other factors, include the homogeneity of the roads in the study. On motorways with a speed limit of 110km/hr, it is evident that the accident rate doesn't increase with roughness. This may be due to the motorways being maintained with good pavement condition, and here crash rates are influenced by factors other than just roughness.

It is also found that the risk of aquaplaning accidents is greater when ruts depths are larger than 7.6mm. The risk further increases when this rut depth is combined with mild cross fall slopes (less than 1.8%) (Ihs 2004, p.9).

In a Swedish driver survey, it was found that road surface condition was considered the most important variable for satisfactory ride comfort, above visibility, road width, car characteristics, other drivers' behaviour and amount of traffic (Ihs 2004, p.1).

At the Australian road safety research conference 2012, an investigation into the benefits of road smoothing found a range of key findings including (Cenek P, Davies R & Jamieson 2012, p.1):

- Road roughness has an increased negative impact on the risk of crashes, as the horizontal curvature increases.
- 10m Wavelength profile variance is the best indicator of crash risk, closely followed by IRI.
- Braking distance increased with higher IRI for cars and light trucks for roads 50km/hr or higher.
- Roughness had the greatest impact around corners at the apex of the curve.
- Smoothing low volume rural roads is cost effective (for safety) when an existing injury crash density exceeds 0.5 reported injury crashes per year per km. for straights and 1.8 for moderate curves.
- Longer wavelengths in the longitudinal profile have a bigger influence on the ride quality of a truck than a car (Austroads 2007).

Roughness may have a benefit on road safety, as drivers reduce their travelling speed and are more alert. There is a limit as to where roughness goes from being a safety benefit to a hindrance.

Australian Research

Research in rural roads in Victoria conducted by ARRB, found a high correlation between increased road roughness and the risk of crashes (Bennett and Cairney 2008, p.3). This study included 1,386km of road and a similar number of crashes (1,344 crashes). As seen in Figure 10, there is a definate increase in road crashes in segements with a roughness beyond 150 counts/km (Bennett and Cairney 2008, p.3). This graph yeilds the relationship:

Crash rate = 0.0049 $(\text{Roughness})^2$ – 0.4948

Where roughness is NRM in counts/km.

Further research is required to support these findings, as there are only a small percentage of high roughness data compared to the sample.

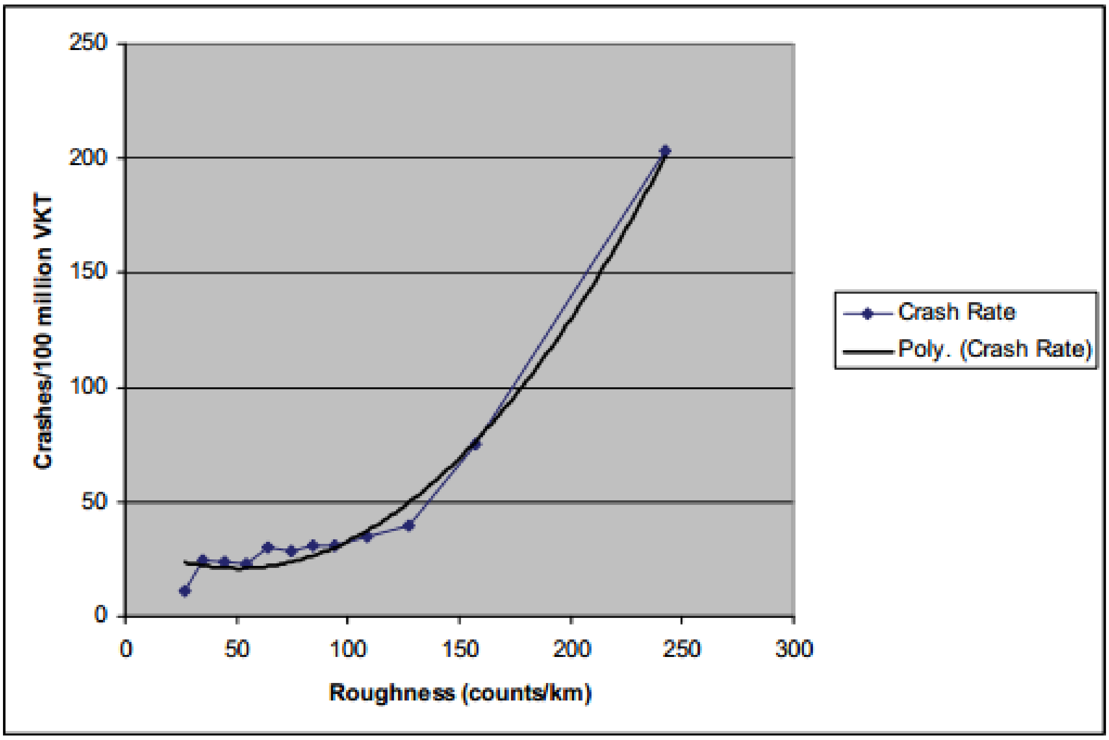

Figure 10: Victorian study on the correlation between roughness and crashes (Bennett, P & Cairney, P 2008, p.5).

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Another more recent study by Bennett and Cairney, highlight a relationship with increasing roughness and increasing crash rate. This is evident in Figure 11 below, where it can be seen a large spike in crash rate occurs when roughness exceeds 130 counts/km. Roughness between 50 to 120counts/km have only a small increase in crash rate per 100 million VKT.

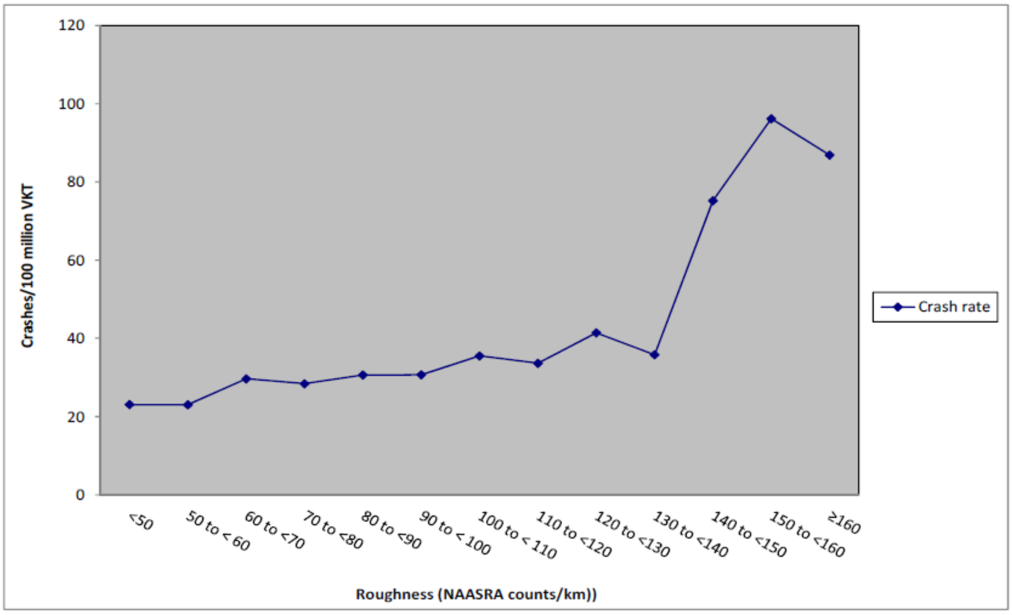

Figure 11: Roughness Study on Rural Victoria Roads (Cairney, P, Bennett 2013, p.41)

2.2.4 Relationship between Roughness and Speed

The relationship between speed and roughness has also been investigated in the Swedish and Indian research.

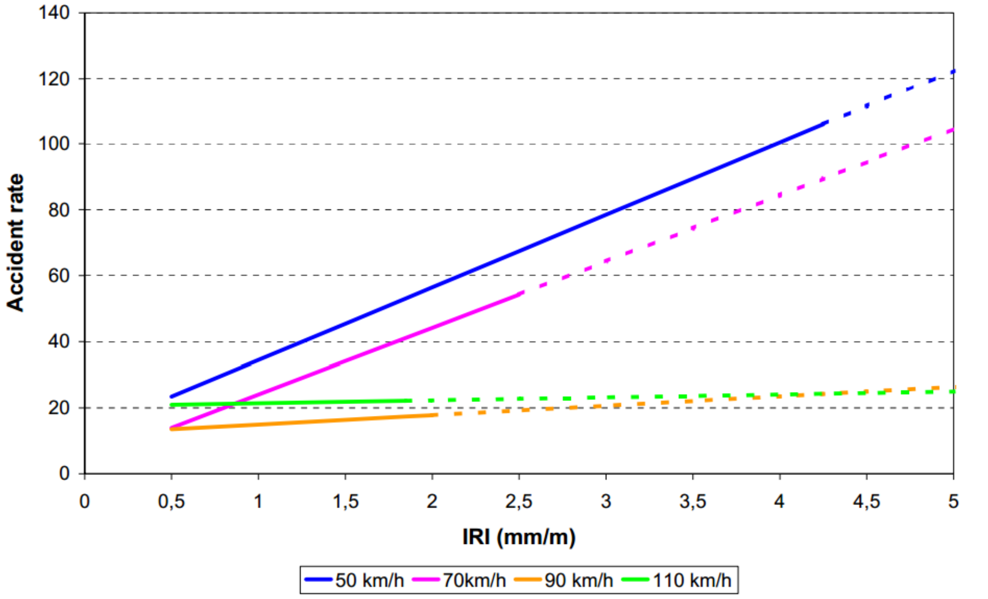

Figure 2 The relation between IRI and accident rate (number of accidents per 100 million axle pair kilometres) in traffic flow class AADT > 12 000 when dividing into different speed limit classes.

Figure 12: Relationship between IRI and speed (Ihs 2004 p.4)

As seen in the Figure 12 above, the Swedish testing found that increased roughness (IRI between 1 and 4) causes an increased accident rate with speed limits of 50km/hr and 70km/hr. This accident rate is using number of accidents per 100 million axle pair kilometres, in the traffic flow class of AADT > 12000. The higher speed ranges may not have been properly represented by the high number of vehicles/day (as roads may be congested).

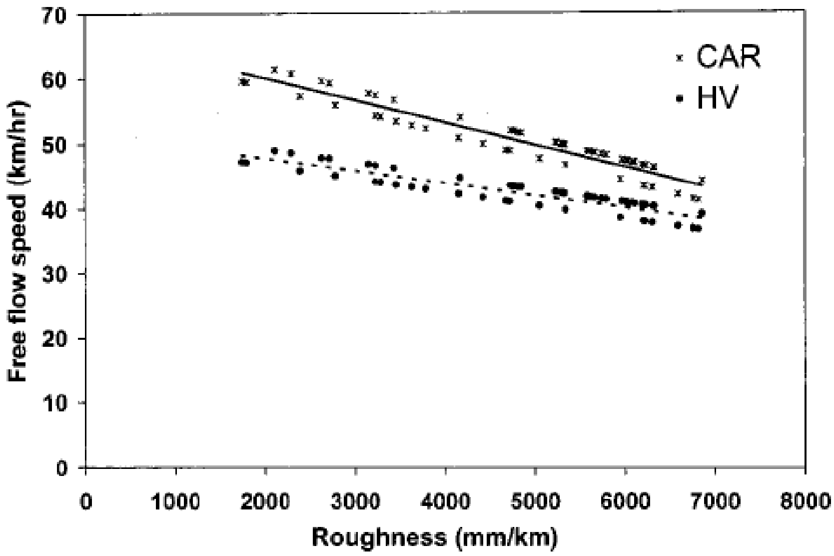

Figure 13: Relationship between Surface roughness and free flow speed (Chandra 2004, p.361).

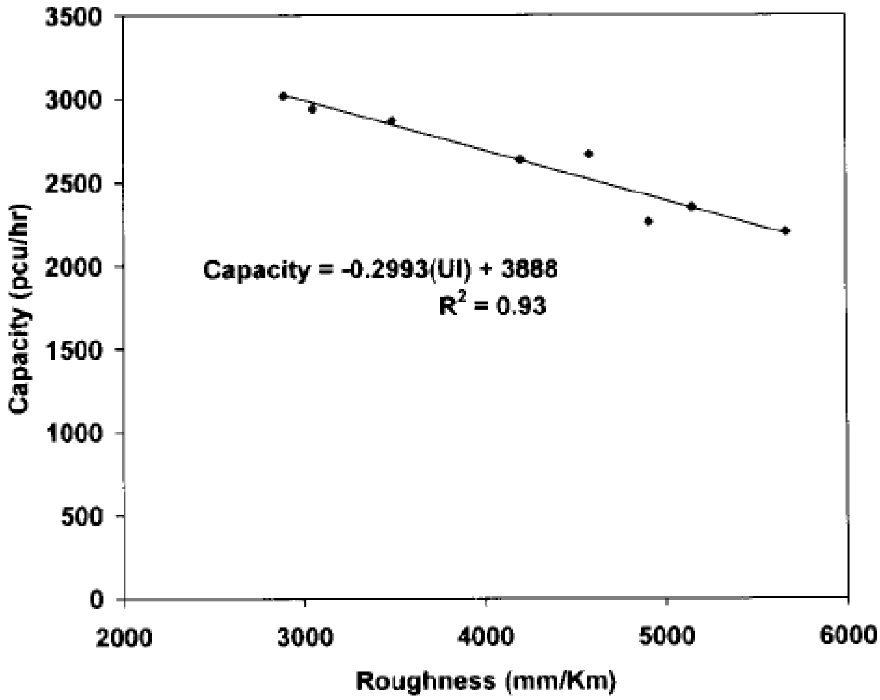

Figure 14: Effect of roughness on capacity on two lane rural roads (Chandra 2004, p.364)

Results from Chandra's (2004, p.364) investigations found that the free flow speed decreased with the surface roughness, and the free flow speed of passenger cars was greater than heavy vehicles for the same roughness. Additionally, it was also found that the capacity of two land rural roads decrease, with a decrease in smoothness.

2.2.5 Driver perception of roughness

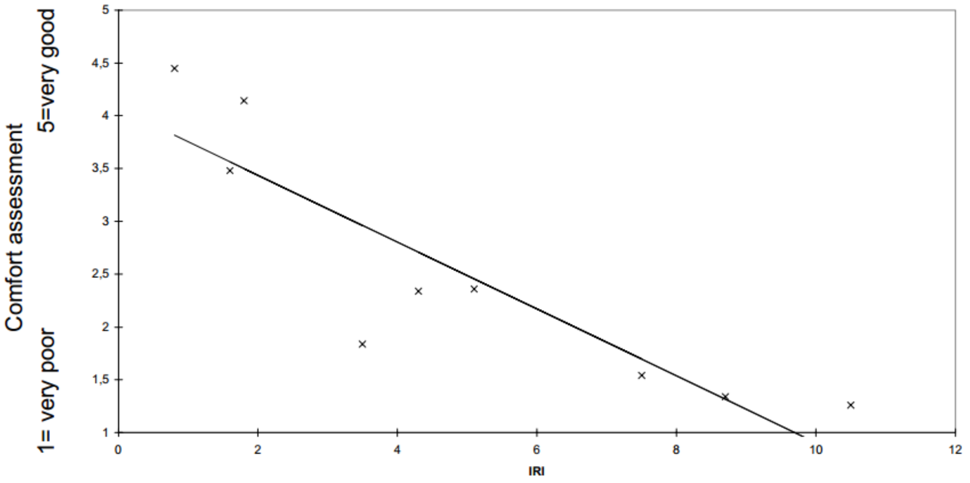

Figure 15: Perception of IRI (Ihs 2004 p.9)

Figure 15 shows the driver perception of IRI when asked to drivers on a range of routes, for comments on the driving comfort. This is evident that the lower the IRI is, the better the ride comfort (Ihs 2004 p.9). Therefore, roughness and other surface deterioration are noticed by the public community. Road authorities are often informed by the public when a road's roughness or other characteristics are below community standards.

Table 6 below are suggested roughness limits for each speed limit. It shows an increasing tolerance of IRI as the speed decreases. Therefore, for higher speeds (100km/hr), there must be a higher level of pavement quality provided than in a 50km/hr zone.

Table 6: Suggested IRI limits for speed enforcement (Chou, Yau & Yu 2006, p.2)

		IRI Threshold at Different Speeds (units: m/km)				
Ride Quality	Jolt (m/s³)	120 km/h	100 km/h	80 km/h	70 km/h	60 km/h
Very good	<6.5	<0.95	<1.14	<1.43	<1.63	<1.90
Good	10.2	0.95–1.49	1.14–1.79	1.43–2.24	1.63–2.57	1.90–2.99
Fair	12.9	1.50–1.89	1.80–2.27	2.25–2.84	2.58–3.25	3.00–3.79
Mediocre	18.4	1.90–2.70	2.28–3.24	2.85–4.05	3.26–4.63	3.80–5.40
Poor	>18.4	>2.70	>3.24	>4.05	>4.63	>5.40
		50 km/h	40 km/h	30 km/h	20 km/h	10 km/h
Very good	<6.5	<2.28	<2.86	<3.80	<5.72	<11.44
Good	10.2	2.28–3.59	2.86–4.49	3.80–5.99	5.72–8.99	11.44–17.99
Fair	12.9	3.60–4.54	4.50–5.69	6.00–7.59	9.00–11.39	18.00–22.79
Mediocre	18.4	4.55–6.25	5.70–8.08	7.60–10.80	11.40–16.16	22.80–32.32
Poor	>18.4	>6.25	>8.08	>10.80	>16.16	>32.32

2.3 Speed Parameters and Compliance

Speed limits are the enforced value in which a driver must not exceed, variable to the length of road driven (Austroads 2008, p.6). Speed limits are applicable on almost all of the road network.

In Queensland, the generally adopted default speed limits are 50km/hr in built-up areas and 100km/hr in rural areas (Queensland Government 2014a). A speed limit is based on the road function, non-interrupted traffic speed, adjacent roadside development, road characteristics and traffic parameters.

The main factors which determine a speed limit on an existing road include the function of the road, the current traffic speeds, and the speed environment. Crash history and safety factors also are investigated in a speed limit review. The function of the road and how it interacts with the road network must be reflective of the speed limit. The function of a road ranges from access and collector roads to arterial roads. The current speed is an important factor, as it is based on the 85th percentile speed or V85 speed. The V85 is pass the point of inflection (maximum) of the normal distribution curve, and represents the speed that the majority (85%) of drivers adopt or driver under. The speed environment is based on the roadside development, road parameters and traffic characteristics. Traffic characteristics include the traffic volumes (AADT), patterns, and composition (% heavy vehicles, pedestrians etc.). Road parameters include the lane and shoulder widths, amount of intersections, roadside hazards, sight distance and the alignment.

There are a range of speed parameters which are used in setting a speed limit. The design speed is related to the geometric parameters of the road, and must reflect the road and driving conditions. The operating speed is the V85 speed, which is normally equal to or lower than the design speed. The desired speed is the V85 on long straights or curves where the drivers will settle at (Roads and Traffic Authority 2011). The Limiting Curve Speed (LCS) is the maximum speed around a curve based on the superelevation on the curve and the absolute maximum value of side friction. The V85 should be less that the LCS.

2.3.1 Speed Compliance

Poor speed compliance levels are seen on arbitrarily imposed speed limits that are too low. Speed limits which realistically reflect conditions can effectively regulate traffic flow, limit crash frequency, increase safety for all road users (particularly inexperienced or vulnerable drivers) and regulate environmental impacts such as noise pollution (Queensland Government 2014a).

2.3.2 Treatment of Roughness

At locations of high roughness, the risk of crashes is significantly increased and revisions to the speed limit should be considered at these sites. The MUTCD Part 4 highlights methods of temporary speed reduction, which should be installed until the pavement surface is rehabilitated or repaired. For short road segments (less than a kilometre), temporary speed reduction advisory signs can be utilised. On longer sections of road (more than a kilometre), speed limit reduction should be applied with advice to drivers for the reason of the speed limit change (i.e. 'rough surface' advisory signage) (Queensland Government 2014a).

Additionally, the MUTCD highlights IRI levels for 110km/hr speed zones. Clause 3.3.2 of Part 4, states that the average pavement roughness should not exceed an IRI of 4 (150 counts/km NRM), with less than 20% of the road segment exceeding an IRI of 4. Further, the absolute maximum pavement roughness is IRI 6 (158 counts/km NRM). These guidelines are further reduced with increased crossfall (exceeding 5% on straights, and 7% on curves), where the absolute maximum roughness should not exceed IRI 4 (Queensland Government 2014a). No roughness guidelines are given in the MUTCD for other speed environments.

2.3.3 Effect of Crash History on speed

A high frequency of crash incidents is an indication of safety issues on the road. One factor contributing to road safety is the speed limit, and an unsuitable speed environment can increase the rate of crashes in a segment. Speed is frequently a contributing factor in road incidents, however is rarely specified as the cause of the crash (Queensland Government 2014a).

Only after thorough investigation into the potential cause of incidents and analysis of other feasible measures to improve the safety, can the speed limit be reviewed.

When analysing the crash history in a speed limit review, there are two methods which can be used to display the risk or frequency of incidents. Firstly, crash history can be taken as the risk to the individual road user, which is measured by the casualty crash rate per 100 million vehicle kilometres travelled (Austroads 2008, p.9). This method provides a more consistent relationship to speed and road parameters. Alternatively, crash history can be expressed as the collective risk, given by the casualty rate per kilometre of road. This method is reflected of the number of casualties, which is a function of the AADT, therefore creating difficulties when comparing low volume and high volume roads (Austroads 2008, p.9).

Lower speed limits have a range of safety benefits for drivers including:

- Allow greater time to locate and assess a hazard, in order to avoid a crash.
- Reduce the vehicle breaking distance and time to stop
- Decreases risk of losing control of the vehicle
- Limit the impact force if crash is inevitable, and decrease crash severity.
- Even a small reduction in speed (1-2%) can greatly reduce the chance of death and injuries (Austroads 2008, p.2).

The balance between road safety and driver compliance is essential for any posted speed.

2.4 Road Safety

Road safety is an essential part of any road network. In Australia, the estimated economic cost of crashes is approximately $27 billion per annum (Australian Government 2014a). With 1193 fatalities on the Australia road network in 2013, the emphasis on road safety is imperative, and the transport authorities regularly campaign to the public and allocate funding for increased road safety.

2.4.1 Crash Costs

Estimated crash costs as used by the Queensland Department and Main Roads to quantify crash severity are:

Figure 16: 2014 Crash Costs (QDTMR 2014c)

Crash Severity	2014 Crash Costs
Property Damage	$10,002
Minor Injury	$36,334
Medical Treatment	$107,049
Hospitalisation	$373,424
Fatality	$8,221,618

These costs are used as a magnitude of the severity of accidents on a stretch of road in dollar terms. The costs indicate not only the upfront costs to the owner due to the property damage, but the ongoing costs to society from the incident.

2.4.2 Improving Road Safety

Road authorities design roads with safety at the forefront of each decision. A range of treatments are applied to improve the safety of the road. These include:

General treatments

- Installing appropriate regulatory signs (control traffic movement), warning signs (alert drivers of hazards), guide signs (advise of directions and destinations) and temporary signs (used around work sites/ road works) to inform the driver of the road conditions e.g. Road subject to flooding signs, or rest areas ahead (Queensland Government 2014c, p.6). This ensures the driver is aware of upcoming scenarios and can adjust their driving behaviour accordingly, e.g. school zone ahead.
- Installing guideposts on either side of road to increase delineation of the horizontal and vertical geometry, particularly at night. They can also be used to gauge available sight distance. Guideposts can be installed at decreased spacing's to highlight hazards or changes to the road conditions, e.g. floodways, culverts, at tight horizontal curves or at width changes (Queensland Government 2014d, p.53).
- Using Raised Pavement Markers (RPM's) on roadways also increase the delineation of the road and also alert the driver if the vehicle veering over the lane edge lines.
- Line marking aids to the delineation of the road and separates the two directions on traffic. Barrier lines convey a no-overtaking zone, which is based on adequate stopping and overtaking sight distances (Queensland Government 2014d, p.53).
- Pavement maintenance (roughness, potholes and cracking) on roads is vital to the road safety.
- Clearing the appropriate clear zones allows adequate space to recover the vehicle in a possible crash scenario, or limit the severity of a crash by decreasing the amount of hazards (RACQ 2014).
- Installing frangible poles and safety barriers also decreases the amount of hazards on the road, and therefore limits the possibility of crashes (RACQ 2014).
- Providing standard cross section widths, providing comfortable widths for vehicles to overtake, and adopt the speed. Sealing shoulders also increases the safety of the road. Figure 17 highlights the relationship between crash rate and

seal width. It is evident that a seal width of 7m to 8m is desirable, with longer widths reducing the crash rate further.

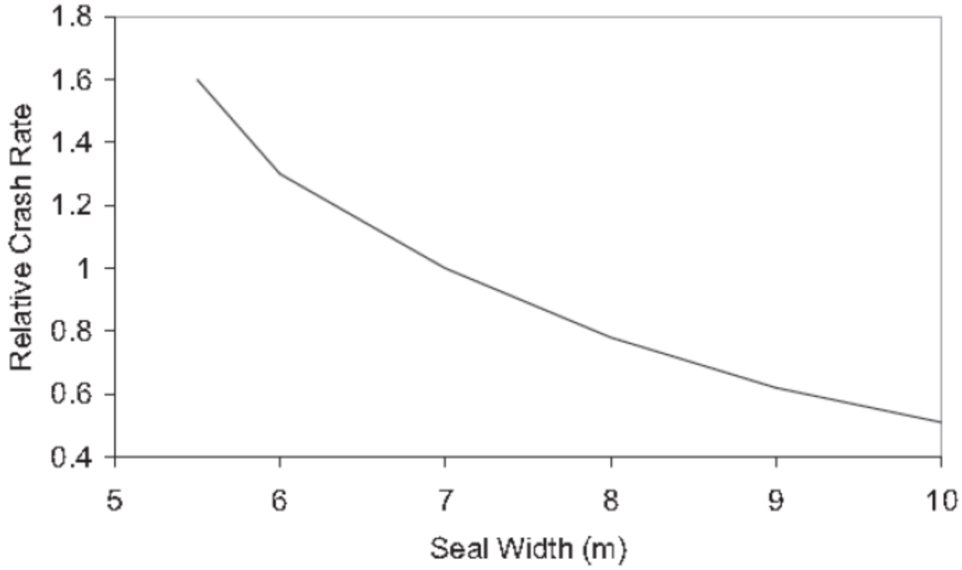

Figure 17: Relative Crash Rate with total seal width (Queensland Government 2013b, p.30)

- Lighting increases the safety of a roadway, as it increases the driver's ability to sense hazards at night-time. Lighting is usually used in built up areas, or areas of hazard (taper of two lanes into one lane, bridge crossing etc.).

Specific Treatments

- Guardrail is used as a barrier between the vehicle and a hazard (e.g. on a bridge to stop vehicles falling into the water, or in steep mountainous terrain).
- Appropriate Intersection treatments for a location are dependent on the current and predicted traffic volumes for each manoeuvre. These options include basic treatments, auxiliary lane treatments, channelized turn treatments which can each be in the left and/or right directions. These treatments remove turning traffic from the through traffic, and therefore limit the risk of rear end collisions. Increased traffic volumes or higher risk locations warrant signals, roundabouts, and overpasses to control each traffic manoeuvre (Queensland Government 2006, p.21-28).
- A widened central median treatment may be used where further separation is required between oncoming traffic and therefore decreases the risk of head on

collisions (Queensland Government 2013b, p.28). This may be in the form of a widened centre line treatment (painted) or a physical median/island.

- In urban areas traffic calming devices such as speed bumps and reverse curves to slow vehicles down, are used as effective safety tools. (Scottish Government 2006)
- Rumble strips or audio tactile line marking (ATLM's) increase driver alertness and are particularly useful in locations with a history of driver fatigue (Scottish Government 2006). They are used on the edge lines as delineation, and when the wheel makes contact the driver senses a load noise and vibration.
- Constructing flatter batter slopes such as 1 on 6 or 1 on 10, to increase recoverability when vehicle transverses off the roadway.
- Designated areas for bicycles, buses, pedestrians or other specialised vehicle categories may increase safety for all road users. This may be in the form of an elusive lane or stopping area.

These treatments are a selection of the options that can be used to improve the safety of the roads. Only some of the above treatments may be applicable to a road scenario.

2.4.3 Road Safety Incentives

In Australia, the Federal and State Government have implemented a range of initiatives to promote road safety. These may include targeting the road quality, by providing funds for substandard roads or educating drivers about road safety. Some of these initiatives include the Black Spot program and Road Safety Action Plan.

Funded by Federal Government the Black Spot Program targets locations with a reoccurring crash history. It aims to reduce crashes, by installing roundabouts or traffic signals at dangerous intersections, installing additional overtaking lanes, or increasing the seal width (Australian Government 2014b). Between 2014 and 2019, the program has $500 million dollars for the improvement of the nation's roads, with 50% of funding dedicated to improving roads in regional Australia (Australian Government 2014b). This program, among other funding initiatives, ensures the necessary financial support for much needed road improvements around the nation.

The Western Australian Government's safety initiatives address safe road use, safe roads and roadsides, safe speeds and safe vehicles. Each of these categories has objectives and initiatives to improve the death toll in the region. Figure 18 highlights the components that influence road safety.

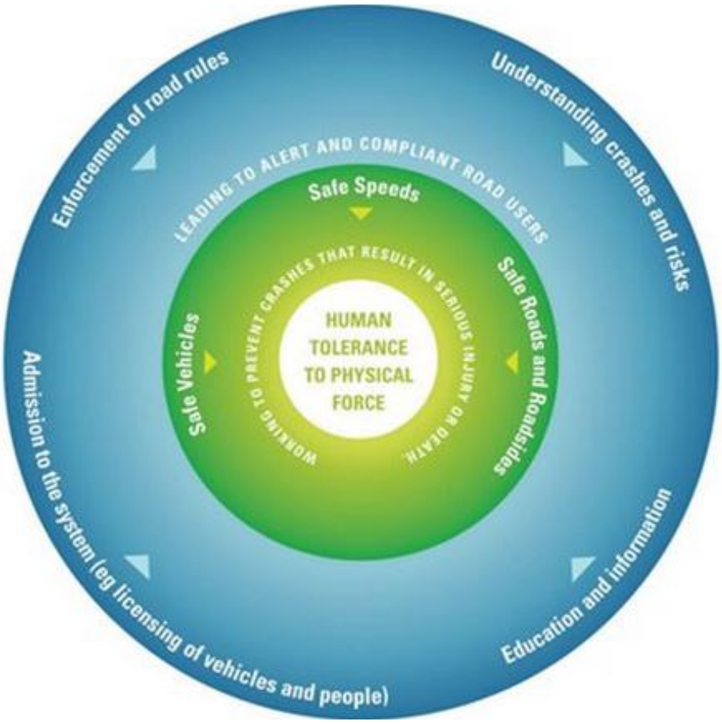

Figure 18: Safety Initiatives implemented in Western Australia (Government of Western Australia 2014)

The Queensland Government has undertaking a range of initiatives in their 2013-2015 Road Safety Action Plan. Some of these initiatives include:

- Alcohol and risk-related trauma injury awareness programs
- Student education programs in schools to highlight the risks vehicles pose.
- Reviewing Speed limits in the Region (refer section 1.2).
- Fast-track safe engineering treatments, such as flashing lights on school signs.
- Reforms to youth and elderly licensing procedures, and motorcyclists (Queensland Government 2014f).
- The ‘Join the Drive to Save Lives’ initiative to promote safe driving practises and to educate the public about crash statistics.

These initiatives and many others work together to improve the community’s culture on issues such as speeding and drink driving. It is these initiatives which improve the driver behaviour on the road network and limit the risk of incidents occurring.

The effect of safety initiatives is evident in the decline in the death toll on Queensland’s roads. Figure 19 highlights the death toll in each year from 1981 to 2012, and the safety initiatives which were implemented throughout this period (Queensland Government 2014f). It can be seen that with an increased emphasis on road safety, the death toll is declining.

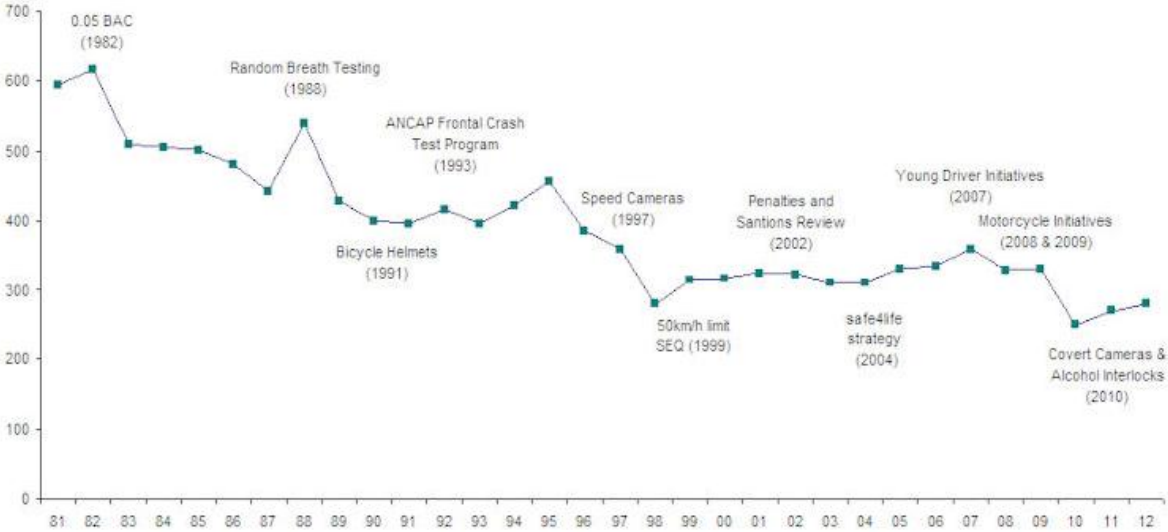

Figure 19: Effect of Safety Initiatives in Queensland on crash rate (1981 to 2012) (Queensland Government 2014f)

By continuing to investigate crashes and parameters which influence crashes, traffic authorities can continue to lower the frequency and severity of road collisions.

Chapter 3: Dissertation Methodology

Chapter 3 defines the methods used within the model, to achieve the research objectives as determined in the introduction (section 1.4). It details the methods of gaining each set of data, and the way it has been utilised in the model. It also defines the equations used to calculate the crash rate from crash history data and road parameters.

3.1 Methodology Approach and Data

This dissertation aims to find the relationship between roughness, speed and safety. If a correlation is found, methods of increasing the road safety by controlling the speed and roughness will be investigated. To complete the analysis, a case study approach is adopted, by investigating the road network in the Downs South West Region, as defined by the Department of Transport and Main Roads. This research has three main components: Roughness, Speed and Safety.

Data for each of the parameters is sourced from Department of Transport and Main Roads ARMIS (A Road Management Information System) database of the network's roads or other similar databases. Roads selected will be state or federal roads in the south east Queensland area. Roads will be rural roads with a posted speed limit of 80km/hr or higher (maximum 110km/hr). The data gathered will be road roughness data, the AADT, traffic land widths (sealed), road geometry, traffic types (%HV, Road train route etc.), location of intersections, crash history and speed counts through the locations. This data will be holistic in nature, any roads with partial data will not be analysed.

The roads to be analysed have been selected in order to gain some worst case situations and some satisfactory cases, which can be compared to each other in analysis stage. The worst case road segments are on roads with sections of high roughness values. The satisfactory case road segments have similar road characteristics however have acceptable roughness levels. By comparing the rough cases with the satisfactory cases or road segments, a conclusion on the effect of roughness can be made, as a range of roughness values will be analysed in the model. Segments of 100m and 1km in length have been analysed. It is expected that 1km segments will be a better representation of roughness as the longer length will have a greater impact on the driver, and therefore the vehicle's speed and crash risk. A 1km length is short enough to focus on the segment being analysed.

3.1.1 Roughness Data

Roughness data was obtained through the DTMR Road Asset Data Request Form, where a description of the data required, the purpose of the data, users of the data and the publication audience of the data are required. Initially, a list of all roads in the region specified was requested, with their corresponding average roughness. From this list, a collection of roads with generally high roughness values were selected. For these selected roads, the roughness data was given in 100m and 1km segments of road. The data was given in NRM units, rather than IRI, as this is still Queensland's main roughness measurement (QDTMR 2014d). The data gathered highlights the road name and number, the start and end chainage for the segments, the roughness through the segment, whether the road is sealed or unsealed and the speed limit through the segment. To maintain homogeneity in the analysis, roads with unsealed stretches were omitted from the analysis.

This data was compared with the standards of roughness, to gain an understanding of the region's road quality. The majority of the state roads in Queensland's South West are highways and main roads with a sign posted speed of 100km/hr. For isolated sections in this category, the roughness level suggested to investigate (in Table 3) is an IRI of 5.3 (139 counts/km NRM) and for lengths larger than 500m recommended roughness levels are 4.2 IRI (110 counts/km NRM) (Austroads 2007, p.18). These benchmarks will be used in analysis.

3.1.2 Speed Data

Speed Data was collected through the DTMR Traffic Analysis and Reporting System (TARS) database. The speed data collected is from 2013 (or 2012 in the rare cases where 2013 data is unavailable). For each road analysed, the site daily speed statistics is collected (QDTMR 2014e). The daily speed data and the average weekly speed data is given, at each tested location along the road. The number of vehicles, the mean speed and the 85^{th} percentile speed is given (V85). A graph with the number of vehicles in each speed group in 5km/hr segments is also given (i.e. 80-85km/hr, 85-90km/hr). From this data, it is evident where the vehicles comply with the speed limit and locations where non-compliance is occurring.

3.1.3 Crash Data

Data in terms of safety can be quantified by analysing the accident rate along the stretch of roadway. The request for crash history data from the Queensland Government was made through the Road Crash, Registration, Licensing and Infringement Data Request Form. For this form, the use of the crash data, the extents of the data, the timeframe (5 years of data), the geographical area and the statistical data required (information about each crash) are defined. A large range of information is available, about the crash, casualties, vehicle types, categories (such as age, gender and license type) and contributing circumstances. For the purpose of this research, information about the crash, vehicle types and the contributing circumstances will be sufficient for most of the data requirements. More detailed information was also investigated, such as if crashes where due to fatigue, drunk driving, weather conditions etc.

All the crash data collected is from the DTMR RoadCrash Database (Qld DTMR RoadCrash Database 2014). For a crash to be a part of this database, the incident must meet the following criteria. The crash (Qld Dept. of Transport and Main Roads' RoadCrash Database 2014):

- Must be reported to police
- Must be caused by at least one vehicle on a road or nearby a road.
- Must be a situation where property damage occurs ($2500 or more damage to property excluding vehicles), or at least a vehicle is towed away, or a person is injured or killed.

The crash data collected will be analysed for the selected roads, and will be used for a range of models, including crash severity type. These models will investigate whether roughness impacts the frequency or severity of crashes.

3.1.4 Other Data Required

A range of other parameters are required for an accurate portrayal of each road case study. Parameters to be included into the analysis include:

- Annual Average Daily Traffic counts (AADT) (veh/day)
- Sealed traffic lane width (m)
- General road geometry (i.e. vertical crests, floodways or horizontal curves).
- General type of traffic using the road way (%HV, Road train route etc.)
- Location of intersections.

Each of these parameters affects driving conditions such as the speed and the frequency of crashes, and therefore must be incorporated to gain homogeneity in the model. The values for each of these parameters can be found using DTMR information. 2013 AADT information is readily available, and the %HV is also found with this information (QDTMR 2014f). Maps are publicly available showing which routes are permitted for the use of Type 1 or 2 Road Trains. Intersection locations are available publicly on Google Maps, or internally through DTMR feature lists. Road Geometry can be seen from Google Map Street View tools, or the internal DTMR program DVR (which shows the road from the perspective of the driver). The sealed width is located within the DTMR ARMIS database.

All data is generally recorded for each road within the model. This breaks the data sets into manageable sizes and allows data to be presented clearly for ease of analysis and comparison.

3.2 Roughness Data Analysis

Using statistical parameters, the roughness on all the Downs South West roads will be investigated. This gives an overview of the data analysed, and represents the current standards and expectations of roughness in this region. It will give information about the demographics of roughness, in order to give recommendations when the results of other models have been presented. A box and whisker plot will be used to graphically represent the region's roughness. When assessing roughness data, any abnormally high values of roughness have been removed from the analysis.

3.3 Road Selection

As there are 143 roads in the Downs South West Region, not all roads are required or are suitable for the model. Instead a sample of the roads will be used, featuring a range of parameters such as AADT and seal width. These roads have been selected for a combination of parameters, most importantly their pavement roughness properties. The roads selected have either a high average roughness, or roughness that is generally satisfactory but has segments of significantly higher roughness. A sample of 15 – 20 roads is desired to give the model enough data and credibility. In addition to roughness properties, the roads must also have some recorded crashes over the last five years, as the model relies on the existence of crash data. Unsealed roads have been exempt from the analysis. The model aims to have a mixture of heavy trafficked roads and low volume roads, in order to present an appropriate representation of the Downs South West Region. However, roads with an AADT of less than 200vpd are not incorporated into the model, as they aren't suitable in the model due to minimal data (speed data and crash history). Inclusion of these roads would add bias into the results, as AADT is a factor of crash analysis calculations. The model aims to effectively represent the types of roads in the Downs South West Region, in terms of roughness, crash data and speed values.

3.4 Analysing Crash Data

When analysing the crash history, a method of quantifying each accident is required. As seen in the literature review, crash statistics can be presented in crashes per 100 million vehicle kilometres travelled (VKT) (Section 2.2.3). There are number of approaches to calculating crashes per VKT. The methods analysed in this research are explained below in sections 3.4.1 to 3.4.3.

The crash data used has a range of limitations. In-depth knowledge about the cause of the crash is generally uncertain, as the information given classifies each crash by incident severity (fatality, property damage, hospitalisation, and so on) and by nature of the crash (as per DCA group (Definitions for Coding Accidents) which define the moments leading up to a crash, such as ‘head on’, ‘rear end’, and ‘off carriageway on straight’) (Queensland Government 2014e, p.9, 26). The causes of a crash are not normally specifically given, for example distracted driver or bad weather, and any information given usually does not represent the full scenario. Information is given in a ‘yes or no’ format, and suggests if the driver was drunk, or if it was raining at the time of the crash. This limitation of information has incorporated some inaccuracy into the results. As all data is collected in this manner, the data is consistent and comparable.

3.4.1 Method A: Using MUTCD approach

The MUTCD Chapter 4: Speed Controls, Appendix E refers to the analysis of crash data. The approach is to calculate the casualty crash rate in order to have an appropriate value for comparison. Here the crashes for each segment is per 10^8 vehicle kilometres travelled (VKT).

The formula for Casualty crash rate is:

$$R = \sum_{t=1}^{20} C_t \ x \ A_t \ \ x \ 10^4 \ x \ \frac{1}{M}$$

(Queensland Government 2014a, p52)

Where C_t = Crash Risk Score (See appendix C)

A_t = Average number of crashes

M= Measure of the crash exposure in VKT (Length of road segment (km) x AADT x 365)

The crash risk score (C_t) is calculated from the nature of the crash or DCA groups , with score classifications for high and low speed environments, and per the risk of the crash occurring. Low risk incidents such as rear end, or hitting a permanent obstruction on carriageway (e.g. median) have a low crash risk score of 26 and 15 respectively (for high speeds greater than 80km/hr). Higher risk incidents include head on collisions, or running into pedestrians, which have a score of 192 and 169 respectively (for high speeds greater than 80km/hr) (Queensland Government 2014a, p.53). The full table is in Appendix C.

The average number of crashes (A_t) is calculated by averaging the number of crashes for each DCA group per year.

The crash exposure is calculated through the combination of length and AADT volumes (similar to most crash rate models). As this variable is on the denominator, crashes on roads which are short with low traffic volumes, have a higher contribution to crash rate. While crashes on roads with longer lengths and high traffic volumes required higher crash frequencies to equal the crash rate of shorter, low volume road segments.

These calculated crash rates can be compared to the comparison crash rates for rural roads in Appendix G, to determine the magnitude of the crash rate and if safety treatments must be adopted.

3.4.2 Method B: Using U.S. Department of Transport approach (100 million)

A widely accepted approach to quantify crash rates is using a method which is less dependent on crash type and instead focuses on AADT and length of the road segment. This calculates the crashes per 100 million vehicle kilometres travelled (VKT), and the formula is expressed as (United States Department of Transportation 2014):

$$R = \frac{C \times 100{,}000{,}000}{V \times 365 \times N \times L}$$

Where:

C is the total number of roadway departure crashes in the study period

V is the Average Annual Daily Traffic (AADT) volumes

N is the years of data

L is the length of the roadway segment in kilometres

(United States Department of Transportation 2014)

Other methods are comparable to this method, usually with some slight variations.

3.4.3 Method C: Using U.S. Department of Transport approach (million)

This method of calculating crash rate is very similar to Method B above. Instead of using crashes per 100 million VKT, it uses crashes per million VKT. This method presents a more suitable approach for roads with less frequency of crashes, lower AADT volumes and shorted kilometres travelled. Each method will provide slightly different results, however both methods are acceptable if it is ensured that values to compare with have been calculated in the same manner.

$$R = \frac{C \times 1{,}000{,}000}{V \times 365 \times N \times L}$$

(Massachusetts Department of Transportation 2014)

Each of these methods has been adopted in the analysis.

3.4.4 Crash Investigations: Crash Segments vs. Non-crash segments

A more simplistic model to gain an understanding on the correlation between roughness and crash rate is to determine the differences between crash segments and non-crash segments. By assigning the status of 'crash segment' or 'non-crash segment' to each kilometre of every road in the model, and then finding the average roughness (in 1km sections) of both categories, a conclusion can be made. The average roughness through crash segments are compared with non-crash segments, to determine which has the highest average roughness. The average roughness through all sections is also worth noting and comparing with the results. If the average roughness in crash and non-crash segments is within a tolerance of plus or minus 1count/km, then the roughness is deemed even for both crash segments and non-crash segments.

3.4.5 Comparison of Crash Data

The above methods to determine crash rate (section 3.4.1-3.4.3) have been used within the analysis. The crash rates will be used to compare with the roughness to determine the relationship between these parameters. Crash rates will be analysed in whole-road data (with the segment size as the length of the road). Crash rates will also be analysed using 100m and 1km segments lengths, and therefore be analysed at each crash location (usually only one crash in the 100m or 1000m length). In cases where there is more than one crash in the segment, there are summed using the approach in the relative formula, see section 3.4.1-3.4.3 above. Crashes will be examined for each crash severity type (property damage, minor injury and so on), to comment on the differences between the influence of roughness. Each severity type will be represented graphically, with a trend line and R^2 coefficient. This will allow comments on the spread of results and the relationship between crashes and roughness for each crash type.

3.4.6 Crash Investigations: Light vehicles and Heavy Vehicles

Comparing the roughness at crash sites involving light vehicles, with the roughness and crash rate of sites with heavy vehicle, investigates if roughness has a greater, lesser or similar impact on different vehicle types. This model will be investigated using the same crash model and roughness data, with another section categorising each crash per vehicle type.

The model investigates the difference between heavy freight vehicles and all other types of vehicles. Heavy freight vehicles are broken down into three categories: Rigid Truck, Articulated truck, and Road train/B-double/Triple. All other vehicles include cars, motorcycles, mopeds, and other light vehicles. The crashes which involved a heavy freight vehicle were noted using RoadCrash Database, and the crash rates and road roughness through these crash segments are collated. This is graphed to determine any correlations or consistencies in this model.

3.5 Analysing Speed Data

The speed data is analysed using the V85 speed, which has been gained on site with pneumatic tube counters, and the posted speed limit. The difference between these two parameters has been calculated to determine the speed variance. This speed variance is plotted against the roughness in 1km segments to compute the relationship between speed data and pavement roughness.

Sites where the posted speed limit is less than 80km/hr have been removed from the data set, as the roughness measured at these speeds gives a skewed representation of the driving conditions.

The results from this graph may give an indication to the magnitude of roughness where the V85 speed is affected by roughness. At this roughness value, investigations of possible changes to the posted speed limit can be explored.

Sites of interest can be analysed to ensure that other factors which affect the drivers chosen speed are not creating bias into the model. An example includes a small radius horizontal curve. These are usually identified onsite by an advisory speed sign at each end of the curve, encouraging drivers to lower their speed to negotiate the curve. Another indicator is the use of Chevron Alignment Markers (CAMs), installed around the outside of the curve (see Figure 20), which also indicate to drives to slow to negotiate the curve. Investigations may show that drivers slow down around the curve, and speed up to their travelling speed on the adjacent straight.

Figure 20: CAMs around a Horizontal Curve (QDTMR 2014a).

3.6 Case study Analysis

A selection of the model will be analysed further in the case study analysis. This study involves selecting a few roads (between 4 and 6), and completing an in-depth analysis of each road, and the various parameters which effect the speed, crash risk and roughness at that location. The seal width, clearzone, road geometry and a range of other variables which effect road quality, speed, crash risk and roughness will be investigated. Site visits will be conducted on roads which require on-site analysis. Resources such as DVR, Chartview and other public and DTMR information will be utilised.

3.6.1 On-Site Analysis

On site analysis is required when there is an unusual or unexplained crash history, or when results are unexpected, or further onsite information is required. This involves driving through the length of the road and taking note of driver comfort, roughness, possible hazards, road parameters (pavement width, clearzone), types of vehicles, geometry etc. Occasionally, field analysis included examining the quality of pavement from the side of the road to gain a visual understanding of roughness. In this case, safety procedures and responsibilities were carried out, such as wearing productive clothing (steel capped boots and high visibility clothing), keeping away from the outside traffic lane and when possible, having another person present to spot for traffic. When the technology was available, the GPS tripmeter from the Department of Transport and Main Roads office was borrowed, to have an accurate understanding of the location (road chainages).

3.7 Financial Modelling

Defining the costs of rectifying or improving the condition of road roughness on Queensland's roads will also be investigated. This involves investigating the types of improvements available, the effectiveness of these methods and the current costs to implement these on-site. This treatment not only lowers the roughness, but improves the pavement quality as a whole.

Some of the roads analysed in the case study will be used as examples in this section to highlight possible treatment locations and to show prioritisation of treatment locations. The case study roads will also be used to compare the cost of crashes (on society), with the cost of upgrades. These costs can be compared to comment on the financial effects of upgrading roads.

The costs highlighted in this section have been estimated using recent projects completed by the Department of Transport and Main Roads, Toowoomba Office. They are suitable for 2014, and will require additional escalation costs if referred to in the future. Escalation costs are generally 5% in the first 2 years, and 6% over the 3rd and 4th years, depending on the economic climate. The costs of materials will vary depending on the cost of treatment. Therefore, costs are approximated with a large tolerance range in attempt to suit most scenarios (including materials chosen – as better quality materials generally have higher costs).

3.8 Correlation

The correlation between roughness, speed and crash risk can then be analysed from the results. When determining the existence of a correlation, it is important to note the many factors which affect the onsite scenario. If required for validation, some road parameters may be accessed through on site investigations. From these correlations, recommendations to improve the safety on the network's roads can be provided.

3.9 Summary

The methodology has outlined the data sources and analysis methods utilised in the research models. This includes the treatment of crash data, speed data, roughness data, and general road characteristic data. This will be used to form the general speed and crash models in Chapter 4, and the more specific case study analysis and financial modelling in Chapter 5.

Chapter 4: Roughness Models

This chapter presents the data and models based upon the roughness in the Downs South West Region and on the relationships between roughness and crash history, and roughness and speed.

4.1 Roughness Analysis

Each of the 143 roads in the Downs South West Region have been analysed for their roughness values using NAASRA roughness, and comparing these with Austroads and DTMR guidelines for acceptable roughness limits. Using 100m segments, some general roughness information can be found (QDTMR 2014d):

- The mean roughness value is 86 NRM for all roads investigated in the Downs South West Region.
- 34% of the Road Network has roughness less than 70 counts/km NRM (satisfactory roughness).
- 24% of the Road Network has roughness greater than 110 counts/km NRM, which is the Austroads guideline for investigation for lengths greater than 500m.
- 10% of Roads has a NAASRA roughness greater than 140 counts/km, the Austroads guideline for investigation for isolated segments.

Less than 10% of the road network is considered 'poor,' therefore the majority of the region has 'satisfactory' or 'good' roughness (based on ranges listed in Table 2). The box and whisker plot for the roughness values throughout the Downs South West Region is shown in Figure 21.

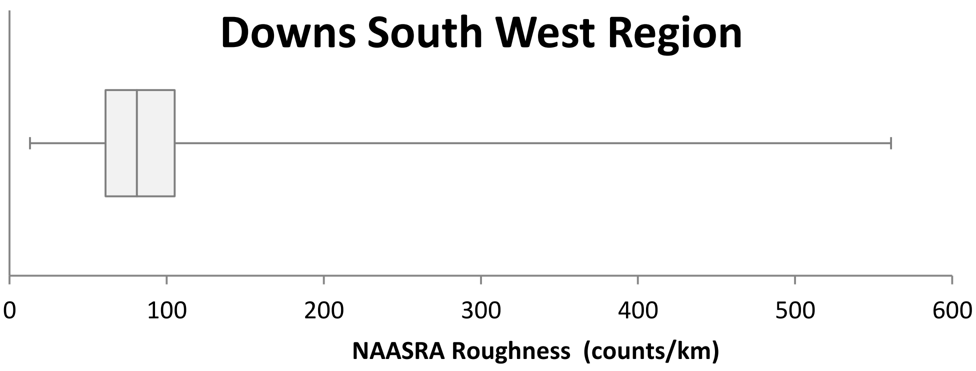

Figure 21: A Box and Whisker plot of the Roughness in Queensland's Downs South West Region.

It is evident that the majority of roughness values range between 70 to 110 counts/km NRM. A range of outlying points with a high NAASRA roughness reading create a right skewed plot. These high values of roughness are probably due to testing procedure which is adopted by the DTMR. The survey vehicle which collects roughness data is fitted with lasers which detect the pavement condition. These lasers record an unusually high roughness values when conditions are particularly rough or at locations with ravelled surface conditions. While some locations have very high roughness readings, the one given by the lasers is an erroneous reading, and therefore these segments will be omitted from the model. Other reasons for this high roughness reading may be due to structures, unfavourable weather conditions, water on the road, obstacles on the road or calibration issues. When omitting these high roughness readings it is evident that the roughness on the Downs South West Region's roads is generally satisfactory, with a small percentage of roads requiring investigation or treatment.

4.2 Road Analysis

Of the 143 Roads in the Downs South West Region, 17 Roads have been chosen for in depth analysis. These roads were selected due to their reasonable AADT, crash history, available speed data and some roughness variation. As this study looks at the correlations between these parameters, roads with limited data were removed from the investigation. Many of the Downs South West Region's roads are in rural areas, and therefore some roads have AADT's of less than 200vpd. Roads of this nature have also been removed from the sample to limit bias in the results. Traffic Volumes in AADT are shown for each road in the model in Appendix F (QDTMR 2014f).

This model incorporates over 1570km and 370 crashes. The roads selected for analysis are located across the Downs South West Region and a listed below with some average road information:

Table 7: Roads used for analysis

Road ID	Road Name	Length of Road (km)	Average Roughness (NRM)	Average AADT	Average Roughness (IRI)	Average Seal Width (m)
3402	Tara - Kogan	43.03	142.24	289	5.42	3.6
3501	Roma - Southern	49.02	121.90	479	4.65	3.6 – 6.0
36A	Balonne Highway (St George - Bollon)	113.27	116.52	2648	4.45	6.0 - 7.0
86A	Surat Developmental (Surat - Tara)	147.86	116.28	1875	4.44	5.5 – 8.0
426	Chinchilla - Wondai	72	103.07	1468	3.94	6.0 - 8.0
416	Dalby - Cooyar	58.2	102.53	1534	3.92	6.0
86B	Surat Developmental (Tara - Dalby)	40.39	101.07	1386	3.86	6.0 - 6.25
340	Dalby - Kogan	47.682	101.02	1570	3.86	7.0 - 8.0
313	Gatton - Clifton	62.677	95.42	1064	3.65	6.5
421	Dalby - Jandowae	47.41	94.75	2533	3.62	6.0 - 9.0
324	Toowoomba - Cecil Plains	79.78	93.69	2330	3.58	6.0 - 7.0
24A	Carnarvon Highway (Mungindi - St George)	118.08	92.95	2318	3.56	6.0 - 8.0
35A	Moonie Highway (Dalby - St George)	293.75	90.62	2104	3.47	8.0
18E	Warrego Highway (Roma - Mitchell)	87.7	87.18	1136	3.34	9.0
341	Chinchilla - Tara	69.72	85.82	3151	3.29	6.0 - 8.0
4144	Gatton - Esk	18	83.06	2369	3.18	7.0 - 8.0
18C	Warrego Highway (Dalby - Miles)	127.74	75.60	5797	2.90	11.0 - 8.0

4.3 Roughness and Crash History

The relationship between pavement roughness and crash history has been investigated by analysing a sample of the roads on the Downs South West Region (seen in Table 7 above). A range of studies have been modelled, such as a comparison between crash segments and non-crash segments, whole road crash analysis, per incident crash analysis, as well as specialised models such as the comparison between light vehicles and heavy vehicles.

The crash history on the rural roads selected in the model highlights that the most common incident type is a run off road crash resulting in colliding with an obstacle (usually trees). This crash type makes up more than half of the total crashes analysed. Rear end, head on, overtaking crashes animal collisions and out of control crashes are also evident in the crash history data.

4.3.1 Crash Segments vs. Non-crash Segments

When investigating the effect of roughness on crash safety, the difference in roughness between crash segments (with a history of an incident within the last 5 years) compared to the rest of the road, provides an insight into potential correlations. This has been analysed by averaging the total roughness in 1km lengths for crash segments and for those without crashes. It is found that the roughness on crash segments was generally higher than the roughness on non-crash segments, for each road accessed.

Figure 22 highlights the difference between crash zones (red) and non-crash zones (green). It is evident that on the majority of roads the average roughness is higher through crash zones. 76% of roads analysed have a roughness through crash segments equal to or higher than the rest of the road. On the 24% of roads where the crash location's roughness is less than the non-crash zones, there are possible reasons for these results.

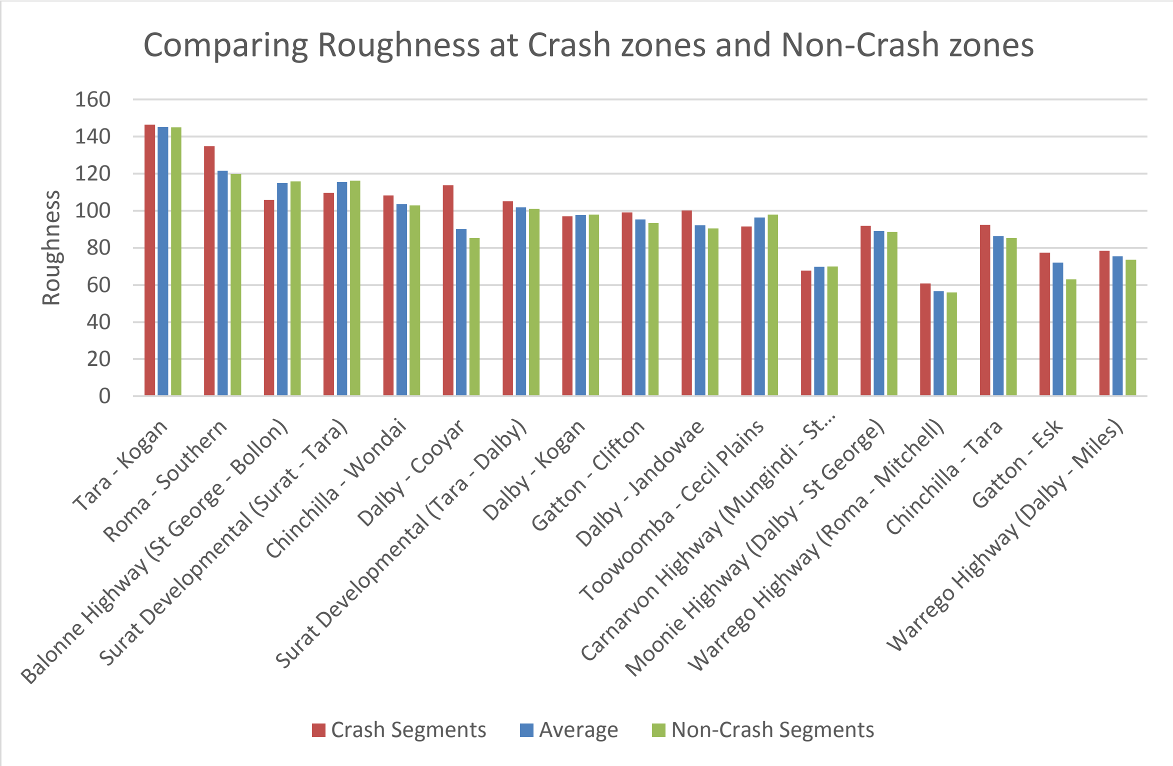

Figure 22: Relationship between crash zones and non-crash zones compared to Roughness.

The four roads where the roughness on the non-crash segments is greater than crash segments are the Balonne Highway (St George to Bollon), Surat Developmental Rd (Surat to Tara), Toowoomba Cecil Plains Rd and the Carnarvon Highway (Mungindi – St George). It is evident that roughness on the Balonne Highway (St George to Bollon) and Surat Developmental Rd (Surat to Tara), is generally very high roughness along the length of the road. Both of these roads are long in length, which combined with a high average roughness would explain this result. The Carnarvon Highway (Mungindi – St George) is also long in length, which may have affected the results also. The Toowoomba Cecil Plains road is fairly normal with its parameters. It has a wide clearzone and generally straight alignment. While it has rough sections which have no crash history, this may be due to having only one parameter that is substandard, and this alone is not enough to greatly impact the cause of incidents.

This model is also represented in Figure 23 which shows the type of segments with the higher roughness values. It is evident that the majority of the roads in our study had an even or higher roughness on 1km segments with a history of crashes, rather than the non-crash segments.

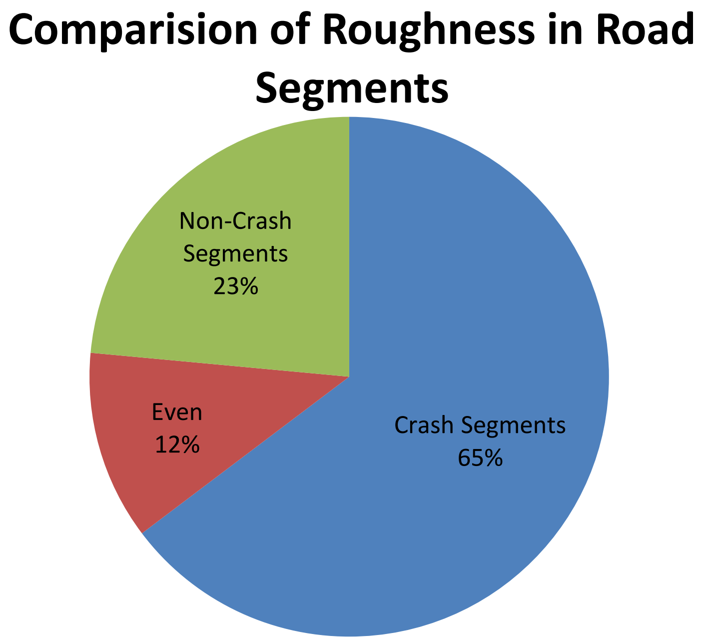

Figure 23: Pie graph representation of roughness in crash segments compared to non-crash segments.

These findings indicate that there is a relationship between high roughness values and crash rates. This relationship will be investigated in further models within this report.

4.3.2 Crash Investigations (per roadway)

Using the sample of roads in the Downs South West Region, the relationship between crash rate and roughness can be investigated. This model investigated the crash rate on each whole road segment. Using the formula to calculate crash rate in section 3.4.3, the rate for each road segment has been calculated. This has been compared to the average road roughness, to gain the relationship in Figure 24.

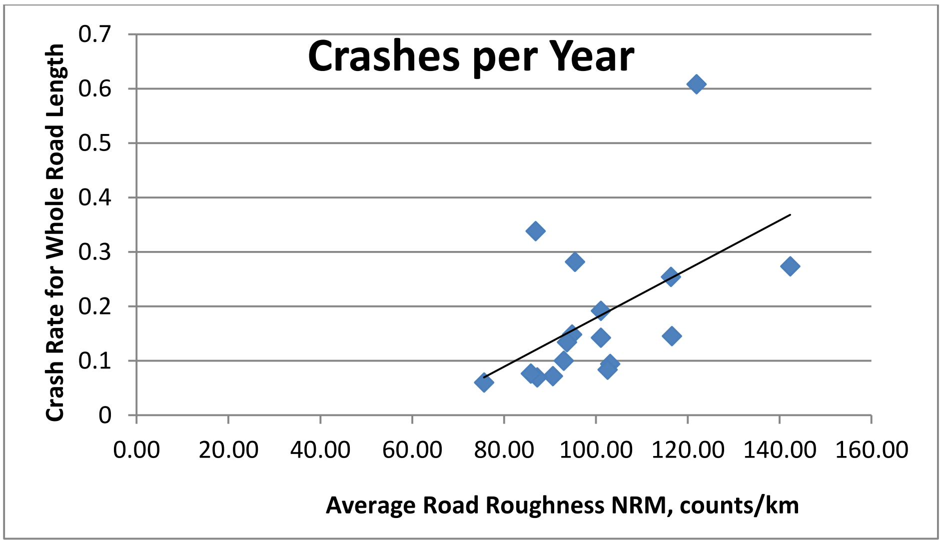

Figure 24: Correlations between crash rate per million VKT and Roughness along each road

It is evident here that there is a relationship between roughness and increasing crash rates. With higher roughness values, there is an increase in crash rate. With the low number of roads that this model investigates, it is still evident that there is a general increase in crash rate as the road roughness increases.

The relationship between roughness and the type of crash has also been investigated. Each crash is categorised into one of 5 categories: Property Damage, Minor Injury, Medical Treatment, Hospitalisation and Fatalities. Table 8 highlights the frequency of each crash type and the total crash cost for each road, given in cost per kilometre (calculated using costs in section 2.4.1). This cost is therefore dependant on the frequency of crashes and the length of the road. This information can be used to model the effect of roughness on each crash severity type.

Table 8: Frequency of Crash Type and Total crash costs.

Road Name	Property Damage	Minor Injury	Medical Treatment	Hospital	Fatal	Cost/kilometre
Tara - Kogan	0	0	1	5	0	$45,879
Roma - Southern	3	1	1	2	0	$18,773
Balonne Highway (St George - Bollon)	1	3	3	2	0	$10,479
Surat Developmental (Surat - Tara)	4	1	2	7	2	$130,851
Chinchilla - Wondai	5	2	3	13	0	$35,088
Dalby - Cooyar	4	0	1	4	2	$310,721
Surat Developmental (Tara - Dalby)	2	0	2	4	1	$246,334
Dalby - Kogan	3	1	4	10	1	$261,113
Gatton - Clifton	7	4	5	11	3	$471,036
Dalby - Jandowae	1	0	3	6	1	$227,659
Toowoomba - Cecil Plains	9	3	9	6	2	$248,762
Carnarvon Highway (Mungindi - St George)	3	1	2	3	1	$81,490
Moonie Highway (Dalby - St George)	13	2	10	30	1	$70,460
Warrego Highway (Roma - Mitchell)	4	1	1	7	0	$31,897
Chinchilla - Tara	5	1	1	7	2	$276,113
Gatton - Esk	10	0	6	27	0	$270,619
Warrego Highway (Dalby - Miles)	15	4	7	34	4	$365,005
TOTAL	89	24	61	178	20	$3,102,279

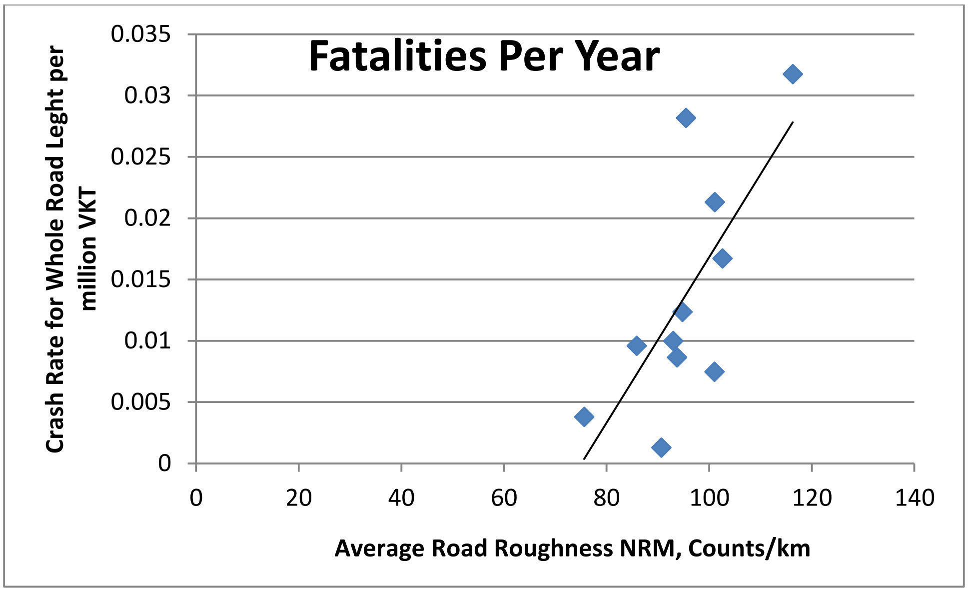

Figure 25: Fatality crash rate per million VKT and Roughness along each road

Figure 25 above shows the relationship between roughness and crash rates for fatality crashes. This crash type has the smallest frequency of incidents, and the crash rates here are very low. However, it is evident that there is a higher crash rate when roughness is 100counts/km, rather than 80counts/km. The fatality model conveys a correlation between increasing crash rate and roughness.

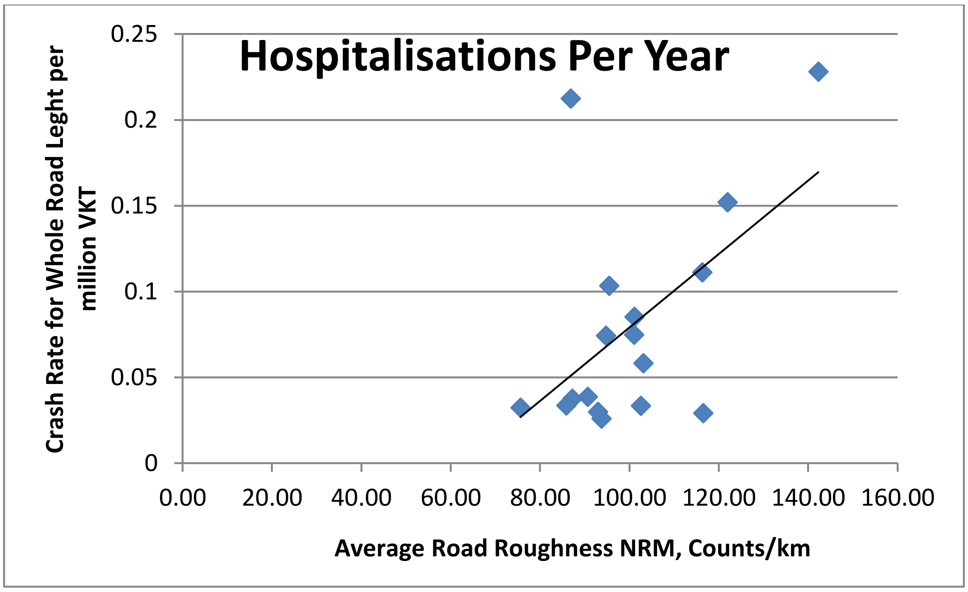

Figure 26: Hospitalisations crash rate per million VKT and Roughness along each road

Figure 26 represents the relationship between hospitalisation crashes and roughness. This relationship has a strong increase in crash rate for the same increase in roughness, compared to the other crash severity types. This data set has the highest frequency of crashes. This data set has some of the roughest road segments in the study.

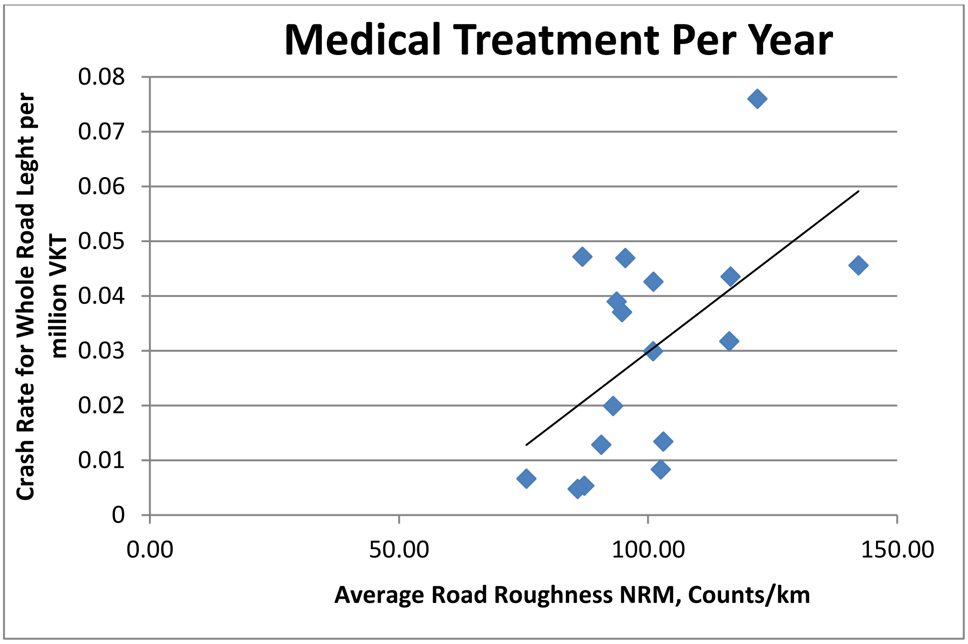

Figure 27: Medical Treatment crash rate per million VKT and Roughness along each road

The relationship between road roughness and medical treatment incidents is evident in Figure 27. It can be seen that the relationship with crash rate again increases with roughness. This model is perhaps more scattered that the other models. This data set has some of the roughest road segments in the model.

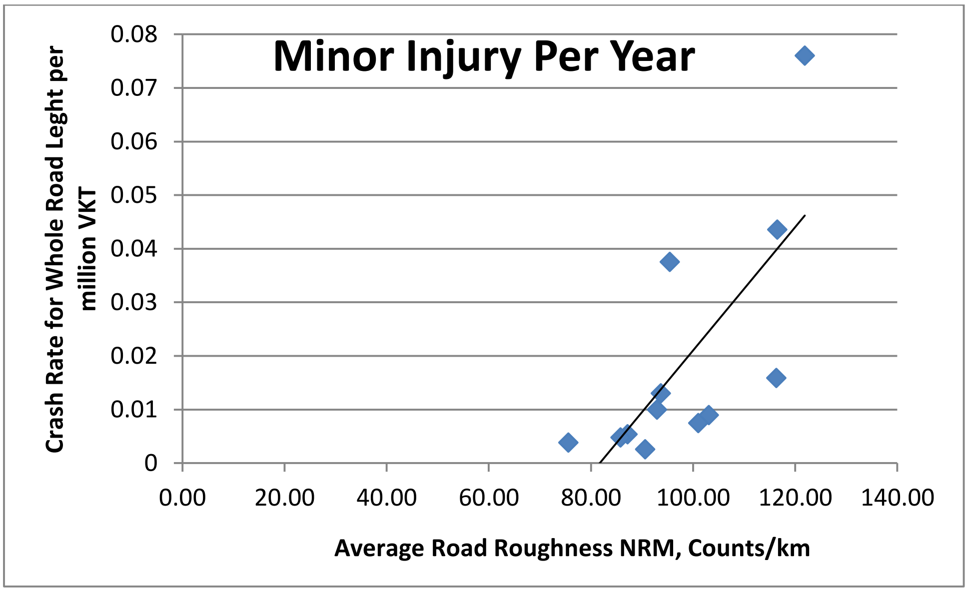

Figure 28: Minor Injury crash rate per million VKT and Roughness along each road

The correlation between road roughness and minor injury crash types can be seen in Figure 28 above. Here the significant correlation between roughness and crash rate is again highlighted.

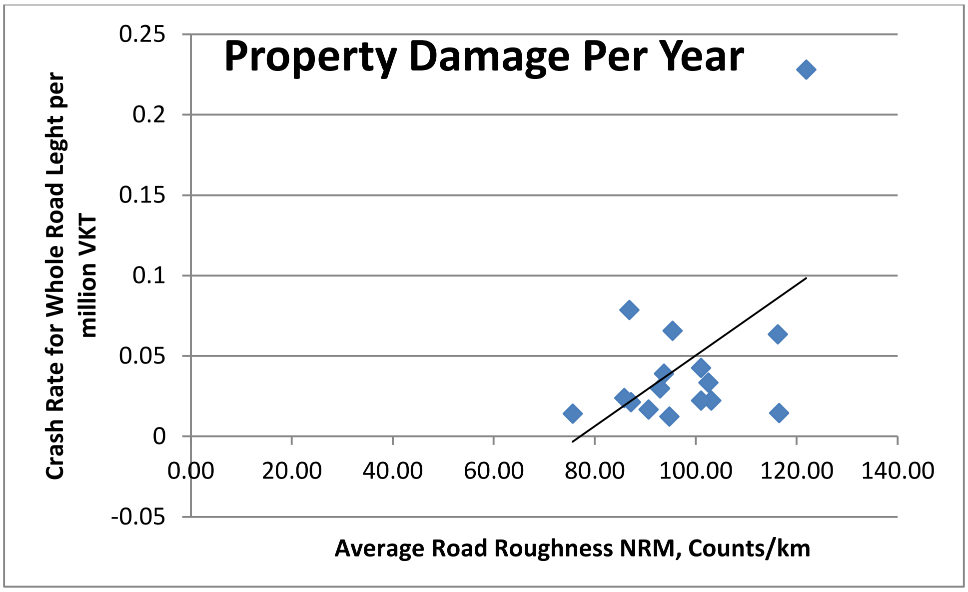

Figure 29: Property Damage crash rate per million VKT and Roughness along each road

Figure 29 highlights the relationship of property damage crashes and road roughness. From the graph it is evident that this crash type has the greatest slope, reflecting that a smaller increase of roughness has a greater effect on the crash rate than the other crash severity types. This suggests that roughness may have a greater effect on property damage crashes, and that improving road roughness will help to improve the safety on the road network.

Table 9: Crash Rates (per million VKT) at a roughness of 100 NRM

Crash Severity Type	Crash rate
Property Damage	0.0507
Minor Injury	0.0258
Medical Treatment	0.0303
Hospitalisation	0.0751
Fatality	0.0193

It can be seen that the crash rates are linearly proportional to the amount of crashes in each category. Hospitalisations and property damage have the highest crash rates at a 100 NRM compared to the other crash severity types. While these two types are the most likely to occur, they are the most affected by increasing roughness.

Table 10: Correlation of data to linear regression line- R^2 values

Crash Severity Type	R^2
Property Damage	0.2691
Minor Injury	0.5243
Medical Treatment	0.3179
Hospitalisation	0.2951
Fatality	0.5114

Table 10 highlights the correlation that the data produces to a linear regression line. It can be seen that no crash type represents a high 'goodness of fit' R^2 value. However, of the 5 crash type categories, fatalities and minor injuries have the best fit with over 50% variance. Hospitalisation and Property Damage have a more scattered graph, with a variance between 25% and 30%. This difference in variance may be due to the smaller frequency of fatal and minor injury crash types compared to high occurring incidents such as hospitalisations. As there are less data points perhaps it is easier to fit a regression line, then to a data set with more points.

4.3.3 Crash Investigations (per 100m and 1km)

Another analysis was undertaken, analysing each and every 100m and 1km in the sample with a crash history, and the roughness at the crash location. Using 100 m and 1km segment lengths, crashes per 100 million VKT was calculated using both Method A and B described in Section 3.4.1 and 3.4.2. For each of the four models, the resulting correlation between roughness and the calculated crash rate per 100 million VKT was very poor. Figure 30 highlights the results of the 1km segment model using Method B to determine crash rate. The other three graphs are seen in Appendix H. The different colours represent each road in the analysis and are highlighted by their road ID in the legend. It is evident here that there is little correlation between roughness and crash rate that can be determined from this result. The other three models generated poor correlation results also.

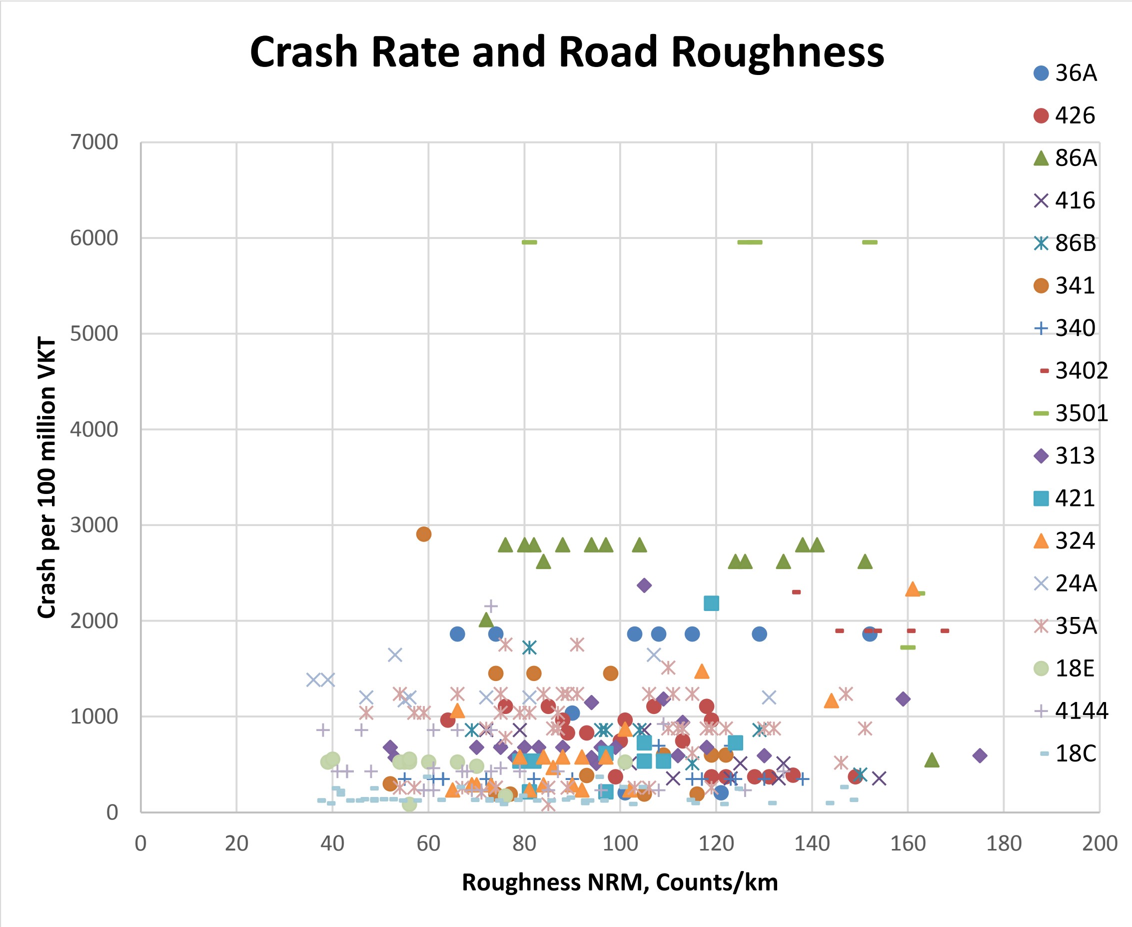

Figure 30: Model of Crash rate and roughness

This little correlation may be due to a few reasons. It was determined that 100m segments are too small to have an effect on the vehicle and roughness. The 1km model is a better representation of roughness, but 1km generally results in 1 or occasionally 2 or 3 crashes in the segment. Therefore, when calculating the crash rate, the result is based on the road's traffic volumes. It can be seen above, that in many cases each road makes a horizontal line in the graph. An example is the Balonne Highway, represented by blue circles, which forms a horizontal line below 200 crashes per 100 million VKT. Roads analysed separately may result in more useful information, see section 4.3.4.

The model was also extended to compute the relationship between roughness and vehicle crash types (property damage, minor injury etc.) for 1km segments. 1km segments were modelled as this provides a better representation of travelling conditions than 100 lengths. Each type of crash severity was modelled for both Methods A and B, producing ten different models. Each of these models is found in Appendix D. While splitting the crash history by crash severity types provided an increased correlation than the full model above, there is still a low correlation between roughness and crash rate.

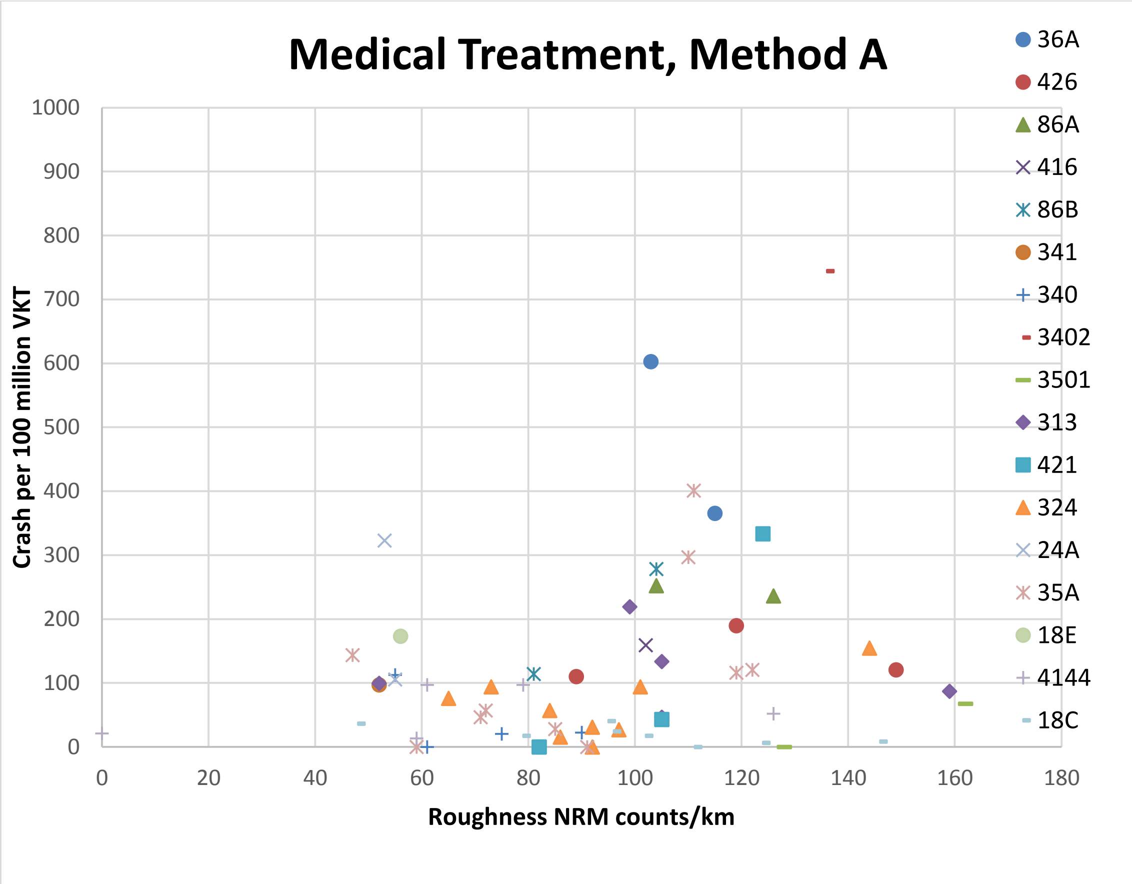

Figure 31: Correlation between medical treatment crashes and roughness (using Method A)

Figure 31 highlights the model of medical treatment crashes, calculated using the MUTCD model of calculating crash rate. Here, it is evident that there is some general increase between crash rates as the roughness increases. However, this relationship is not strong enough to identify a correlation between the roughness and crash rate.

The cause of the low correlation between roughness and crash rate may be a reflection of the vast causes of crashes. As crashes may be contributed to driver error (fatigue, drink driving, slow reaction time), environmental/external conditions (wind, rain, poor visibility, animals, other vehicles), vehicle malfunction (braking, tyres) or road conditions (lack of clearzone, poor sight distance, pavement quality), it is difficult to standardise these variables. In most cases, it is a combination of these conditions which result in an incident (e.g. poor visibility and fatigue). While the model investigates roughness as a contributing factor, it may be that there are too many other contributing factors towards each crash, or that at some locations roughness isn't a contributing factor at all and therefore these data points create a result with little correlation.

4.3.4 Individual Road Investigations

The Toowoomba Cecil Plains Road was modelled using both Method A and Method B for calculating crash rate. The difference in the graphs is evident below. It can be seen that Method B of determining Crash Rate, provides a much greater correlation between crash rate and roughness. This is due to the method of calculating both methods. Method A relies on the crash risk score. This score is based on the risk of crashes occurring. This weighting may not be linearly comparable to the effect of roughness, creating a graph of little significance, as seen in Figure 32.

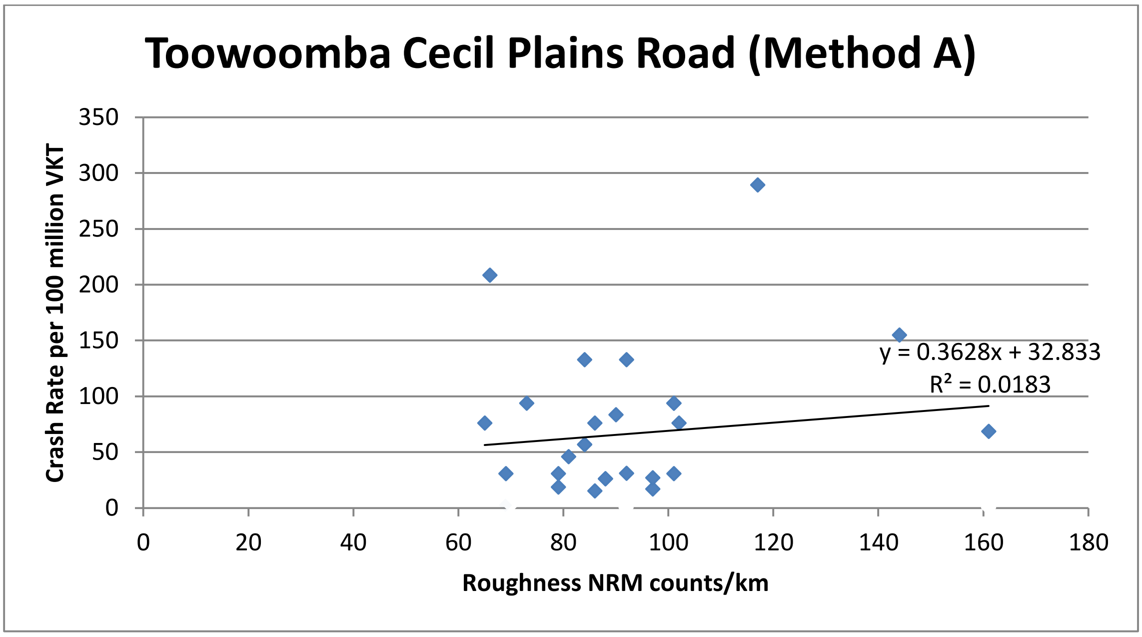

Figure 32: Crash rate on Toowoomba Cecil Plains Rd, using Method A

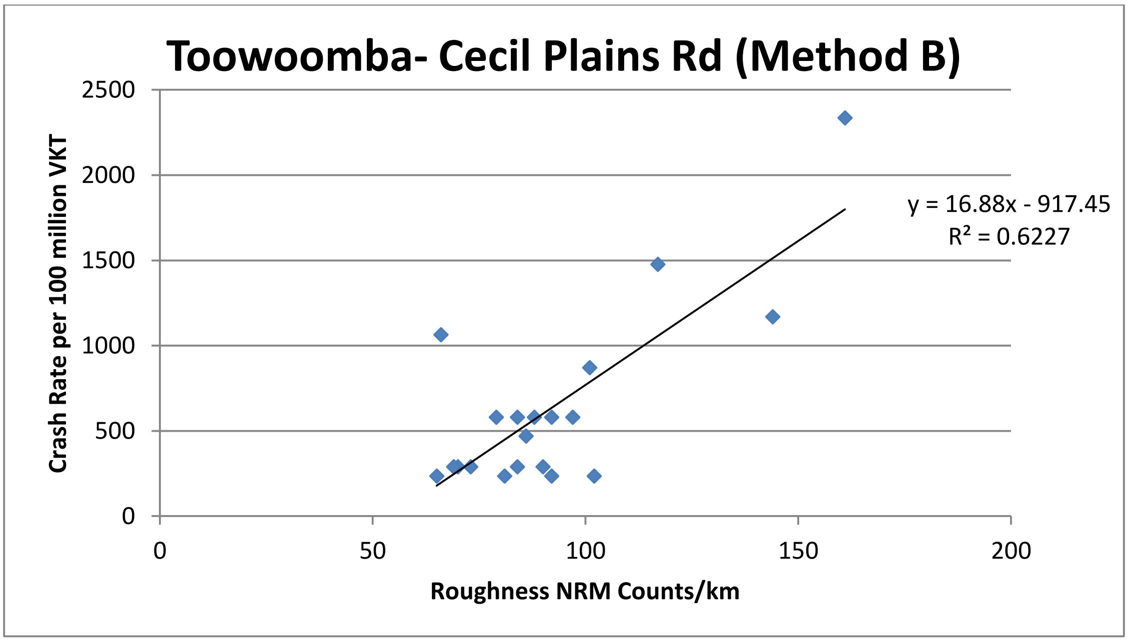

Figure 33: Crash Rate on Toowoomba-Cecil Plains Road, using Method B

Figure 33 highlights the relationship between roughness and crash rate, computed using Method B to determine crash rate. This graph shows a high comparison with increasing road roughness and higher crash rates. This method returns a better correlation then Method A, as it is not dependant on the cause of crash, but rather the AADT and segment length. There are fewer factors involved in the weighting, therefore the model returns higher correlations with roughness. On the Toowoomba Cecil Plains Road, it is evident that generally high crash rates occur on segments with higher roughness values.

Not all roads in the model have such a high correlation between crash rate and roughness as seen on the Toowoomba Cecil Plains Road. Figure 34 below highlights the same model for the Gatton Clifton Road. It can be seen here that while there is increasing crash rate, over increasing roughness, this correlation isn't as strong as the Toowoomba Cecil Plains road. On the Toowoomba Cecil Plains Road at a roughness of 150counts/km, the crash rate is above 1500 crashes per 100 million VRT. For the same roughness on the Gatton Clifton Rd, the crash rate is 900 crashes per 100 million VRT, which is much less than Toowoomba Cecil Plains Rd. This may be due to the different characteristics of both roads, and the causes of crashes on each road. Gatton Clifton has a section with small radius horizontal curves and other design minima, while the Toowoomba Cecil Plains road has generally satisfactory design parameters. On the Gatton-Clifton other geometric issues such as low radius horizontal curves, or seal width may be affecting crash rate more significantly than roughness.

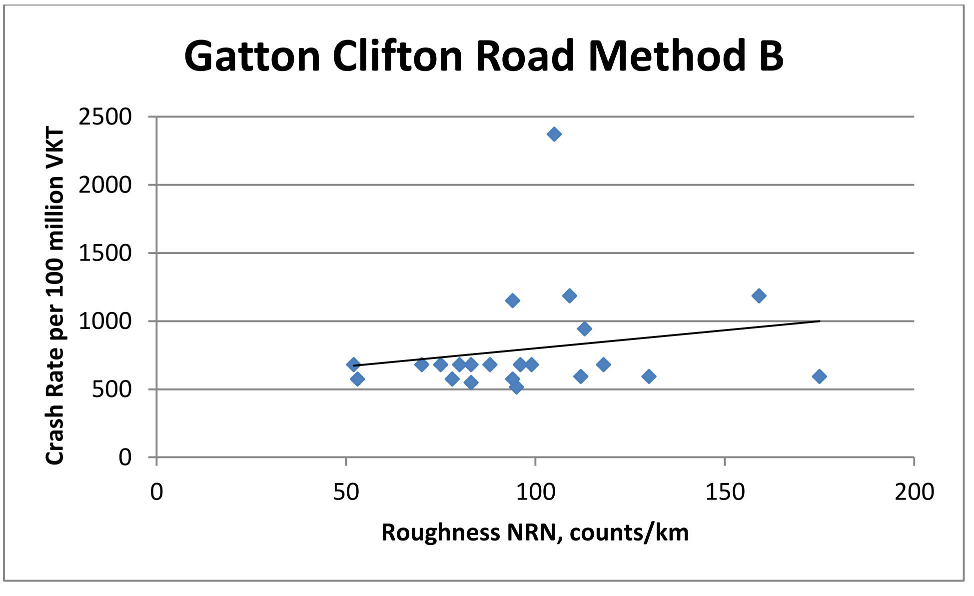

Figure 34: Crash Rate on the Gatton Clifton Road using Method B

4.3.5 Crash Investigations: Light vehicles and Heavy Vehicles

This model investigates the difference that roughness has on the safety of light vehicles compared to heavy freight vehicles. Method B has been used to calculate crash rate for both models. It can be seen in Figure 35 below that heavy vehicle crash rates are affected by increasing roughness.

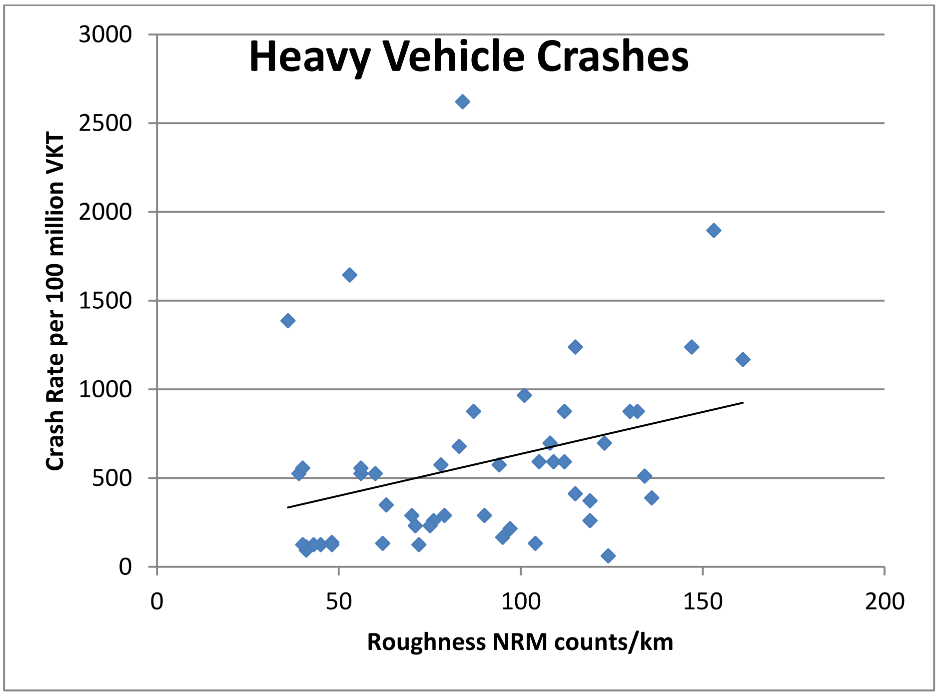

Figure 35: Crash Rate of incidents with Heavy Freight Vehicles.

The gradient of the trend line for the heavy vehicle model is 4.7. This graph can be compared with Figure 36, which models the light vehicle crashes with roughness. It is evident that there are many more crashes in the model with light vehicles, than heavy freight vehicles. The gradient for the light vehicle model is 8.3. This is higher than the heavy vehicles, and therefore light vehicles crash rate is more affected by the same increase in roughness. This may be contributed partly to braking distance. Cenek, Davis and Jamieson (2012, p.1) found that braking distance for cars increases with higher roughness for speeds over 50km/hr. Longer braking distance may increase crash rates, as vehicles are colliding with trees, animals and other objects on the rougher roads. While heavy vehicles are less affected by roughness, there is still an increase in crash rate with increasing roughness.

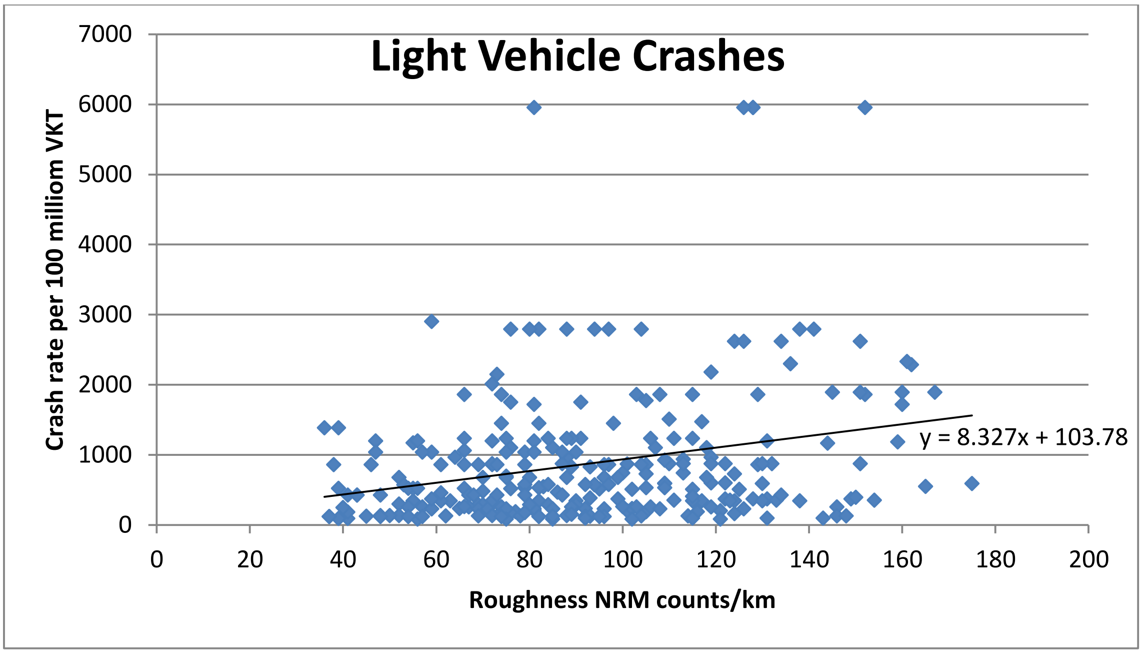

Figure 36: Crash rate for light vehicles

4.3.6 Crash Rate Comparison

The calculated crash rates for the models can be compared to the benchmark crash rates evident in Appendix G, which are derived from the MUTCD (Queensland Government 2014a, p55). When applied to the roads in the model, the typical casualty crash rates range from 811.8 to 1049.6 10^4 equivalent risk unit (ERU) per 10^8 VKT.

It is evident that crash rates calculated in the models are well below the comparative crash rates shown in Appendix G. Therefore, the crash rates are low enough to not warrant any safety treatments being applied (based on crash rates alone). This highlights that the QDTMR safety initiatives, road design standards and maintenance works are delivering a suitable standard of road network to the community.

4.3.7 Summary

Within all the models which investigate the relationship between roughness and crash rate, there are varied results. Generally, it can be concluded that an increase in roughness corresponds to an increase in crash rate. This result is similar with results discussed in the literature review, with some variance in the nature of the regression lines. Therefore, on Downs South West Region Roads, roughness is a contributing factor to crash rates.

4.4 Roughness and Speed

The effects of roughness on the V85 operating speed was investigated on the sample roads. Using the difference between the posted speeds and the V85 speed, the driver compliance can be determined. This is modelled in Figure 37 below, where the compliance (positive for speeding vehicles and negative for complying vehicles) is graphed against the roughness at the recorded location. It can be seen in Figure 37 below, that the roughness (in 1km segments) has little effect on the driver's speeds with roughness less than 120 counts/km NRM. However, with roads where the roughness is greater than 120counts/km NRM (or an IRI of 4.6m/km), it can be see that there is total compliance in V85 speeds and that 100% of drivers choose to travel between 5km/hr and 15km/hr less than the posted speed limit.

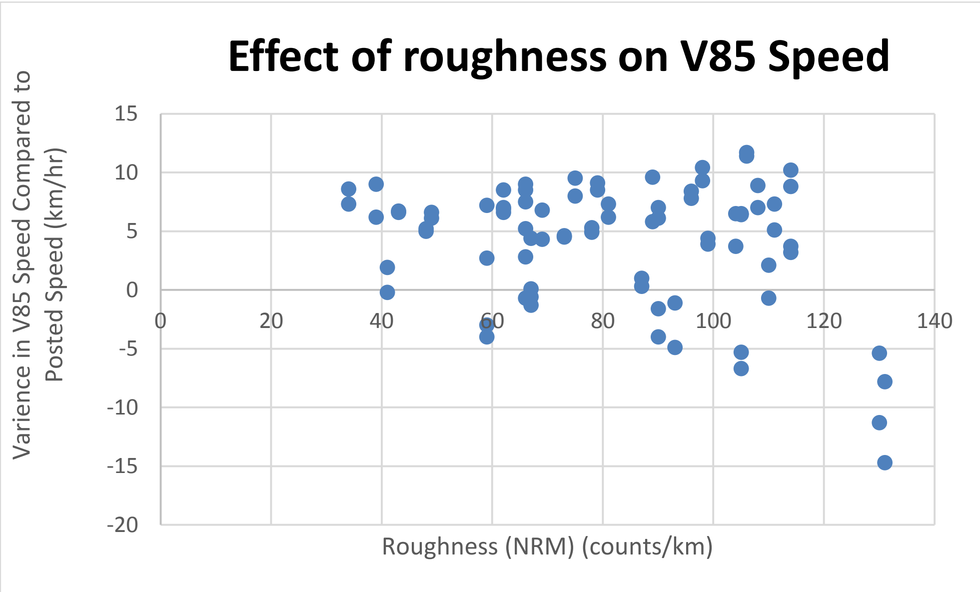

Figure 37: Relationship between Roughness and Speed Compliance

While roughness is one of the many factors which may adjust a driver's speed limit, the benchmark for roughness of 120counts/km NRM can be used in speed limit setting and reviews. This benchmark is consistent with information given by Austroads and other traffic authorities. Table 3 defines Austroads roughness levels where investigation is warranted, and highlights an IRI of 4.2m/km (110counts/km NRM) for segments greater than 500m. This is comparable to our value of an IRI of 4.6m/km (120counts/km NRM), and gives some credibility to the results. Also, this benchmark is similar to the Victorian Study on rural roads, highlighted in section 2.2.4, where in crash rate increases rapidly after a roughness of 130counts/km.

Lower speeds are known to improve the road safety in an isolated scenario. It some scenarios, roughness may improve the safety as it is lowering the travelling speed for roughness over 120counts/km and the driver may be more alert. When resurfacing is carried out, in some locations the operating speed and crash rate increases (Atabak 2014, p.6). There is a fine line between roughness as a safety benefit and roughness contributing to crashes. Finding whether roughness is beneficial or a disadvantage is site specific, and requires engineering judgement. In this study, the increase in crash rate with increasing roughness has a strong relationship, and therefore on the roads analysed it seems that roughness has a disadvantage on safety.

4.4.1 Locations with roughness higher than 120counts/km

The four sites (two locations, gazettal and against gazettal) which have roughness values higher than 120counts/km, occurred on the Warrego Highway (Dalby to Miles) at Ch. 78km and the Gatton Clifton Road at Ch. 34km, with two sites on each road (QDTMR 2014e). Both sites are signposted at 100km/hr, and recorded V85 speeds substantially below the posted speed limit.

Factors other than roughness that influence the speed must be considered. One factor may be due to high traffic capacity, as the large volumes reduce the operating speed. This is very unlikely on the Gatton Clifton Road due to the low traffic volumes. It is more likely on the Warrego Highway, particularly due to the high volumes of heavy vehicles that may have a slower travelling speed due to their large loads. Of the 7 speed data sites on the Warrego Highway (Dalby-Miles), 2 sites (one being at Ch.78km) reflect that the V85 speed is 5km/hr under the speed limit or more. If heavy vehicles or high traffic volumes were influencing the speed, this would be consistent along the length of the road.

Other factors that may affect driver speed include the presence of the police, or any other emergency service. As the police enforce the road rules, particularly the speed limit, their presence may skew the data. In this model, we have assumed that police were not present at data collection locations.

At the Warrego Highway location at Ch. 78km, there is a Channelised Right Turn (CHR) treatment nearby the speed data location. It is possible that turning vehicles may have influenced the V85 speed. A CHR treatment would limit the reduction in speed by the through traffic, as turning vehicles have a separate deceleration lane. If the side road (which leads to a sports centre) has high traffic volumes, this may affect the V85 of the Warrego Highway. If the side road has low traffic volumes, this will have little impact on the V85 speed on the Warrego Highway. Being a sports centre entrance, it most likely has high traffic volumes at certain times (before and after games). This would have limited effect on the V85 speeds on the Warrego Highway.

The site at Gatton-Clifton road has fairly straight geometry at the recording location. In a 5km range there are a series of horizontal curves which may be slowing vehicles, however this should have little effect on the recording site as vehicles will then speed up after negotiating these hazards. Therefore, there are only minor site conditions which would have an impact on the travelling speeds at these locations other than the site roughness.

4.4.2 Treatment of Rough Segments with Speed

The results indicate that speed is affected when the roughness is higher than 120km/hr, therefore traffic authorities may need to revise the posted speed limits on those sections. The nature of the speed reduction can be permanent or temporary. Temporary reductions in speed are only required until the pavement maintenance can be completed. This option is usually used when the pavement maintenance will restore the all known safety issues at that location. A permanent reduction in speed is investigated when there is a combination of safety issues which are challenging to mitigate, combined with a crash history or public complaints of safety risks. Both temporary and permanent speed reductions can be suitable treatments, given a suitable situation based on engineering judgement.

The Queensland Government has guidelines around the modification of speed limits, defined in part 4 of the MUTCD. There are a range of restrictions on the modification of speed limit zones. One factor includes the length of the speed zone. Recommended minimum lengths are defined in Table 11. From 100km/hr (which is the posted speed at the majority of locations), the normal minimum length is 3km, but this length can be reduced to 2km in certain locations. These limits apply directly to permanent speed reductions.

Table 11: Minimum Speed Zone Lengths (Queensland Government 2014a, p.20)

Speed Limit (km/h)	Normal Minimum Length (km)	Absolute Minimum Length (km)
40: General	0.4	Not applicable
40: School zone only	Not applicable	0.2
40: High pedestrian activity zone only	Not applicable	0.2
50: Default urban limit	Not applicable	Not applicable
50	0.5	Not applicable
60	0.6	Not applicable
70	2.0	0.7
80	2.0	0.8
90	2.0	0.9
100	3.0	2.0
110	Not applicable	20.0 (see Section 3.3)

When changing the posted speed, directly due to a particularly rough surface, guidelines are highlighted in part 5.2.8 of the MUTCD. For sections of less than 1km, temporary speed advisory signs indicating ‘rough surface should be installed until maintenance can be completed. For lengths greater than 1km, the speed limit should be temporarily reduced and the ‘rough surface’ sign should be displayed to inform drivers of the reason of speed reduction (Queensland Government 2014a p.27). Therefore, for shorter lengths an advisory sign is warranted, while lengths over a kilometre require a reduction in the enforced speed limit.

The magnitude of the speed reduction is also another important factor. From the data in this study, a recommendation may be to reduce the speed by 10km/hr, as this was the average V85 speed at these locations. However, Chapter 4 of the MUTCD states that, ‘Speed zone changes of only 10km/hr should be avoided where possible. This particularly applies in rural and semi-developed areas’ (Queensland Government 2014a, p.20). Therefore, careful consideration should be taken when deciding the magnitude of the reduction. A location with a significant crash history may warrant a 20km/hr reduction (from 100km/hr to 80km/hr).

In May 2014, a site visit to the Moonie Highway found a section of road reduced to 80km/hr due to rough surfaces (from 100km/hr), using a temporary speed limit reduction sign and a ‘rough surface’ advisory sign. This is an onsite example of this treatment being implemented in the Downs South West Region. Recently, pavement repair works commenced on this section of road.

Treating a deficiency in road quality by reducing the speed can spark public approval or uproar. It is important to consider all other possible remedial treatments, before reducing the speed limit. If a speed limit reduction is the temporary treatment until maintenance is scheduled, site specific investigations are required to determine if a 10km/hr or 20km/hr reduction is warranted.

Chapter 5: Roughness Case Studies and Financial Model

This chapter will investigate the findings found in Chapter 4 further, through case study analysis on 5 roads within the model. Modelling of the costs to rectify pavement roughness will also be detailed in this chapter.

5.1 Case Studies

A smaller selection of roads have been analysed in the case study model. The case study focuses on the parameters of speed, crash history and roughness, but also investigates road parameters such as AADT, pavement width, road geometry and other site specific features, to gain a holistic picture of the situation. The roads chosen have been identified for their higher AADT volumes and crash frequency, allowing significant data to analyse. In most cases, site visits have been conducted to access the onsite conditions at these locations.

5.1.1 Dalby Kogan Road

Situated west of Dalby, the Dalby Kogan Road services the recently developed coal seam gas industry. The current AADT is 1570 vpd which is a significant growth from recent years, and 34% of road uses are heavy vehicles (QDTMR 2014f). This route permits the use of Road Type 1 Trains. Pavement width is varied along the road, with sealed widths generally between 6m to 7m. The alignment is generally flat with a series of horizontal curves and vertical crests. Some vertical crests on the road have stopping sight distance deficiencies. The average roughness value is 101counts/km over the 47km, which is greater than the region's average. This road has segments of high roughness values at Ch. 11-12.5km and 27-42km. The typical road cross section is given in Figure 38.

Through analysis of the locations of crashes, it is evident that no crashes occurred on vertical straights. This omits any suspected impact from sight deficiencies on crests, from effecting roughness correlations. There are a few crashes which occur on horizontal curves. These crash locations on curves have a higher average pavement roughness, than crash location on horizontal straights. All crashes on curves are hospitalisations. The frequency of horizontal curve incidents will be monitored in other case studies, however it is apparent that horizontal curves combined with high roughness have an inverse effect on safety.

Figure 38: Dalby-Kogan road, taken on-site (King 2014).

Dalby Kogan road has a large percentage of heavy vehicles, with the majority of traffic being local vehicles or mining vehicles (due to the large amount of coal seam gas mining in the area, see section 5.2). This may impact the driver behaviour on this road.

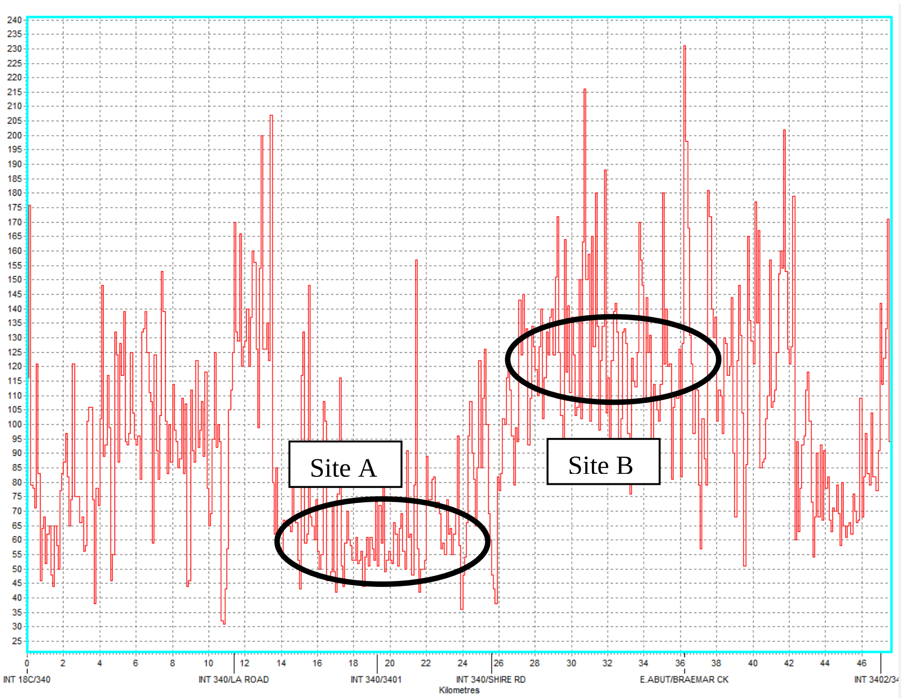

Figure 39: Roughness on Dalby Kogan Rd (Sourced from Chartview, QDTMR 2014b)

When analysing the roughness through Dalby Kogan road, it can be seen that it fluctuates along the length of the road (see Figure 39). Site A and B are two segments with differing roughness values. Site A (Ch. 13-27km) has roughness values of less than 100counts/km (average of 77counts/km), while Site B (Ch. 27- 42km) has higher values, mostly over 100counts/km (average of 125counts/km). These 15km segments both have a similar crash rate, with Site A recording 3 crashes and Site B recording 4 crashes over the last five years. This indicates that on this road, roughness may not be such a contributing factor.

When completed site visits to this road, the clearzone is fairly similar through both sections, and the traffic volumes are also fairly constant through the length of the road. There are no other evident onsite parameters that would impact crashes.

An in-depth report of the crash history on the Dalby-Kogan road was sourced. This shows that of the 18 crashes over the last 5 years, 3 crashes occurred during rain events, no crashes were due to drink driving and 2 crashes where due to speeding. However, on this road 5 crashes where due to fatigue and 5 crashes due to disobeying road rules. 6 crashes involved heavy freight vehicles, and one with a motorbike.

The crashes at Site A have been caused by factors relating to rain (wet pavement), disobeying road rules and heavy vehicle involvement. Site B crashes are attributed to fatigue related crashes. This supports that roughness was a secondary contributor in the causes of these crashes. Fatigue combined with perhaps a longer braking distance (due to rougher surfaces) may have resulted in these crashes.

The speed data available is located at two locations, at Ch. 6 and 34km. Both V85 speeds exceed the posted speed by between 0-10km/hr.

It is evident that roughness is a secondary factor influencing crashes on the Dalby Kogan road, and horizontal curves may have an increasing effect on crash rate. The impact on mining vehicles has also impacted the driver behaviour on the road (see section 5.2).

5.1.2 Moonie Highway (35A)

The Moonie Highway services vehicles travelling west of Dalby to St George. The town of Moonie is situated at Ch.113km, and it forms a crossroads at Moonie, with the other directions leading to Goondiwindi and Miles. Road parameters include an average AADT of 1448, a maximum heavy vehicle volume of 33%, and a road of 293km in length (QDTMR 2014f). This road is a Type 1 Road Train Route, and is generally straight and flat in geometry.

When analysing the geometry of the road, again there are no crashes which coincide with vertical crests. There are some crashes which occur on horizontal curves. These crash locations on curves also have a higher average pavement roughness, than crash location on horizontal straights.

When comparing the locations of crashes and the roughness over the length of the road, it is evident that there is a higher frequency of crashes at roughness peaks, evident in Figure 40 below (extracted from DTMR Chartview database). A segment with high average roughness is compared with a site with low average roughness, as seen in site C and D below. Both sites have a length of 30m. Site C (Ch. 60- 90km) has an average roughness of 118counts/km (with each kilometre having a roughness greater than 100) while Site D (Ch. 158 – 188km) has an average roughness of 70counts/km (each kilometre having a roughness less than 100). These two sites were chosen for their consistency of roughness standard over a considerable stretch of road.

Site C has 5 crashes over the last five years, averaging at 1 crash per 6km (in 5 years). Site D has 2 crashes over the last five years, resulting in 1 crash per 15km (in 5 years, omitting crashes at intersections). It can be seen here that the site with the higher average roughness, also has a higher probability of crashes based on the recent crash history. When comparing these two locations onsite, it can be seen that the clear zone widths and general layouts are similar. There is comparable vertical and horizontal geometry, with generally straight and flat alignment with the occasional curve or crest.

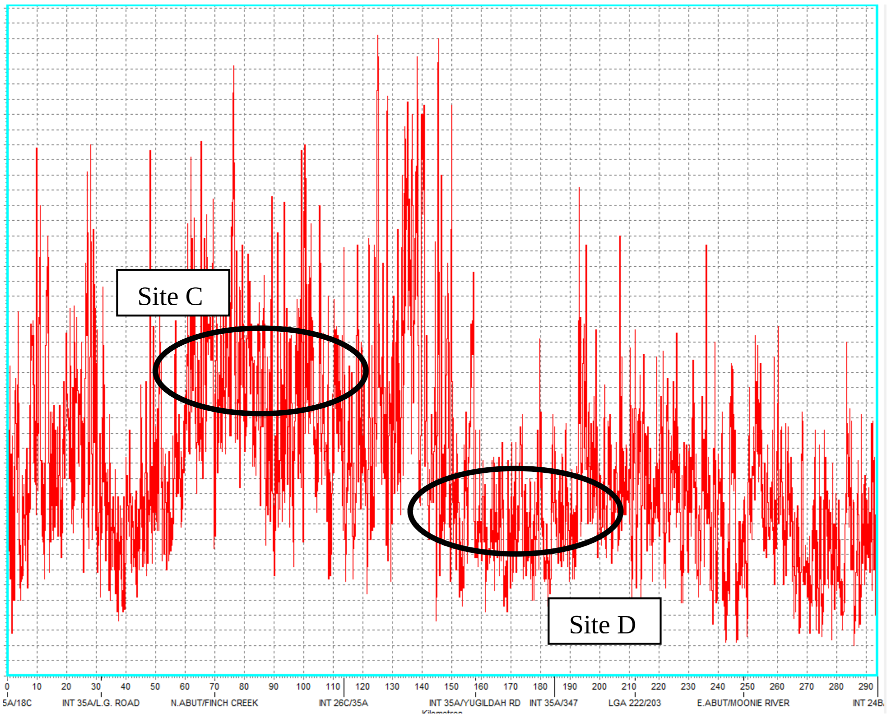

Figure 40: Moonie highway crash history (past 5 years) and roughness data (Sourced from Chartview, QDTMR 2014b)

The option to repair the rough selection through Site C and therefore potentially decrease the crash probability through this section is analysed in Section 5.3.2 below.

There are 5 speed data locations on the Moonie Highway. All locations have a V85 equal to or exceeding the posted speed limit, which is posted at 100km/hr or 110km/hr.

5.1.3 Warrego Highway (Dalby to Miles)

The Warrego Highway is the major highway connecting south - western Queensland to the metropolitan areas (Brisbane and the Gold Coast). This section services traffic from the western centre of Dalby to the township of Miles. This road has high traffic volumes, with an AADT of 4505 vehicles, and has a high number of heavy vehicles transporting goods to western areas, with the maximum percentage of heavy vehicles as 38% (QDTMR 2014f). This is a Type 1 Road Train Route. A typical cross section is evident in Figure 41 below.

Figure 41: Warrego Highway between Dalby and Chinchilla (King 2014)

The roughness in NRM through the Warrego Highway is depicted in Figure 42 below. Here the high roughness reading around Ch. 80km is the segment through the town of Chinchilla. Here the posted speed drops to 60km/hr through this area, and therefore the corresponding roughness values are not a true representation of the travelling conditions. Some of the high spikes in roughness in figure 42 are due to these low speed enrivonments.

Also in Figure 42, it is evident that there are some high spikes of roughness, which aren't in low speed zones. At Ch. 45, the spike is perhaps due to the join from the new pavement repairs. At this location, there is also the Cooranga Creek Bridge, which may also cause increased roughness.

The roughness through the section Ch. 35km to Ch. 45km has a particularly low roughness values. This is due to recent pavement repairs through this section, which have significantly improved pavement quality, from about 115counts/km to 40counts/km. Here the magnitude of the reduction in pavement roughness is evident, after the completion of pavement repairs.

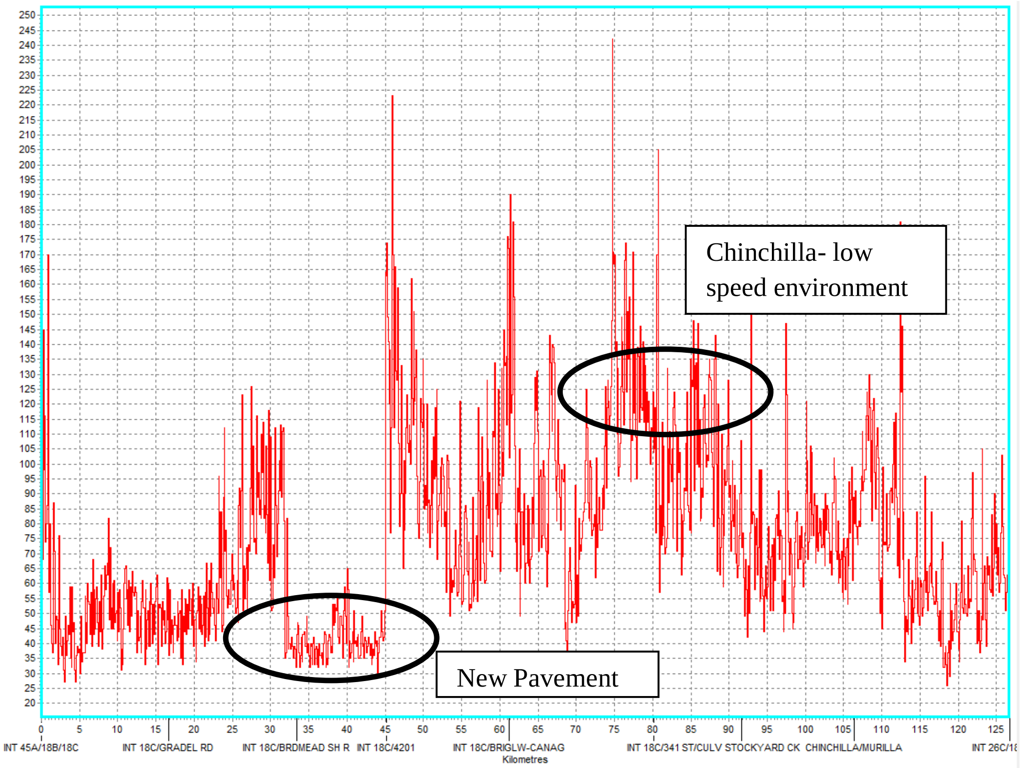

Figure 42: Pavement roughness on Warrego Highway between Dalby and Miles (Sourced from Chartview, QDTMR 2014b)

There are 7 locations of speed data on the Warrego Highway. At some of these locations there is generally speed compliance, and in other cases the V85 exceeds the posted speed.

5.1.4 Gatton-Clifton Road, 313

The Gatton-Clifton Road is a state road connecting the Warrego Highway and the New England Highway at the towns of Gatton and Clifton. This road has traffic volumes (AADT) of 930vpd and has a maximum percentage of heavy vehicles of 24% (QDTMR 2014f). This road has a generally flat geometry, however there are a series of horizontal curves through the alignment, some which are very tight, and require slower speeds to negotiate these curves.

The roughness as Site E and F are compared. Site E is at 12km stretch from Ch.21-35km (omitting Ch. 28.7 to 31.7, due to reduced speed area), with high roughness values over 100 counts/km (average of 128counts/km). This segment is posted at 80km/hr through some of this section, and some substandard horizontal curves and bridges (some narrow) are also evident through this section. The clearzone is very narrow in some sections. Site F is also a 12km stretch (Ch. 42-54), with lower roughness values mostly below 100counts/km (average of 87counts/km). Site F has a much wider clearzone. Both sites have a similar seal width, varying from 6m to 8m. Site E, with higher roughness values, has 6 recorded crashes. This equates to 1crash/2kms (over 5years). This is a particularly high crash rate, especially for a road with low to medium traffic volumes, but may be the result of a combination of minima. 3 of the recored crashes have resulted in fatalities, which are the worst category of crashes and have the greatest impact on society. Site F has 1 recorded crash in the last 5 years, and this site has fairly standard conditions. In this scenario, it is evident that roughness has contributed to the significant difference in crash rate in these two locations. It could also be concluded that horizontal curves, and reduced clearwidth have a significant contribution to crash risk. This is parrallel to the research conducted by Cenek, Davies and Jamieson (2012, p.1), where there is direct link between increased horizontal curvature and the negative impact that roughness has on crash rate (Section 2.2.3). On the Gatton – Clifton Road the high roughness values have contributed with reduced clearzone width and hoirzontal curves to create an adverse effect on crash history.

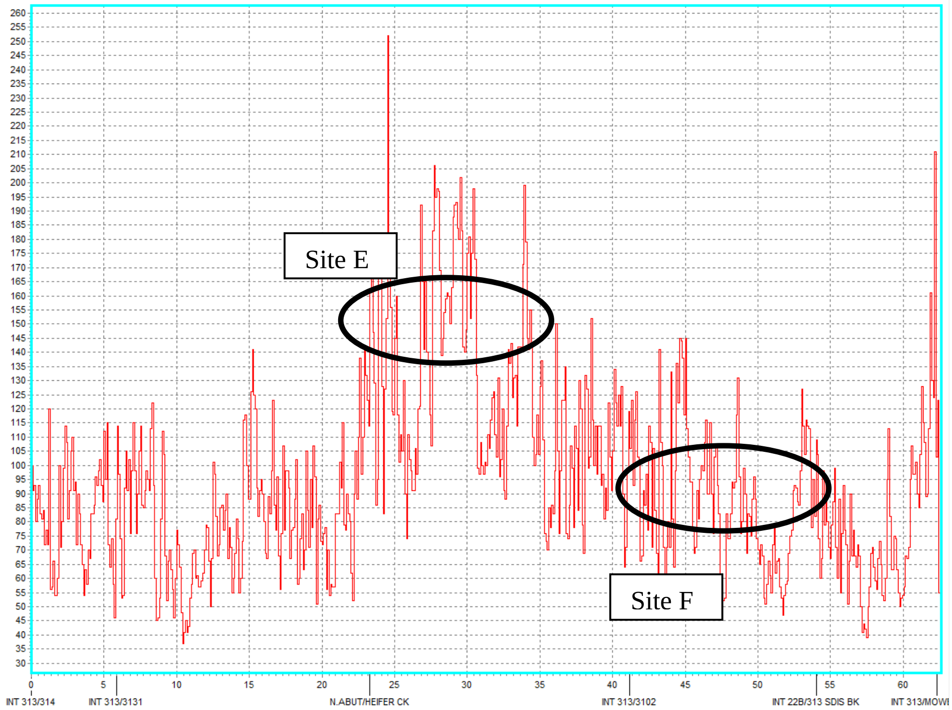

Figure 43: Roughness on Gatton Clifton Road (Sourced from Chartview, QDTMR 2014b)

The costs that crashes cause to society per kilometre, will be compared in section 5.3.2 below, to the cost of rehabilitation the pavement to reduce the roughness (and therefore the crash risk). This will be analysed on site E, for the Gatton Clifton Road.

5.1.5 Surat Developmental Road (Surat - Tara), 86A

The Surat Developmental Road connects the western towns of Suart to Tara. This road has generally straight and flat geometry, has an average AADT of 223vpd, and is therefore one of the lower volume roads analysed. The percentage of heavy vehicles along this road varies from 10%-30%, and this is Type 1 Road Train Route (QDTMR 2014f).

Site G and Site H were chosen for their similar roughness properties. Both sections are 15km long and have roughness values about 130counts/kilometer. From crash data over the last five years, it can be seen that Site G has 2 recorded crashes, and that Site H has no recorded crashes. These two sites have been compared to investigate other factors which may effect crash rate in these areas.

Figure 44: Surat Developmental Road (King 2014)

From investigation, both sites have similar clearzones, with trees either side of the road corridor, delinating the road path. Both sites also have a pavement seal width of 8m. This length is suitable for the traffic volumes on the road. One noticable difference between Sites G and H, is their proximity to nearby towns. Site H, which has no recent recorded crashes, is 20km out of Tara. While Site G, which has two recent recorded crashes, is 60 or 70km from Surat. The majority of traffic in this area is local traffic. It seems that driver fatigue and other driver-related causes may been impacting here, as there is a higher crash rate about halfway along the length of the road. When further investigating the two crashes at Site G, one has recorded data stating fatigue was a main causal factor in the crash. The other crash has no recorded information about the causal factors of the crash. This supports the hypothesis that fatigue is the major difference between the crash history at these locations.

Another factor may be the reduction of speed on high roughness sections. This may be causing a safety benefit, and reducing the number of crashes. Further speed investigations are required, to determine if vehicles are slowing down through site H. Due to the time restrictions of this study, speed data at this location could not be collected.

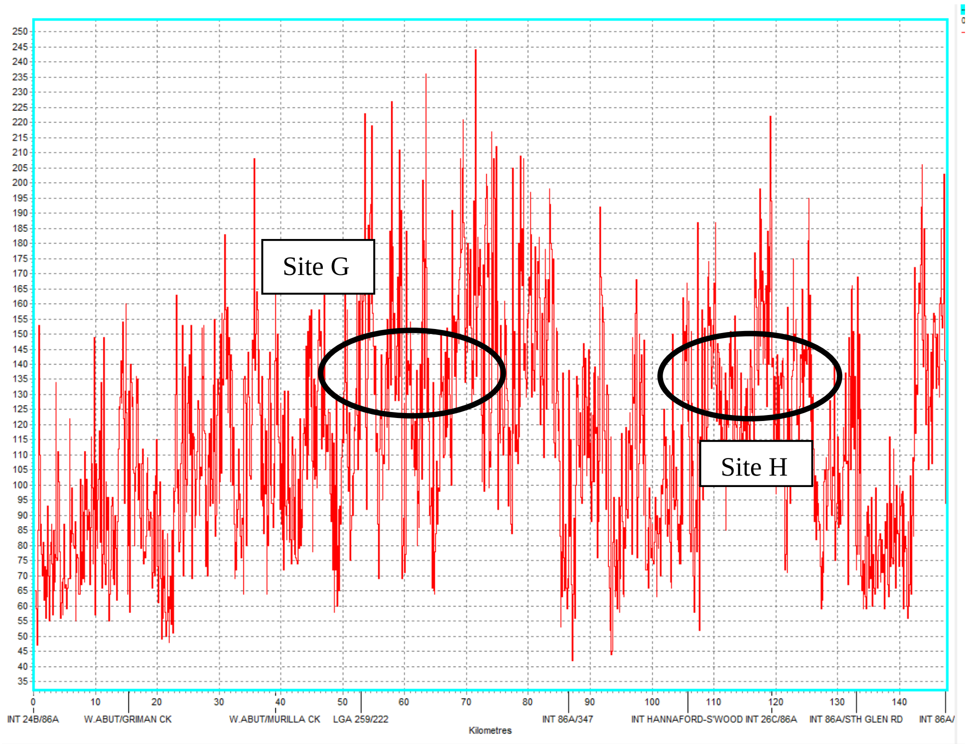

Figure 45: Roughness on the Surat Developmental Road (Sourced from Chartview, QDTMR 2014b)

There are many mitigating treatments which can be utilised on this road, to prevent or minimise incidents occurring from driver fatigue. Initiatives such as the driver reviver are unfeasible in this location, due to its remote location and low traffic volumes. Options for this remote area which are cost effective include the installation of fatigue prevention signs. These are located on many roads around South East Queensland where driver fatigue has been identified and range from driver quizzes (Bruce Highway) to limericks about safety and driver fatigue (New England Highway). Other options include installing Audio Tactile Line Marking (ATLM) treatment, to prevent run off road crash types. These are more expensive, and further investigations will be required to determine whether the cost to benefit ratio proves this treatment to be worthwhile.

5.2 Effect of Mining Vehicles on Crash Rates and Speed Data

In recent years, a wide area of the Downs South West Region has been influenced by the increase in traffic volumes due to the Clarence- Moreton Basin and Surat Basin Mining of Coal Seal Gas (See Figure 46). This industry has created significant growth to some roads including the Warrego Highway, and other state roads particularly those west of Dalby such as Dalby-Kogan Road and Chinchilla Tara Road (both have been analysed in the model). On these roads which directly service the gas sites, a significant proportion of the traffic is industry vehicles. These are generally trucks transporting goods to the sites, company four-wheel drives and even buses computing workers from nearby towns. The mining industry has a stringent approach to staff safety, and many companies install speed detection radar through GPS navigation. These GPS devices record and store the travelling speeds of work vehicles, and is paired with a strict policy to adhere to the posted speed limit. This workplace regulation is even evident in speed data collected in the coal seam gas region.

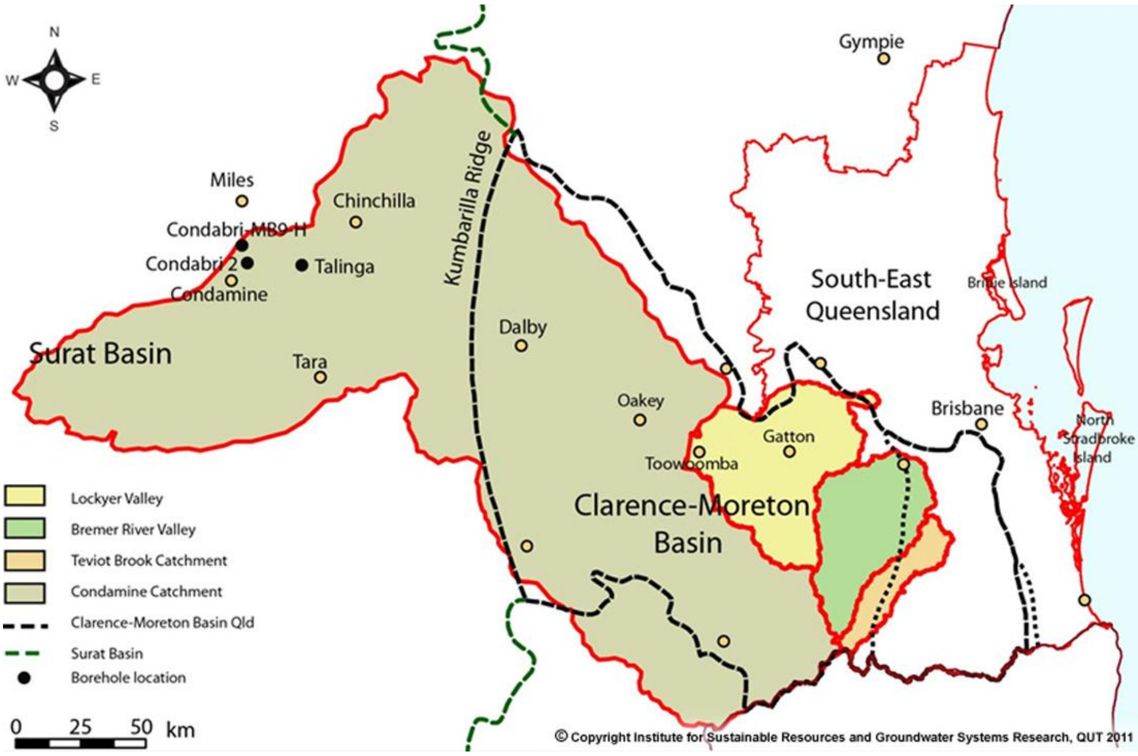

Figure 46: Mining Basins in the Downs South West Region (Cox 2014)

5.2.1 Daily Speed Data on the Dalby Kogan Rd

Dalby Kogan Rd is an arterial road which services many coal seal gas sites and related industries. It is evident from onsite investigations that large components of the traffic volumes are made up of company vehicles and trucks. The posted speed limit is 100km/hr. A speed count completed at Ch. 39.17km, highlights the effect on the mining industry on speed data. Between the hours of 6am to 5pm on Monday to Friday, there is 100% driver compliance. Outside these general working hours the V85 speed jumps to 100-110km/hr, generally in the early morning about 5am, and evenings at about 7pm-9pm. On weekends, there seems to be little pattern to the compliance levels, where some hours record a V85 speed of less than 100km/hr and others exceed the posted speed. The weekly speed data for this site is available in Appendix E.

The roughness at this location is shown in Table 12 below, in 1km segments. It is evident that the roughness around the speed survey location is generally high as it ranges around the 115 to 140counts/km. This may affect the speed of the vehicles through this section. This may explain why on weekends, and outside work hours, there isn't an extremely high increase from the posted 100km/hr limit. It also may explain the behaviour of non-mining local vehicles using this road.

This effect on the V85 speed is important, as the V85 speed is used to determine the design speed on some projects. If a large volume of monitored vehicles use a road temporarily and the speed data is collected during this time, it may convey a lower V85 speed then the actual speed in the long term. Investigations into the 85th percentile speed and the reasons behind the data are important to investigate before adopting the value for design purposes.

Table 12: Roughness at Speed Data Location

Start Chainage	End Chainage	Roughness (NRM) counts/km
36.00	37.00	138
37.00	38.00	117
38.00	39.00	115
39.00	40.00	114
40.00	41.00	123
41.00	42.00	140
42.00	43.00	102

5.3 Cost Comparison Analysis

5.3.1 Improving Roughness on Queensland Roads

From the models investigating the effects of roughness on speed and safety, it is evident that decreasing the roughness, especially in high roughness locations, will have a positive effect on driver's safety. Therefore, investigating the costs to improve the road's roughness is warranted.

There are many ways to improve the road's pavement to achieve a lower roughness value. This treatment depends on the amount of funding available and the type of treatment required to rectify the pavement failure/cause of high roughness. In Australia, road authorities have routine maintenance schedules and funding for periodic maintenance and resealing. In the various public services there is strong competition for funding, and this is also evident within the traffic authority itself, with a heavy emphasis on prioritising. Traffic authorities (particularly in Australian states such as Queensland and New South Wales) have competition of funds between the metropolitan, high trafficked urban areas, and the rural areas which define the state's economy. With such a high importance on spending funds in the right areas, some rural roads within the analysis may be considered less important than other roads in the state.

To improve the pavement quality on rough roads (for example a roughness value of 120 counts/km or greater) there are three main treatments to investigate. These include pavement rehabilitation including either a thin asphalt overlay or insitu stabilisation treatment, or a pavement replacement including full pavement reconstruction treatment. When used in the correct scenario, each of these treatment methods can decrease the roughness to approximately 50-80 counts/km (depending on original roughness, and the many factors which effect roughness i.e. construction quality, moisture penetration etc.). Table 13 investigates the treatment methods available to improve the pavement roughness.

Table 13: Types of Pavement Treatment to improve Roughness

Treatment Type	Pavement rehabilitation : Thin Asphalt Overlay	Pavement Replacement: Full Pavement Reconstruction	Pavement Rehabilitation : Insitu Stabilisation
Description	Works include a Reseal and Thin Asphalt Overlay.	Excavate and box out to subgrade level, then stabilise subgrade and reconstruct pavement with new material.	Reuse existing materials using stabilisation techniques. This treatment often includes the addition of shape correction gravel (typically 50mm – 100mm).
Cost (approximate)	$20-30/m^2$ (Reseal $7/m2 + Asphalt $13 = $23/m2 depending on location)	$90-130/m^2$	$50-60/m^2$
Effectiveness	Suitable for low amplitude, high frequency roughness (or 'chattery roughness'). Very effective treatment if completed at a suitable time (cannot be too cracked, or subgrade deteriorated otherwise ineffective treatment).	Suitable for almost all cases of roughness. Use of good quality materials and construction techniques should give pavement a long design life. A cost effective solution when moisture has penetrated the subbase and subgrade (therefore roughness issues are present in these layers).	This treatment includes 50-100mm of shape correction gravel (placed on top of existing pavement), and insitu stabilisation to a full depth (between 250mm and 300mm depending on existing pavement depth). The insitu stabilisation includes pulverising the new gravel, existing seal, and existing gravel underneath. Then a stabilising agent is added (perhaps cement, lime, fly ash or slag). This is specialised treatment, useful in only suitable situations (soil type and so on). In scenarios where it is suitable, this technique usually effective.

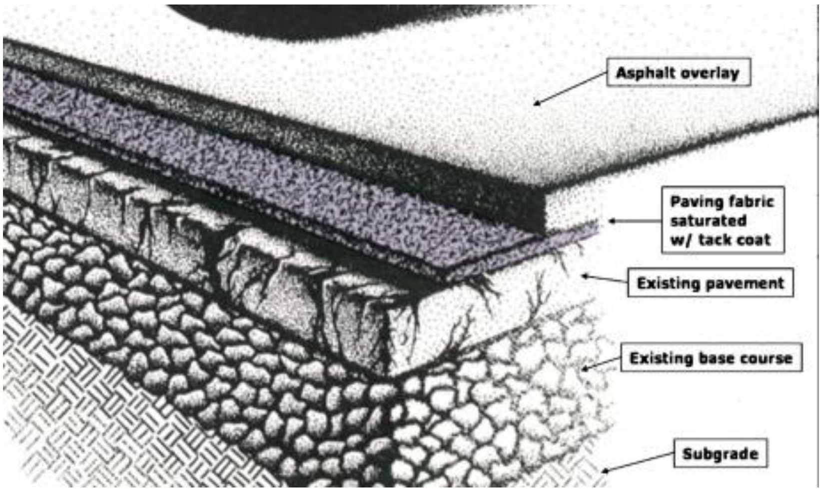

Figure 47: Asphalt Overlay with Fabric seal (Bygness et.al. 2006)

Figure 47 highlights an overlay asphalt treatment (with a fabric seal). The existing pavement, base course and subgrade remain, unlike the full pavement reconstruction where this material is all removed. The overlay treatment involves a tack coat (which allows adhesion between the existing seal and the new asphalt seal). If a fabric seal is a part of the pavement design, then this is acts as a middle layer and is applied after the tack coat, and before the asphalt seal.

Costs in Ttable 13 are indicative only, and represent the total cost of the works for general programming purposes, rather than the additional construction costs such as design, contract administration and contingencies, plus any additional or specialised works such as replacement of culverts, signage, alignment modifications etc.

The cost of replacing a 10km stretch of 8m wide formation (2 x 3.5m lanes, 2 x 0.5m shoulders) is calculated below, for each of the three treatment types. The design life of the pavement (in the case of pavement replacement works) is usually site-specific, but may range to 10 or 20 years. If pavement replacement is chosen, the seal will last between 5 and 10 years, depending on the condition of the subgrade.

Table 14: Treatment costs for 10km of repairs

Treatment	Cost (8m x 10000m = 80000m^2)
Pavement rehabilitation : Thin Asphalt	\$1.6million – \$2.4million
Pavement Replacement: Full Pavement Reconstruction	\$7.9million – \$10.4million
Pavement Rehabilitation : Insitu Stabilisation	\$4million - \$4.8million

5.3.2: Site Examples

The Moonie Highway was one of the roads analysed in all models within this dissertation. The cost of crashes over the last five years has cost society \$70,460/kilometre on this road, from Table 8. This cost is one of the cheapest costs of all the roads analysed. Over ten kilometres, this cost \$704,600. In comparison, the cost to treating the roughness on this road is \$2 - \$9 million (as the seal with is currently 8m) which may last for 10 to 20 years (depending on location parameters i.e. soil, and treatment type). Based on crash costs alone, the treatment is more expensive than the costs to society. On the Moonie Highway, there are generally high roughness values and this road is a very lengthy. Therefore, fixing an isolated section on the Moonie Highway may not be as beneficial as fixing sections in other areas. Drivers may identify that this road is generally a little rougher than expected, and therefore modify their driving approach to suit these conditions. Generally, a road with satisfactory parameters which are consistent throughout is desired by road design engineers, rather than a varied standard (i.e. changing from 9m to 6m seal width), to send a uniform standard to drivers on that road. Given the site conditions, general routine maintenance may be the best way to address the roughness on the Moonie Highway.

Another road analysed was the Gatton- Clifton Road, which has a much higher crash cost per kilometre, of \$471,036/km. Over ten kilometres, this cost is \$4.7 million to society. As the Gatton-Clifton Road has a seal width of 6.5m, the treatment costs are reduced from Table 14 above, to approximately \$1.5 million for pavement rehabilitation using thin asphalt, and \$6.6million for full pavement reconstruction. In this scenario, there is one section of high roughness, which also coincides with significant crash history. It would be beneficial to investigate and design the pavement treatment here, as the costs to improve the roughness are comparable to the cost of crashes to society. Note that due to the additional safety work that may be required, such as widening clearzones, or modifying the alignment to improve horizontal curves, there will be additional construction costs. This cost is not incorporated into the model, as they are site specific and required detailed in-depth analysis.

When comparing the Moonie Highway (Dalby- St. George) with the Gatton Clifton Road, it is evident that spending funds on the Gatton Clifton Road would be more beneficial to upgrade the road network as a whole, and to provide a safer road system. This comparison has only analysed the parameters investigated in the models, and there may be external reasons as to a change in funding prioritisation. While the Moonie Highway has a slightly higher AADT, the investigations on the Gatton Clifton Road highlight the correlation between roughness, clearzone width and curves, with crash risk. Furthermore, the rough section on the Gatton-Clifton road is unlike the rest of the road. To achieve a consistent standard of road quality along this road, it is essential to complete further upgrade projects through this section.

Chapter 6: Result Analysis

This section investigates all the models analysed in Chapter 4 and 5 and investigates the trends of these models. The assumptions and limitations of the models are also investigated.

6.1 Assumptions and Limitations

Throughout this model, there have been a range of assumptions and limitations taken into account. The majority of these surround the data collected through the Queensland DTMR databases, including the methods of collection and accuracy of the results. Due to the three main elements of this investigation (roughness, speed and crash data), all being tested, collected and inputted by a number of different people, it is subject to human or mechanical error. Other elements such as AADT and seal width dimensions may also be subject to inaccuracies. Such inaccuracies may be using out-of-date information, made redundant by a recent surge in traffic volumes, a spike in crashes or increased pavement deterioration. It is assumed that all testing equipment is calibrated correctly and that the machines are gaining and interpreting data correctly (pneumatic tube counters or permanent counters for speed and AADT data or laser profilometer for roughness). Limitations of the model surround the assumption that all data is gathered in homogenous conditions. This is unlikely, due to ever changing weather conditions which may affect roughness lasers, and that the roadway has no external factors affecting the data (such as rubbish, road kill and spilt loads).

Another assumption is the homogeneity of the model. When comparing roughness to crash rates or speed data, it is assumed that other factors that may affect these parameters are constants. This is not the case in reality as all roads have varying seal widths, pavement types, surrounding features, etc. However some measures have been taken to minimise the variance between each road, such as choosing all rural roads and omitting residential/commercial areas and intersections from the analysis.

Limitations of the model involve the constrictions of the data and the model. Only the parameters investigated in the models can be analysed. For example, there are many elements that may cause crashes. Only the causes investigated in this model have been considered. Adverse weather is a factor of crashes, which has generally not been analysed in the models, and therefore this external factor is not included. While there are a range of factors that influence and cause crashes, this model investigates the relationship between roughness and crash history. The model shows the relationships between these parameters, and makes conclusions that roughness is a contributing factor (rather that the sole cause). Roughness as a causal factor of crashes is difficult to prove and record. Some crashes in the model will be affected directly by the road roughness, and others will not, and the magnitude of this effect is investigated in this research. Therefore, the model effectively investigates crash rate over varying roughness values.

6.2 Results Analysis

From the range of models in Chapter 4 and 5 of this dissertation and from the literature review in Chapter 2 of this topic, the trends, abnormalities and findings are highlighted. These are discussed below:

- The State roads as a part of the Downs South West region have generally satisfactory standards in terms of pavement roughness. The majority of the roads have a roughness between 61 and 105counts/km (which are the Q1 and Q3 values - 25th percentile and 75% percentile of the data distribution). 24% of the regions roads have higher roughness than 110counts/km, these roads exceed the roughness levels in Austroads standards for highways and main roads.
- In section 4.3.1, it was concluded that generally crash segments have higher pavement roughness then segments without crash history. This indicates that roughness is one of the many factors which contribute to crashes.
- The crash analysis on each length of roadway, found a distinct increase in crash rate per million VKT when the roughness increased. This relationship was particularly significant for the crash severity category of hospitalisation and property damage, as seen in section 4.3.2. Crashes which resulted in hospitalisation or property damage had the steepest increase in crash rate per million VKT, when graphed against roughness. All other crash severity types found a correlation between increasing crash rate and increasing roughness.
- The model comparing roughness with each crash in the model (either in 100m or 1km segments), resulted in little correlation between these parameters. The effect of AADT and length may have retarded the results, as there is a very small frequency of crashes in each segment analysed (100m or 1km).
- It was evident that 100m segments are too small to properly represent roughness values, making 1km segments a better representation. A segment length of 1km is used both to accommodate for the roughness to be able to have an effect on the drivers speed and their safety, and also to accommodate for any inaccuracies on crash data chainages.
- The model of crashes (per 1km segments) based on crash produced some correlations, but these correlations were not strong enough to support any conclusions between roughness and accident rate.

- The model of crashes in 1km segments against crash rate provided a better correlation when investigated per road. When investigating the Toowoomba Cecil Plains Road, a strong correlation between increasing roughness and higher crash rate was evident. This strong correlation was not seen in all roads in the model.
- When calculating crash rate, it was found that using Method B and C and not factoring crashes according to crash type, yields the optimum data for the model. Method A provides alternative results, as the crash risk score is factored into the crash rate, however this model provides different results due to the factoring by the type of crash. This creates issues where comparing these values to the roughness at the crash location.
- It is evident that heavy vehicle crash rates are less affected by increasing roughness, than light vehicles crash rates.
- By comparing the calculated crash rates with the critical crash rates (as specified in the MUTCD), it is evident that these crash rates are well below the levels specified in Appendix G. Therefore this suggests that the QDTMR safety and maintenance procedures effectively address safety issues.
- The speed analysis in section 4.4 highlights that for segments with roughness higher than 120counts/km, there is 100% speed compliance. Vehicles at these locations were recorded driving at 5-15km/hr under the posted speed limit. This decrease in travelling speed and evident driver discomfort has negative impacts on productivity on the trucking industry and motorists alike. Roads with roughness higher than 120counts/km should be investigated for rehabilitation treatment. If funding doesn’t allow for treatment or before works can commence, a temporary reduction of the posted speed may be warranted. Permanent speed reduction options can be investigated where there is a combination of safety issues, and a crash history or public complaints about safety risks. Reductions in speed would generally only be 10km/hr- 20km/hr under the current posted speed.
- Through case study analysis, it is apparent that vertical crests are not a significant factor which influences crash rate. This conclusion is based on a relatively small sample of roads, and a larger investigation would be required to confirm this trend.

- Horizontal curves may have an inverse effect on safety, particularly when combined with other design minima such as high pavement roughness.
- Distance from townships has been identified as another possible cause for higher crash rates in the case study models. This is only relevant to rural areas, and further investigations of similar locations at different distances from towns are required to support this theory. These crashes are fatigue related incidents, and where these types of crashes are identified there are a range of safety treatments which can be implemented.
- The compliance of the Mining Industry vehicles is affecting the 85th percentile speed within business hours (Monday to Friday, 6am to 5pm) on roads where their traffic volumes are high. This may vary the design speed that can be adopted for engineering projects (when based on this V85 speed).
- Pavement treatment options include pavement rehabilitation including thin asphalt overlay and insitu stabilisation, and pavement replacement which includes a full pavement reconstruction. Pavement treatment is more affordable, but will not rectify pavement roughness if the failure occurs in the subbase and subgrade levels. Pavement reconstruction is more expensive but is a suitable treatment for all roughness types.
- Cost comparison investigations find that in some situations the cost of crashes per kilometre is more costly than costs to rectify that section of pavement roughness to a satisfactory level. However, this is only applicable to long segments of high roughness. Treatment is cost effective for isolated rough lengths (say, up to 10km). If the length of roughness is a large percentage of the length of the road, than typically drivers are aware of the conditions throughout the road, and will adjust their driving behaviour accordingly. Long lengths of high roughness should be eventually addressed through routine maintenance scheduled in the area, by the traffic authority's maintenance planning systems. Short lengths of high roughness which coincide with high crash rates, should be repaired or replaced as soon as funding is available.

Each of the models in this investigation together with similar studies completed by researches around the globe, featured in Chapter 2, highlight the correlation between increasing roughness values and high crash rates. In some models this is more evident than others. Pavement roughness is an ongoing issue, which road authorities must continually investigate and schedule pavement maintenance for, to ensure a satisfactory level is provided to the community.

Chapter 7: Conclusion

7.1 Overall Conclusions

Through investigating 1570km on 17 roads in the Downs South West Region of Queensland, Australia, a collection of models have indicated that road roughness does effect traffic speed and road safety. Each project objective has contributed to the final conclusions describing the effect of road roughness on traffic speed and road safety.

Road safety is of utmost important to all traffic authorities, and therefore is a key component of this dissertation. From all the models completed, it is evident that increasing road roughness increases the risk of crashes for all types of crash severity. The overall conclusions are similar to both the Australian and International studies and standards which discuss roughness and safety. However, the results presented in this dissertation differ slightly from the few studies which have completed similar models. While the only Australian study, completed in Victoria, depicts an exponential relationship for rural roads, this model shows a linear relationship between crash rate and roughness. This contradicts the Victorian result which shows that there is a substantial increase in crash rate after a particular roughness value has been exceeded. The model also shows a higher increase in accident rate with increasing roughness than the Swedish model in Figure 9, for similar AADT ranges. This suggests that Australian roads are more dangerous than the Swedish roads with the same roughness. This may be due to external contributing factors, such as longer road lengths between towns which may cause more fatigue related crashes and lower quality on rural roads for example narrower seal widths. Therefore, in Queensland the relationship between roughness and crash rate is linear and more severe than the Swedish results.

Traffic speed is the other main parameter investigated with changing roughness, as it indicates driver behaviour. The model also found that roughness levels above 120counts/km NRM decreases the operating speed of vehicles to about 10km/hr under the posted speed. This disadvantages the driver, leading to driver confusion and time delays, which is especially problematic for the trucking industry. It also highlights the driver discomfort at roughness above 120 counts/km NRM, and acts as warning of a safety hazard. Roughness at or above this benchmark is unacceptable for significant lengths or on roads with high traffic volumes, and therefore repairs or maintenance is required at these locations. There are limited models that have investigated the operating speed with roughness, and therefore it is difficult to compare this result. In terms of guidelines for maintenance and inspection, this result is consistent with current standards. Austroads states the investigation level of roughness for highways and main roads at 100km/hr is 110counts/km NRM (Austroads 2007, p.18), while the Queensland Department of Transport and Main Roads indicates the 20 year vision for roughness below 110-130counts/km for rural road traffic volumes (Queensland Government 2010, p.7). Therefore, the benchmark of 120counts/km is adequate to apply on Queensland's rural roads.

As this model has established a relationship between increasing roughness and increasing crash rate, this information can be used to make our roads a safer place. By integrating the parameters of road safety, the road, the driving environment and the driver, and focusing on their relationships, traffic authorities can better understand the components that lead to crashes. With this understanding, crash prevention mechanisms can be delivered on the roads through road quality improvements implemented by traffic authorities, such as regular pavement inspection and maintenance. Additionally, funding prioritisation can be managed more efficiently and the effect of roughness can be incorporated into traffic engineering decisions. Details of safety improvements which can be applied by traffic authorities are listed in the recommendations.

7.2 Recommendations

The recommendations for this investigation are derived from the model results. The majority of recommendations can be applied in Traffic Authority decision making, or can be validated in further research. It is hoped that these recommendations can be implemented into traffic authority procedures, in order to make our road network a safer and more reliable transportation system for all users.

Recommendations from this dissertation include:

1. Ensuring each road authority has a suitable maintenance program, which addresses roughness among other factors. This routine maintenance would aim to inspect and prioritise maintenance on each road in the network, ensuring periodic analysis of pavement quality (particularly roughness). Maintenance works aim to reduce the roughness to approximately an IRI of 1.9m/km.
2. Implementing quality construction methods to optimise pavement life, by reducing the causes of roughness (poor construction techniques/materials, moisture penetration etc.) should be encouraged. This can be done through incentives to contractors, either monetary or otherwise, if they provide a suitable quality of pavement roughness over an agreed upon timeframe. The terms around this incentive would be agreed upon during the tendering phase, and clearly stated in contract documents.
3. When roughness is above 120counts/km for a segment of 2km of more, traffic authorities should prioritise repairs and can investigate the effects of reducing the posted speed due to the driver discomfort and safety risks. This could be implemented temporarily or permanently, depending on expected pavement maintenance timeframes and site situations, such as crash history, public complaints, reduced seal width, high traffic volumes or a combination of geometric design minima.
4. Investigating the main causes of crashes on the analysed road, and implementing safety mechanisms which address that issue. For example, where it is found that roughness contributes greatly to crashes, than pavement maintenance is beneficial. However, if more incidents are linked to fatigue or sight deficiency, these parameters can be addressed through anti-fatigue mechanisms (such as ATLM's or signs) and by increasing the sight deficiency by regrading a crest or installing mitigating treatments. Treat each situation independently, but

investigate the known contributors to crashes such as curves, sight distance and roughness.

5. Road Authorities may investigate the effect that mining vehicles have on the 85th percentile speeds in rural areas. If it is found that there is an effect, the adopted design speed must be adequately investigated to ensure it is representative of the long term traffic behaviour. The design speed can be reduced to the posted speed if onsite surveys show compliance and any mining vehicle activity is expected to be long term. If mining vehicles are in the area for the short term, a suitable design speed must be adopted to suit the traffic behaviour once mining industry activity decreases.
6. Rough routes with a high percentage of heavy vehicles, may be less impacted by the roughness than other routes with a lower percentage of heavy vehicles. This may be useful for prioritisation purposes, if two sites are similar in other parameters.
7. Continue adopting QDTMR approaches to safety, as the crash rates indicate that they are well below the critical level.

Each of these recommendations can be implemented by traffic authorities, together with specifications mentioned in Austroads guides and the MUTCD to create a safer road network for all users. These measures, combined with a range of other initiatives, will work together to decrease frequency and severity of crashes on the road network.

7.4 Further Research

There are many topics future researches could investigate on the topic of road roughness in relation to traffic speed and road safety. Further research in this area, may lead to better ways to increase the safety on our road network. These proposals were not completed in this analysis due to lack of information and timeframe limitations. Areas of future research include:

1. A wide-scale crash model study would be useful, as this model has been based on a small scale of roads, all with fairly similar site parameters. A model that included both rural and urban roads across a broader area may be able to suggest where the greatest effect of roughness occurs. This model may also investigate if there are differences in urban environments compared to rural environments.
2. A larger model on the link between roughness and speed, to confirm the recommended roughness of 120count/km. This further research is required to further understand and consolidate the results found in this model, and others in the literature review.
3. Studies investigating the effect of other road parameters, and the effect that has on speed and road safety. A model such as this may find that parameters such as clearzone width or seal width have a correlation with speed and safety. These results compared with the relationship with roughness, may be useful in prioritising traffic authority funds (should a reseal of a rough section be completed, or should the seal be widened?).

Further information will allow traffic authorities to make more informed decisions regarding funding prioritisation and ultimately improve the safety on the road network.

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Chapter 9: Appendices

Appendix A – Project Specification

University of Southern Queensland

FACULTY OF HEALTH, ENGINEERING AND SCIENCES

ENG 4111/ 4112 Research Project

PROJECT SPECIFICATION

FOR: **Bernie-Anne King**

TOPIC: The Effect of Road Roughness on Traffic Speed and Road Safety

SUPERVISOR: Ron Ayers

SPONSORSHIP: Queensland Department of Transport and Main Roads

PROJECT AIM: The project seeks to investigate the effect of road roughness on traffic speeds and road safety on state and federal roads in Southern Queensland.

PROGRAMME: (Issue C, 22/10/2014)

1. Research the topic of pavement roughness. This includes recording roughness, the parameters which effect roughness and the relationship of roughness between crash rate and speed.

2. Investigate the factors which influence speeds and road safety. Research the current methods in which roughness is treated by speed reviews, the relationship between speeding and crash rate, and the treatments used to improve road safety.

3. Attain traffic speed, pavement roughness and crash data on all declared roads in South-East Queensland. Ten to twenty appropriate roads will be selected for modelling (DTMR data).

4. From the crash history, calculate the crash rate. Investigate the roughness on the roads selected in relation to the crash rate and speed data. When investigating crash data consider heavy vehicles effect and investigate crash data by crash severity type.

5. Complete a case study analysis on roads of interest, and investigate the effect of external factors. Utilise site visits to accurately assess current road conditions.

6. Determine a roughness level where the operating speed is impacted. Analyse the effects of reducing/ changing posted speeds and methods of improving safety where high crash rates occur.

7. Produce results and evaluate all findings, and present these in a graphical or tabular format (as appropriate).

8. Complete an academic Dissertation providing conclusions and recommendations on the relationship between pavement roughness, speed compliance and road safety.

AGREED: BKing (Student)   [signature] (Supervisor)

Date 24/10/2014   24/10/2014

Examiner/ Co-examiner: ______________________

Appendix B – IRI to NRM

Table 15: Conversion Table between IRI and NRM roughness values (Austroads 2007, p.38)

NRM (counts/km)	**IRI** (m/km)		**IRI** (m/km)	**NRM** (counts/km)
20	0.8		1.0	25
30	1.2		1.5	38
40	1.6		2.0	52
50	1.9		2.5	65
60	2.3		3.0	78
70	2.7		3.5	91
80	3.1		4.0	105
90	3.4		4.5	118
100	3.8		5.0	131
110	4.2		5.5	144
120	4.6		6.0	158
130	5.0		6.5	171
140	5.3		7.0	184
150	5.7		7.5	197
160	6.1		8.0	211
170	6.5		8.5	224
180	6.8		9.0	237
190	7.2		9.5	250
200	7.6		10.0	264
210	8.0		12.0	317
220	8.4		14.0	370
230	8.7		16.0	423
240	9.1		18.0	476
250	9.5		20.0	529

Note: IRI values are quarter car, i.e. IRIqc.

Appendix C – Analysis of Crash Data Tables

This table is used to determine the crash risk score, from Part 4 of the MUTCD.

Table 16: DCA crash risk scores (Queensland Government 2014a, p52).

TWO VEHICLE CRASHES				
DCA Code Group	DCA Codes	Description	Crash Risk Score $*10^4$ (Risk Unit) Low Speed (<80km/h)	Crash Risk Score $*10^4$ (Risk Unit) High Speed (>=80km/h)
1	100-109	Intersection, from adjacent approaches	23	60
2	201, 501	Head on	57	192
3	202 - 206	Opposing vehicle turning	26	56
4	301 - 303	Rear end	15	26
5	305 - 307, 504	Lane change	18	27
6	308, 309	Parallel lanes, turning	19	40
7	207, 304	U-turn	29	47
8	401, 406 - 408	Entering roadway	21	64
9	503, 505, 506	Overtaking, same direction	29	71
10	402, 404, 601, 602, 604, 608	Hit parked vehicle	20	49
11	903	Hit railway train	93	234
SINGLE VEHICLE CRASHES				
12	001-009	Pedestrian	44	169
13	605	Permanent obstruction on carriageway	13	15
14	609, 905	Hit animal	25	31
15	502, 701, 702, 706, 707	Off carriageway on straight	32	53
16	703, 704, 904	Off carriageway on straight hit object	34	53
17	705	Out of control on straight	23	51
18	801, 802	Off carriageway on curve	41	41
19	803, 804	Off carriageway on curve hit object	46	75
20	805, 806, 807	Out of control on curve	44	49

Appendix D – Results from Crash Study

The following graphs are a part of Section 4.3.3, and have been discussed generally in this section.

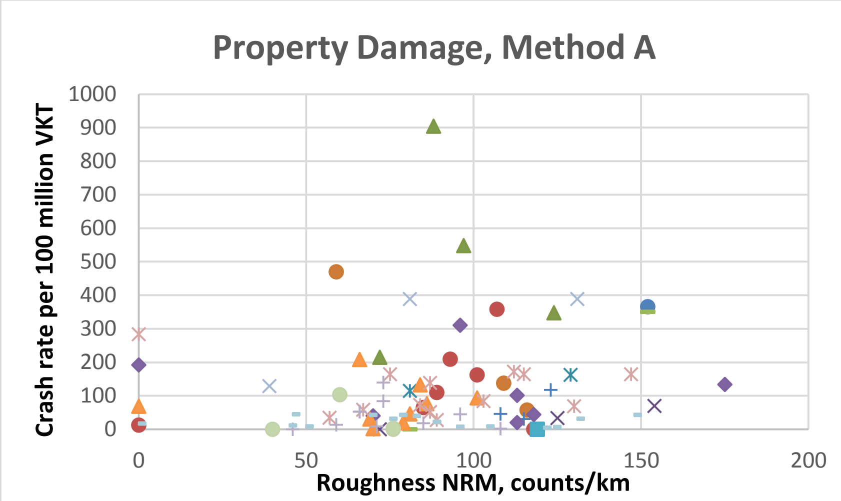

Figure 48: Crash rate of Property Damage using Method A

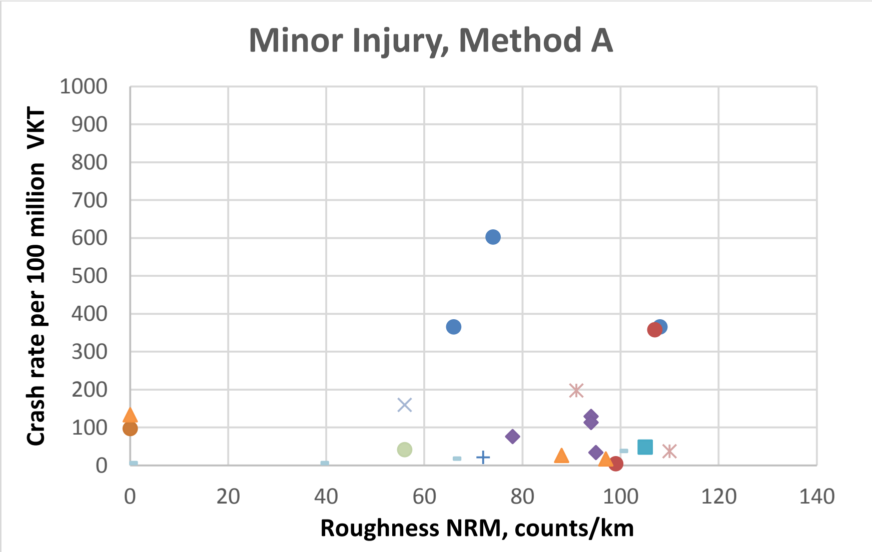

Figure 49: Crash rate of Minor Injury using Method A

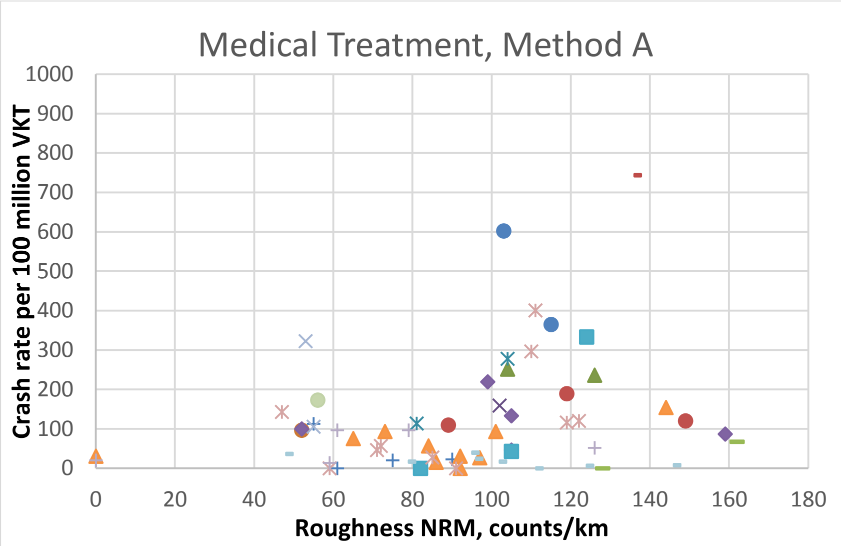

Figure 50: Crash rate of Medical Treatment using Method A

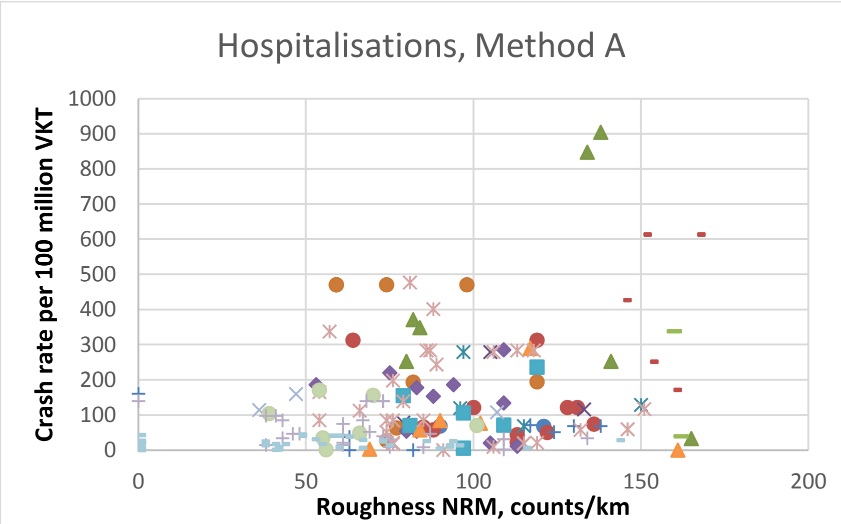

Figure 51: Crash rate of Hospitalisations using Method A

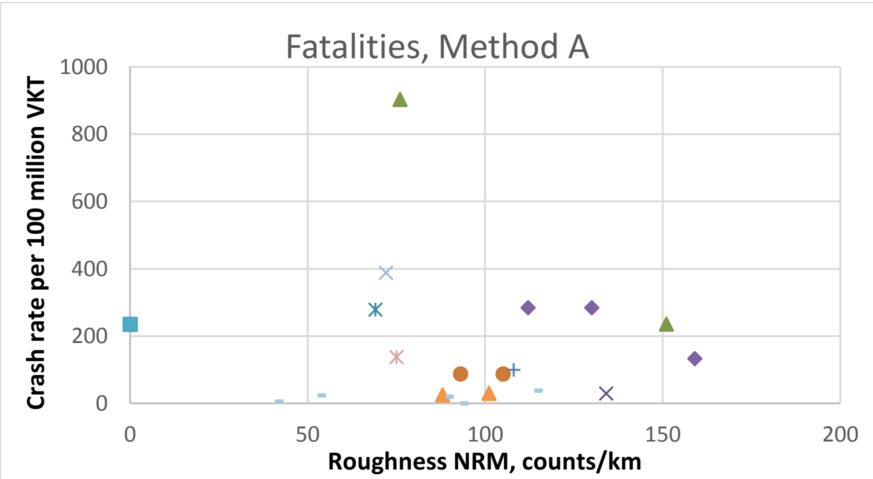

Figure 52: Crash rate of Fatalities using Method A

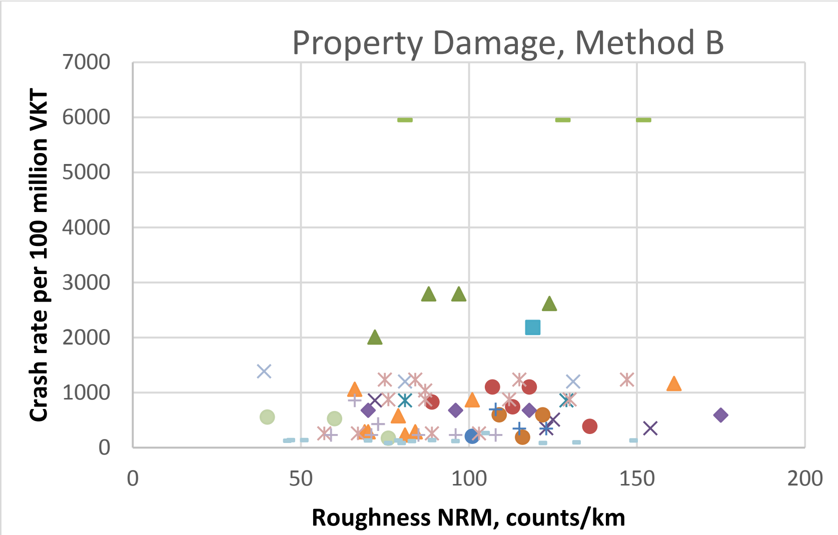

Figure 53: Crash Rate for Property Damage using Method B

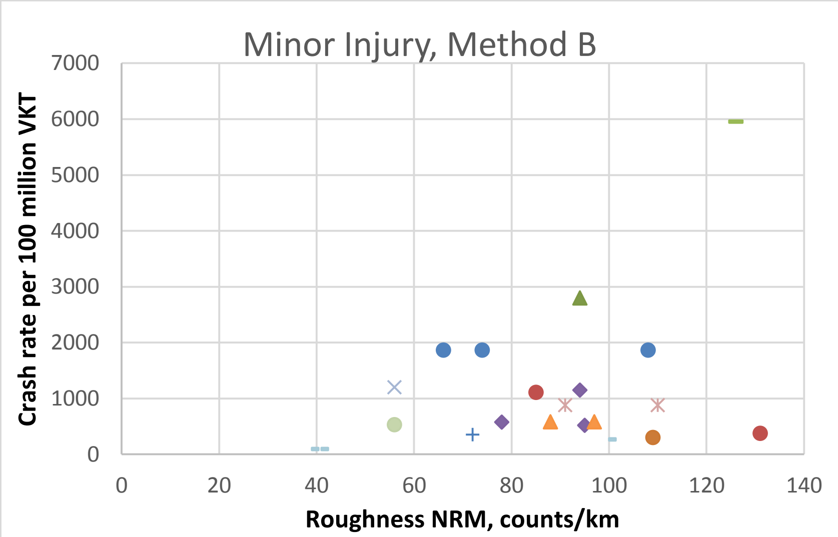

Figure 54: Crash Rate for Minor Injury using Method B

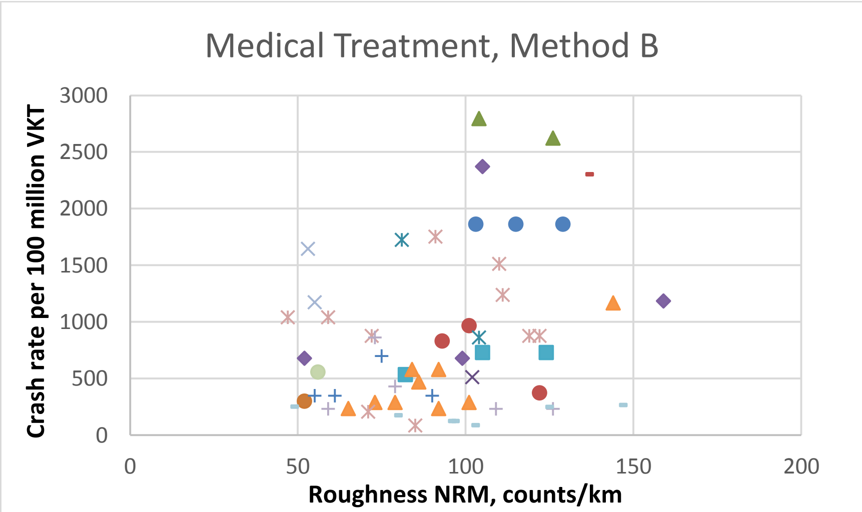

Figure 55: Crash Rate for Medical Treatment using Method B

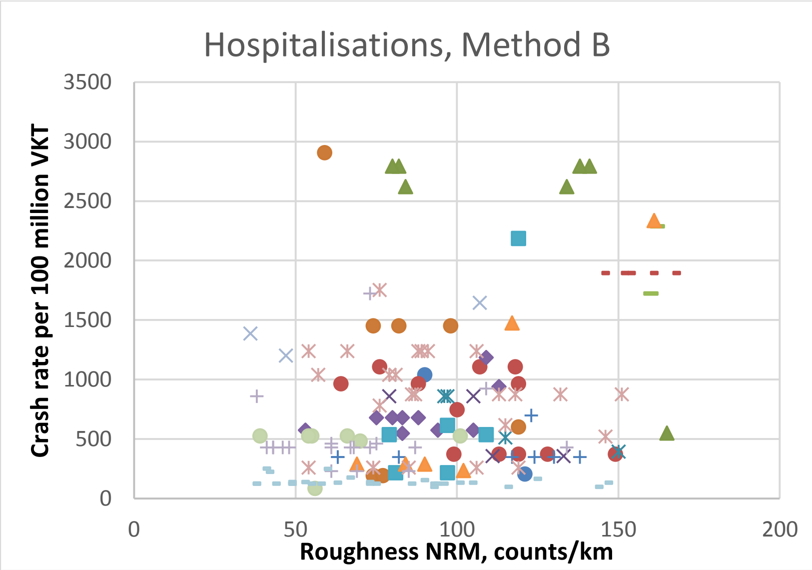

Figure 56: Crash Rate for Hospitalisations using Method B

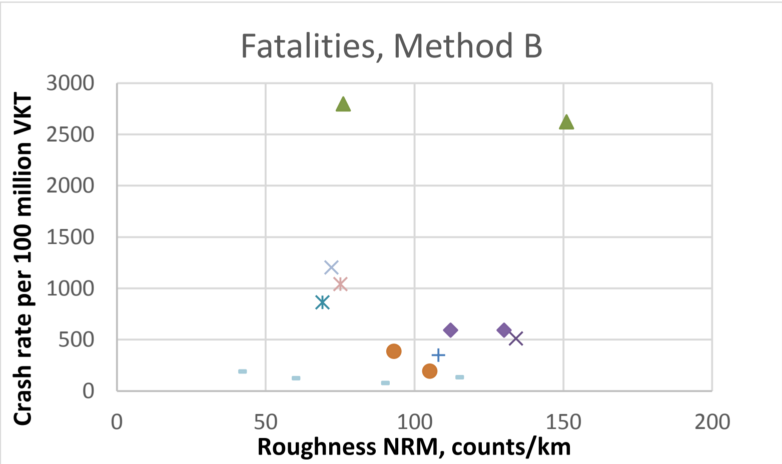

Figure 57: Crash Rate for Fatalities using Method B

Appendix E– Speed Compliance on Dalby Kogan RD

The attached information is the hourly speed counts completed on the Dalby Kogan Road in 2013 (QDTMR 2014g).

* Tuesday, 26 November 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0900	127	61	1	19	9	4	1	2	3	15	5	7	0	89.1	99.4
1000	134	69	4	22	13	3	0	0	0	15	7	1	0	89.7	100.1
1100	124	72	2	12	5	3	2	1	1	16	6	4	0	87.8	100.1
1200	100	58	1	12	9	1	0	1	0	11	7	0	0	89.3	101.2
1300	124	69	3	11	5	2	0	1	1	21	8	3	0	86.8	98.3
1400	125	68	0	14	8	5	0	1	1	16	10	2	0	85.7	97.6
1500	140	81	4	22	2	4	0	1	3	18	3	2	0	85.9	96.1
1600	137	83	5	23	1	1	0	0	1	14	7	2	0	91.0	99.4
1700	89	57	0	10	0	3	1	0	1	11	3	3	0	89.4	102.6
1800	53	38	1	6	2	0	0	1	1	3	0	1	0	96.7	104.4
1900	29	22	0	3	0	0	0	0	0	2	2	0	0	98.2	110.5
2000	8	3	1	1	1	0	0	0	0	0	2	0	0	83.5	–
2100	14	5	0	1	0	0	0	0	0	6	2	0	0	84.3	103.7
2200	7	2	0	1	0	0	0	0	0	2	2	0	0	85.5	–
2300	2	1	0	0	0	0	0	0	0	0	0	1	0	88.7	–
07–19	**1153**	**656**	**21**	**151**	**54**	**26**	**4**	**8**	**12**	**140**	**56**	**25**	**0**	**88.6**	**99.7**
06–22	**1204**	**686**	**22**	**156**	**55**	**26**	**4**	**8**	**12**	**148**	**62**	**25**	**0**	**88.8**	**100.1**
06–00	**1213**	**689**	**22**	**157**	**55**	**26**	**4**	**8**	**12**	**150**	**64**	**26**	**0**	**88.8**	**100.1**
00–00	**1213**	**689**	**22**	**157**	**55**	**26**	**4**	**8**	**12**	**150**	**64**	**26**	**0**	**88.8**	**100.1**

* Wednesday, 27 November 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	4	2	0	0	0	0	0	0	0	1	1	0	0	77.2	–
0100	3	2	0	0	0	0	0	0	0	1	0	0	0	74.1	–
0200	0	0	0	0	0	0	0	0	0	0	0	0	0	–	–
0300	2	2	0	0	0	0	0	0	0	0	0	0	0	83.3	–
0400	18	10	1	1	1	0	0	1	0	4	0	0	0	88.2	102.6
0500	62	48	1	8	2	0	0	0	0	2	1	0	0	96.1	102.6
0600	102	66	2	10	2	2	1	0	1	16	2	0	0	88.7	101.2
0700	115	65	4	13	6	2	3	1	0	8	11	2	0	89.3	100.4
0800	136	83	1	13	8	2	1	1	1	12	10	4	0	83.4	96.8
0900	122	60	2	17	5	1	3	1	0	18	11	4	0	85.7	100.1
1000	157	84	3	22	11	1	1	1	0	14	13	7	0	88.2	98.3
1100	118	68	2	16	4	2	0	1	1	8	11	5	0	89.8	100.1
1200	143	87	2	15	12	3	2	0	1	12	7	2	0	90.2	100.1
1300	113	61	1	16	2	1	1	0	2	18	8	3	0	88.5	99.7
1400	113	63	1	14	5	1	0	0	0	14	13	2	0	88.1	100.8
1500	139	80	3	14	2	3	2	0	0	20	10	5	0	87.2	100.4
1600	141	90	3	18	5	0	0	0	0	15	7	3	0	88.5	100.1
1700	128	88	0	17	5	1	0	1	0	9	2	5	0	91.8	102.2
1800	59	44	1	4	1	2	0	0	1	1	1	4	0	91.4	101.9
1900	37	32	0	1	0	0	0	0	0	4	0	0	0	95.6	109.8
2000	7	3	0	1	0	0	0	0	0	0	0	3	0	88.2	–
2100	11	7	0	0	0	0	0	0	0	2	0	2	0	88.7	98.6
2200	8	2	0	1	0	0	0	0	0	4	1	0	0	82.4	–
2300	12	3	2	2	0	0	0	0	0	4	1	0	0	78.2	84.2
07–19	**1484**	**873**	**23**	**179**	**66**	**19**	**13**	**6**	**6**	**149**	**104**	**46**	**0**	**88.3**	**100.4**
06–22	**1641**	**981**	**25**	**191**	**68**	**21**	**14**	**6**	**7**	**171**	**106**	**51**	**0**	**88.5**	**100.8**
06–00	**1661**	**986**	**27**	**194**	**68**	**21**	**14**	**6**	**7**	**179**	**108**	**51**	**0**	**88.4**	**100.4**
00–00	**1750**	**1050**	**29**	**203**	**71**	**21**	**14**	**7**	**7**	**187**	**110**	**51**	**0**	**88.6**	**100.8**

* Thursday, 28 November 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	1	0	0	0	0	0	0	0	0	1	0	0	0	98.6	-
0100	1	1	0	0	0	0	0	0	0	0	0	0	0	96.1	-
0200	3	1	0	0	2	0	0	0	0	0	0	0	0	81.3	-
0300	5	5	0	0	0	0	0	0	0	0	0	0	0	82.0	-
0400	19	13	1	1	0	0	1	0	0	3	0	0	0	79.5	92.2
0500	55	37	0	4	0	0	0	0	0	7	6	1	0	89.3	98.6
0600	117	74	4	15	1	2	0	1	0	14	3	3	0	90.5	101.5
0700	144	72	4	22	6	3	1	2	0	16	10	8	0	87.4	97.9
0800	109	54	2	10	3	4	4	0	0	14	10	8	0	83.0	96.8
0900	120	63	3	8	3	3	1	0	5	13	19	2	0	87.3	100.1
1000	128	63	1	13	7	3	3	1	0	22	7	8	0	84.7	98.6
1100	154	79	4	12	4	0	2	2	0	28	18	5	0	85.0	96.5
1200	105	55	1	16	5	2	2	1	0	11	8	4	0	88.8	100.8
1300	136	62	3	17	6	3	1	1	0	23	12	8	0	88.1	101.5
1400	100	49	4	14	5	3	1	0	0	11	7	6	0	87.6	99.7
1500	113	66	1	10	7	1	0	0	0	13	7	8	0	89.0	102.2
1600	127	80	4	15	5	1	0	0	0	8	9	5	0	89.8	101.2
1700	115	73	4	21	2	1	1	1	0	5	4	3	0	93.5	102.6
1800	61	40	3	8	3	1	0	0	0	5	0	1	0	92.3	101.5
1900	32	20	1	4	1	0	0	0	0	2	2	2	0	89.3	99.4
2000	16	8	2	4	0	0	0	0	0	1	0	1	0	79.9	90.4
2100	6	3	0	2	1	0	0	0	0	0	0	0	0	94.4	-
2200	3	3	0	0	0	0	0	0	0	0	0	0	0	98.0	-
2300	7	4	1	0	0	0	0	0	0	1	0	1	0	75.6	-
07-19	**1412**	**756**	**34**	**166**	**56**	**25**	**16**	**8**	**5**	**169**	**111**	**66**	**0**	**87.8**	**99.7**
06-22	**1583**	**861**	**41**	**191**	**59**	**27**	**16**	**9**	**5**	**186**	**116**	**72**	**0**	**88.0**	**100.1**
06-00	**1593**	**868**	**42**	**191**	**59**	**27**	**16**	**9**	**5**	**187**	**116**	**73**	**0**	**87.9**	**100.1**
00-00	**1677**	**925**	**43**	**196**	**61**	**27**	**17**	**9**	**5**	**198**	**122**	**74**	**0**	**87.9**	**99.7**

* Friday, 29 November 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	5	3	1	0	0	0	0	0	1	0	0	0	0	81.6	-
0100	3	2	0	0	0	0	0	0	0	1	0	0	0	88.1	-
0200	2	1	0	0	0	0	0	0	0	0	0	1	0	93.2	-
0300	4	2	0	1	0	0	0	0	0	0	0	1	0	67.9	-
0400	11	8	0	2	0	0	0	0	0	0	1	0	0	87.0	100.1
0500	72	54	0	6	1	0	0	0	0	10	0	1	0	94.5	101.2
0600	101	66	1	12	0	3	0	1	1	8	5	4	0	89.9	101.2
0700	114	54	4	10	5	4	1	1	0	18	13	4	0	87.4	99.0
0800	144	77	5	15	3	1	1	1	1	21	14	5	0	84.4	96.5
0900	113	56	2	10	3	3	1	0	1	19	12	6	0	85.9	97.9
1000	122	60	3	14	5	1	2	0	1	21	10	5	0	86.2	98.6
1100	131	60	4	19	3	0	1	1	0	25	14	4	0	88.3	99.0
1200	128	63	5	14	4	0	3	2	1	16	14	6	0	87.3	99.0
1300	107	54	3	13	6	0	1	0	0	14	10	6	0	89.9	100.8
1400	142	81	6	14	6	2	2	0	0	19	8	4	0	85.8	97.9
1500	117	65	4	12	4	3	1	1	0	11	11	5	0	90.2	99.7
1600	115	63	8	19	2	1	0	1	1	8	9	3	0	91.3	101.5
1700	83	62	1	9	1	3	0	2	0	3	1	1	0	92.8	101.2
1800	57	44	1	3	3	0	0	0	0	2	2	2	0	87.5	99.0
1900	38	24	0	5	1	0	0	1	0	6	1	0	0	86.4	100.8
2000	17	9	1	1	0	0	0	0	0	5	1	0	0	88.0	98.6
2100	8	2	1	0	0	0	0	0	0	5	0	0	0	78.7	-
2200	13	7	1	1	0	0	0	0	0	4	0	0	0	75.0	79.6
2300	4	1	1	0	0	0	0	0	0	2	0	0	0	77.3	-
07-19	**1373**	**739**	**46**	**152**	**45**	**18**	**13**	**9**	**5**	**177**	**118**	**51**	**0**	**87.8**	**99.0**
06-22	**1537**	**840**	**49**	**170**	**46**	**21**	**13**	**11**	**6**	**201**	**125**	**55**	**0**	**87.9**	**99.4**
06-00	**1554**	**848**	**51**	**171**	**46**	**21**	**13**	**11**	**6**	**207**	**125**	**55**	**0**	**87.8**	**99.4**
00-00	**1651**	**918**	**52**	**180**	**47**	**21**	**13**	**11**	**7**	**218**	**126**	**58**	**0**	**88.0**	**99.4**

* Saturday, 30 November 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	4	3	0	0	0	0	0	0	0	1	0	0	0	83.3	-
0100	3	3	0	0	0	0	0	0	0	0	0	0	0	75.9	-
0200	1	1	0	0	0	0	0	0	0	0	0	0	0	67.6	-
0300	1	0	0	1	0	0	0	0	0	0	0	0	0	60.7	-
0400	5	4	0	1	0	0	0	0	0	0	0	0	0	85.7	-
0500	45	34	1	4	1	0	0	0	0	3	2	0	0	83.9	96.8
0600	67	50	1	6	1	1	0	0	0	5	3	0	0	91.3	99.4
0700	69	36	2	9	4	0	1	0	0	11	5	1	0	81.5	101.2
0800	85	57	2	7	2	1	0	0	0	8	8	0	0	93.4	102.2
0900	66	35	0	10	5	1	0	0	0	7	8	0	0	89.8	99.0
1000	67	40	1	5	4	2	0	1	0	14	0	0	0	91.9	100.1
1100	86	53	0	9	1	2	1	0	0	15	5	0	0	91.7	101.9
1200	66	41	3	7	4	0	0	0	0	10	1	0	0	91.5	101.2
1300	61	39	3	5	4	1	0	0	1	7	1	0	0	91.6	99.7
1400	56	40	0	5	1	0	0	0	0	9	0	1	0	89.3	99.7
1500	63	41	1	9	3	0	0	0	0	9	0	0	0	89.3	99.4
1600	78	57	3	4	3	1	0	0	0	9	1	0	0	91.5	99.7
1700	56	42	5	5	1	0	1	0	0	1	1	0	0	91.2	103.7
1800	41	28	0	4	1	0	0	0	0	8	0	0	0	91.4	101.9
1900	21	12	0	2	0	0	0	1	0	5	1	0	0	91.1	105.1
2000	15	8	0	0	0	0	0	0	0	6	1	0	0	84.2	94.3
2100	30	18	3	3	0	0	0	0	0	6	0	0	0	82.3	93.2
2200	9	5	1	0	0	0	0	0	0	3	0	0	0	82.8	-
2300	13	2	0	1	0	0	0	0	0	10	0	0	0	85.0	91.4
07-19	**794**	**509**	**20**	**79**	**33**	**8**	**3**	**1**	**1**	**108**	**30**	**2**	**0**	**90.4**	**100.8**
06-22	**927**	**597**	**24**	**90**	**34**	**9**	**3**	**2**	**1**	**130**	**35**	**2**	**0**	**90.1**	**100.4**
06-00	**949**	**604**	**25**	**91**	**34**	**9**	**3**	**2**	**1**	**143**	**35**	**2**	**0**	**90.0**	**100.4**
00-00	**1008**	**649**	**26**	**97**	**35**	**9**	**3**	**2**	**1**	**147**	**37**	**2**	**0**	**89.6**	**100.4**

* Sunday, 1 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	6	0	0	0	0	0	0	0	0	6	0	0	0	84.2	-
0100	3	0	0	0	0	0	0	0	0	3	0	0	0	83.5	-
0200	8	0	0	0	0	0	0	0	0	8	0	0	0	80.0	-
0300	8	3	0	0	0	0	0	0	0	5	0	0	0	89.8	-
0400	5	3	0	1	0	0	0	0	0	1	0	0	0	92.5	-
0500	47	41	1	4	0	0	0	0	0	1	0	0	0	94.4	103.3
0600	42	31	0	3	0	0	0	0	0	7	1	0	0	91.9	100.8
0700	47	30	1	3	2	2	0	0	0	9	0	0	0	91.5	99.0
0800	40	21	3	5	2	1	0	0	0	5	2	1	0	90.7	101.9
0900	57	37	3	2	5	2	0	1	0	6	1	0	0	92.3	100.4
1000	68	44	4	5	2	0	0	1	0	9	2	1	0	90.7	100.4
1100	59	42	0	7	0	1	0	0	0	7	2	0	0	93.3	101.9
1200	66	41	4	6	1	2	0	0	1	10	1	0	0	90.0	101.9
1300	68	44	8	5	1	1	0	0	0	7	2	0	0	87.9	97.2
1400	50	29	1	4	0	1	0	1	0	11	3	0	0	91.9	103.7
1500	60	38	4	9	2	0	1	0	0	5	1	0	0	89.8	99.0
1600	89	62	5	11	2	0	0	1	0	3	5	0	0	93.8	101.9
1700	60	39	2	10	0	2	0	0	0	5	2	0	0	93.1	101.2
1800	32	21	1	2	0	0	0	0	0	8	0	0	0	89.9	99.4
1900	20	14	0	1	0	0	0	0	0	5	0	0	0	89.5	98.3
2000	22	9	3	1	1	0	0	0	0	8	0	0	0	87.4	94.3
2100	12	5	1	1	0	0	0	0	0	5	0	0	0	87.1	95.8
2200	16	5	1	0	0	0	0	0	1	9	0	0	0	86.2	97.2
2300	12	3	0	0	0	0	0	0	0	9	0	0	0	85.9	90.7
07-19	**696**	**448**	**36**	**69**	**17**	**12**	**1**	**4**	**1**	**85**	**21**	**2**	**0**	**91.3**	**101.2**
06-22	**792**	**507**	**40**	**75**	**18**	**12**	**1**	**4**	**1**	**110**	**22**	**2**	**0**	**91.1**	**100.8**
06-00	**820**	**515**	**41**	**75**	**18**	**12**	**1**	**4**	**2**	**128**	**22**	**2**	**0**	**91.0**	**100.4**
00-00	**897**	**562**	**42**	**80**	**18**	**12**	**1**	**4**	**2**	**152**	**22**	**2**	**0**	**91.0**	**100.4**

* Monday, 2 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	6	1	0	0	0	0	0	0	0	5	0	0	0	81.1	-
0100	10	1	2	0	0	0	0	0	0	7	0	0	0	82.1	-
0200	8	0	0	0	0	0	0	0	0	8	0	0	0	82.2	-
0300	5	2	0	1	0	0	0	0	0	2	0	0	0	84.3	-
0400	16	11	0	2	0	0	0	0	0	3	0	0	0	90.3	103.3
0500	71	57	4	6	0	0	0	0	0	4	0	0	0	96.6	104.8
0600	115	81	1	13	1	3	0	2	0	9	3	2	0	91.3	102.2
0700	100	62	4	10	1	0	2	0	1	9	7	4	0	87.7	97.6
0800	121	59	3	17	3	2	1	0	1	19	12	4	0	87.9	98.6
0900	127	67	2	14	3	1	0	0	1	20	13	6	0	86.2	100.1
1000	142	71	5	18	5	1	2	0	0	23	11	6	0	88.9	96.8
1100	105	49	3	14	7	1	1	0	0	14	13	3	0	88.1	96.8
1200	107	55	3	8	6	0	4	0	0	15	15	1	0	89.5	99.7
1300	128	59	3	17	6	1	0	0	1	21	11	9	0	86.1	98.6
1400	126	75	2	15	0	0	2	0	0	17	12	3	0	91.3	99.7
1500	94	49	3	11	3	1	0	0	1	10	9	7	0	86.4	97.9
1600	143	89	5	20	6	0	1	0	0	11	10	1	0	93.0	101.2
1700	113	77	5	13	0	5	1	0	0	1	10	1	0	93.1	101.5
1800	78	55	0	8	1	0	0	1	0	11	2	0	0	93.0	102.6
1900	27	15	3	3	1	0	0	0	0	4	0	1	0	90.9	103.3
2000	24	12	0	2	0	1	0	0	0	9	0	0	0	91.5	101.2
2100	11	3	0	1	0	0	0	0	0	7	0	0	0	87.0	93.2
2200	11	1	0	0	1	0	0	0	0	8	1	0	0	83.2	87.5
2300	7	1	0	0	0	0	0	0	0	5	0	1	0	82.9	-
07-19	**1384**	**767**	**38**	**165**	**41**	**12**	**14**	**1**	**5**	**171**	**125**	**45**	**0**	**89.2**	**99.7**
06-22	**1561**	**878**	**42**	**184**	**43**	**16**	**14**	**3**	**5**	**200**	**128**	**48**	**0**	**89.4**	**100.1**
06-00	**1579**	**880**	**42**	**184**	**44**	**16**	**14**	**3**	**5**	**213**	**129**	**49**	**0**	**89.4**	**99.7**
00-00	**1695**	**952**	**48**	**193**	**44**	**16**	**14**	**3**	**5**	**242**	**129**	**49**	**0**	**89.6**	**100.1**

* Tuesday, 3 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	6	0	0	0	0	0	0	0	0	6	0	0	0	83.2	-
0100	4	0	0	0	0	0	0	0	0	4	0	0	0	86.3	-
0200	9	0	0	0	0	0	0	0	0	9	0	0	0	84.6	-
0300	5	2	0	0	0	0	0	1	0	2	0	0	0	86.7	-
0400	12	11	0	1	0	0	0	0	0	0	0	0	0	91.7	100.1
0500	81	61	1	11	0	0	0	0	0	4	3	1	0	93.7	102.6
0600	128	87	2	16	5	2	0	0	0	7	5	4	0	90.8	99.7
0700	128	72	5	10	10	1	2	0	0	8	16	4	0	89.3	99.7
0800	157	99	2	8	6	1	2	0	0	19	14	6	0	88.3	99.4
0900	119	68	2	9	3	2	1	2	1	14	17	0	0	90.4	100.4
1000	125	67	2	14	4	0	1	0	0	19	14	4	0	87.8	97.9
1100	134	71	1	11	7	2	1	0	1	17	21	2	0	86.9	98.6
1200	149	77	1	17	5	4	2	0	2	12	25	4	0	84.2	96.8
1300	107	60	2	9	6	0	1	1	0	14	13	1	0	91.2	100.4
1400	98	59	1	12	2	1	1	1	0	7	13	1	0	91.2	101.5
1500	122	72	1	10	4	1	1	3	1	12	17	0	0	90.8	98.3
1600	160	111	5	11	3	0	0	2	0	13	12	3	0	90.6	100.4
1700	134	92	5	17	6	0	1	0	0	2	7	4	0	91.7	100.4
1800	57	36	2	8	1	0	0	0	0	4	5	1	0	94.5	103.0
1900	25	14	1	3	2	1	0	0	0	2	2	0	0	94.4	106.9
2000	13	7	0	2	1	0	0	0	0	0	3	0	0	91.7	101.2
2100	12	8	1	1	0	0	0	0	0	1	0	1	0	92.5	97.9
2200	8	4	0	0	0	0	0	0	0	2	0	2	0	72.7	-
2300	7	2	0	0	0	0	0	0	0	2	2	1	0	72.5	-
07-19	**1490**	**884**	**29**	**136**	**57**	**12**	**13**	**9**	**5**	**141**	**174**	**30**	**0**	**89.4**	**100.1**
06-22	**1668**	**1000**	**33**	**158**	**65**	**15**	**13**	**9**	**5**	**151**	**184**	**35**	**0**	**89.6**	**100.1**
06-00	**1683**	**1006**	**33**	**158**	**65**	**15**	**13**	**9**	**5**	**155**	**186**	**38**	**0**	**89.4**	**100.1**
00-00	**1800**	**1080**	**34**	**170**	**65**	**15**	**13**	**10**	**5**	**180**	**189**	**39**	**0**	**89.6**	**100.1**

* Wednesday, 4 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	4	3	0	0	0	0	0	0	0	0	1	0	0	90.9	–
0100	5	4	0	0	1	0	0	0	0	0	0	0	0	86.2	–
0200	2	0	0	2	0	0	0	0	0	0	0	0	0	87.7	–
0300	6	3	0	0	1	0	0	0	0	1	1	0	0	61.9	–
0400	11	6	0	0	0	0	0	0	0	3	2	0	0	88.3	97.2
0500	90	61	1	12	2	0	0	0	0	7	7	0	0	93.8	101.5
0600	131	81	3	10	6	2	0	1	0	8	16	4	0	88.0	98.3
0700	105	55	4	11	3	1	3	0	0	12	13	3	0	89.9	97.9
0800	135	71	2	13	3	2	1	1	0	12	26	4	0	89.4	99.7
0900	119	62	2	10	3	2	1	1	2	20	13	3	0	87.7	97.9
1000	162	85	4	10	7	6	4	0	1	21	24	0	0	85.4	99.4
1100	122	61	4	13	5	1	0	1	0	13	18	6	0	87.6	99.0
1200	153	91	3	13	6	1	2	0	2	19	16	0	0	88.1	99.0
1300	113	65	2	12	4	2	0	1	1	12	12	2	0	88.8	99.7
1400	133	73	1	15	5	2	0	2	0	13	20	2	0	87.2	97.2
1500	125	77	1	13	1	1	2	1	0	6	18	5	0	92.8	101.5
1600	135	96	4	13	4	0	0	0	0	8	7	3	0	92.2	99.7
1700	104	65	3	16	5	0	0	0	1	4	8	2	0	93.0	103.0
1800	52	43	0	1	2	1	0	0	0	1	4	0	0	95.3	104.4
1900	28	21	0	3	1	0	0	0	0	2	1	0	0	92.2	107.3
2000	11	10	1	0	0	0	0	0	0	0	0	0	0	89.8	95.4
2100	2	1	0	0	0	0	0	0	0	1	0	0	0	91.6	–
2200	7	6	0	0	0	0	0	0	0	1	0	0	0	91.2	–
2300	5	2	1	0	0	0	0	0	0	1	1	0	0	85.4	–
07-19	**1458**	**844**	**30**	**140**	**48**	**19**	**13**	**7**	**7**	**141**	**179**	**30**	**0**	**89.3**	**100.1**
06-22	**1630**	**957**	**34**	**153**	**55**	**21**	**13**	**8**	**7**	**152**	**196**	**34**	**0**	**89.3**	**100.1**
06-00	**1642**	**965**	**35**	**153**	**55**	**21**	**13**	**8**	**7**	**154**	**197**	**34**	**0**	**89.3**	**100.1**
00-00	**1760**	**1042**	**36**	**167**	**59**	**21**	**13**	**8**	**7**	**165**	**208**	**34**	**0**	**89.4**	**100.1**

* Thursday, 5 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	2	0	1	0	0	0	0	0	0	1	0	0	0	82.0	–
0100	2	2	0	0	0	0	0	0	0	0	0	0	0	105.0	–
0200	1	1	0	0	0	0	0	0	0	0	0	0	0	81.3	–
0300	4	2	1	0	0	0	0	0	0	1	0	0	0	95.4	–
0400	12	7	0	0	1	0	0	1	1	0	2	0	0	84.8	93.6
0500	100	64	1	7	3	0	0	0	0	12	12	1	0	92.8	101.5
0600	131	79	2	17	4	4	0	1	0	9	13	2	0	89.1	100.1
0700	129	71	1	12	8	1	2	0	1	15	15	3	0	85.6	98.6
0800	128	78	2	9	0	1	1	0	0	10	22	5	0	89.0	99.0
0900	120	60	2	12	3	2	2	1	0	23	12	3	0	88.3	98.6
1000	102	44	1	16	6	4	2	0	3	15	10	1	0	89.1	97.6
1100	127	74	3	11	5	1	1	0	0	14	15	3	0	90.4	100.4
1200	109	61	2	13	1	1	2	0	2	17	8	2	0	90.3	98.6
1300	159	85	5	17	4	2	0	0	0	21	19	6	0	84.4	97.6
1400	133	85	0	17	5	1	1	0	0	11	12	1	0	90.6	98.3
1500	119	61	0	13	4	3	2	0	0	18	15	3	0	90.3	100.1
1600	142	98	3	15	2	2	0	0	0	11	11	0	0	93.1	102.6
1700	126	83	1	13	6	2	0	1	1	6	12	1	0	93.4	102.6
1800	55	36	4	4	4	0	0	1	0	0	3	3	0	95.2	103.0
1900	24	15	1	3	0	1	1	0	0	2	1	0	0	91.6	106.9
2000	14	9	0	3	1	0	0	0	0	1	0	0	0	85.1	98.6
2100	17	13	0	1	1	0	0	0	1	1	0	0	0	86.9	94.0
2200	9	8	0	1	0	0	0	0	0	0	0	0	0	90.6	–
2300	4	3	0	1	0	0	0	0	0	0	0	0	0	93.1	–
07-19	**1449**	**836**	**24**	**152**	**48**	**20**	**13**	**3**	**7**	**161**	**154**	**31**	**0**	**89.6**	**99.7**
06-22	**1635**	**952**	**27**	**176**	**54**	**25**	**14**	**4**	**8**	**174**	**168**	**33**	**0**	**89.6**	**99.7**
06-00	**1648**	**963**	**27**	**178**	**54**	**25**	**14**	**4**	**8**	**174**	**168**	**33**	**0**	**89.6**	**99.7**
00-00	**1769**	**1039**	**30**	**185**	**58**	**25**	**14**	**5**	**9**	**188**	**182**	**34**	**0**	**89.7**	**100.1**

* Friday, 6 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	2	2	0	0	0	0	0	0	0	0	0	0	0	95.3	-
0100	1	1	0	0	0	0	0	0	0	0	0	0	0	91.7	-
0200	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-
0300	1	1	0	0	0	0	0	0	0	0	0	0	0	100.9	-
0400	15	9	0	0	1	0	0	0	0	4	1	0	0	91.2	100.1
0500	88	67	1	11	1	1	0	0	0	5	2	0	0	95.0	103.3
0600	103	63	1	19	1	0	0	2	3	7	7	0	0	89.4	101.9
0700	122	65	3	13	6	2	2	1	0	10	16	4	0	86.6	98.3
0800	145	79	3	14	2	1	1	0	0	15	26	4	0	88.3	98.3
0900	139	68	3	18	2	0	2	1	0	22	20	3	0	89.1	98.6
1000	116	55	1	12	6	2	2	1	3	16	16	2	0	89.7	99.7
1100	91	47	4	9	2	2	3	0	1	8	14	1	0	88.9	100.4
1200	119	67	3	15	2	1	2	1	0	13	13	2	0	90.9	100.1
1300	108	58	5	13	3	2	0	3	0	7	16	1	0	91.5	100.8
1400	110	72	0	10	3	2	2	2	0	14	1	4	0	88.9	100.4
1500	108	75	4	11	4	2	1	1	0	9	0	1	0	90.9	101.2
1600	128	80	8	19	10	0	1	0	0	7	2	1	0	91.6	100.8
1700	101	72	4	10	2	3	0	0	0	5	4	1	0	93.0	101.5
1800	54	43	0	3	1	1	1	0	1	3	0	1	0	94.9	103.3
1900	23	19	0	3	0	0	0	0	1	0	0	0	0	93.1	104.8
2000	17	12	1	1	1	1	0	0	0	0	0	1	0	92.0	105.1
2100	5	4	0	0	0	0	0	0	0	0	0	1	0	88.5	-
2200	12	11	1	0	0	0	0	0	0	0	0	0	0	85.3	97.9
2300	4	2	1	0	0	0	0	0	0	1	0	0	0	72.3	-
07-19	**1341**	**781**	**38**	**147**	**43**	**18**	**17**	**10**	**5**	**129**	**128**	**25**	**0**	**90.1**	**100.4**
06-22	**1489**	**879**	**40**	**170**	**45**	**19**	**17**	**12**	**9**	**136**	**135**	**27**	**0**	**90.1**	**100.4**
06-00	**1505**	**892**	**42**	**170**	**45**	**19**	**17**	**12**	**9**	**137**	**135**	**27**	**0**	**90.0**	**100.4**
00-00	**1612**	**972**	**43**	**181**	**47**	**20**	**17**	**12**	**9**	**146**	**138**	**27**	**0**	**90.3**	**100.8**

* Saturday, 7 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	3	3	0	0	0	0	0	0	0	0	0	0	0	89.7	-
0100	1	0	0	0	0	0	0	0	0	1	0	0	0	92.8	-
0200	2	2	0	0	0	0	0	0	0	0	0	0	0	82.3	-
0300	3	3	0	0	0	0	0	0	0	0	0	0	0	98.3	-
0400	8	7	0	1	0	0	0	0	0	0	0	0	0	93.7	-
0500	59	46	1	3	0	0	0	0	0	6	3	0	0	95.5	105.5
0600	73	48	3	7	0	0	0	0	0	4	10	1	0	92.4	102.2
0700	85	50	5	7	1	3	1	2	0	7	9	0	0	91.3	99.0
0800	88	53	4	7	3	1	0	0	1	13	5	1	0	88.5	99.4
0900	68	26	3	11	3	3	0	1	0	4	16	1	0	91.0	99.7
1000	63	31	1	15	2	0	1	0	0	9	2	2	0	89.0	99.7
1100	68	41	5	9	3	1	0	0	0	5	4	0	0	93.2	102.6
1200	102	54	8	16	5	2	0	1	0	12	3	1	0	89.9	100.1
1300	77	58	1	5	0	1	0	0	0	10	2	0	0	90.1	101.2
1400	83	51	3	12	5	3	0	0	0	8	1	0	0	89.7	99.0
1500	78	47	4	11	1	1	1	1	1	7	3	1	0	89.1	99.7
1600	71	55	3	9	0	0	0	0	1	2	1	0	0	92.3	102.2
1700	64	52	1	8	1	0	0	1	0	0	1	0	0	94.8	104.0
1800	35	30	0	3	1	0	0	0	0	0	1	0	0	93.4	99.4
1900	28	26	0	0	1	0	0	0	1	0	0	0	0	97.3	108.0
2000	5	2	0	2	0	0	0	0	0	1	0	0	0	86.6	-
2100	15	13	1	0	0	0	0	1	0	0	0	0	0	100.6	111.2
2200	5	3	0	1	0	0	0	0	0	1	0	0	0	84.4	-
2300	5	5	0	0	0	0	0	0	0	0	0	0	0	85.9	-
07-19	**882**	**548**	**38**	**113**	**25**	**15**	**3**	**6**	**3**	**77**	**48**	**6**	**0**	**90.8**	**101.2**
06-22	**1003**	**637**	**42**	**122**	**26**	**15**	**3**	**7**	**4**	**82**	**58**	**7**	**0**	**91.2**	**101.5**
06-00	**1013**	**645**	**42**	**123**	**26**	**15**	**3**	**7**	**4**	**83**	**58**	**7**	**0**	**91.2**	**101.5**
00-00	**1089**	**706**	**43**	**127**	**26**	**15**	**3**	**7**	**4**	**90**	**61**	**7**	**0**	**91.4**	**101.5**

* Sunday, 8 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	2	1	0	0	0	0	0	1	0	0	0	0	0	95.2	-
0100	2	2	0	0	0	0	0	0	0	0	0	0	0	73.9	-
0200	2	2	0	0	0	0	0	0	0	0	0	0	0	87.0	-
0300	2	2	0	0	0	0	0	0	0	0	0	0	0	81.6	-
0400	9	7	0	1	0	0	0	0	0	0	1	0	0	98.3	-
0500	54	37	1	7	0	0	0	0	0	4	5	0	0	95.6	101.9
0600	44	33	0	3	2	0	0	1	0	2	3	0	0	90.8	102.2
0700	52	36	2	5	1	2	1	0	1	2	1	1	0	93.7	100.1
0800	61	31	2	8	1	2	1	0	0	12	4	0	0	90.4	97.9
0900	66	41	1	9	3	0	0	1	1	7	2	1	0	89.4	98.3
1000	68	42	4	5	3	0	0	1	2	7	4	0	0	91.6	102.6
1100	66	39	2	6	2	2	0	2	0	11	2	0	0	90.7	100.4
1200	60	30	8	9	2	2	1	1	0	4	3	0	0	83.9	97.9
1300	63	32	3	9	1	0	1	2	1	8	5	1	0	89.4	101.2
1400	79	51	4	4	3	1	0	0	0	11	3	2	0	88.1	97.6
1500	63	37	1	10	2	1	0	1	0	9	2	0	0	88.4	100.4
1600	124	94	1	18	1	0	1	0	0	8	1	0	0	91.5	100.1
1700	59	43	3	10	0	0	0	1	0	2	0	0	0	95.1	105.5
1800	26	13	3	4	0	0	1	1	0	0	1	3	0	91.3	101.5
1900	19	14	1	2	2	0	0	0	0	0	0	0	0	93.7	103.7
2000	17	14	0	2	1	0	0	0	0	0	0	0	0	88.0	94.3
2100	11	5	2	0	0	1	0	0	0	3	0	0	0	86.9	95.0
2200	13	8	2	0	1	0	0	0	0	2	0	0	0	87.7	97.9
2300	3	2	1	0	0	0	0	0	0	0	0	0	0	84.7	-
07-19	**787**	**489**	**34**	**97**	**19**	**10**	**6**	**10**	**5**	**81**	**28**	**8**	**0**	**90.2**	**100.8**
06-22	**878**	**555**	**37**	**104**	**24**	**11**	**6**	**11**	**5**	**86**	**31**	**8**	**0**	**90.3**	**100.8**
06-00	**894**	**565**	**40**	**104**	**25**	**11**	**6**	**11**	**5**	**88**	**31**	**8**	**0**	**90.2**	**100.8**
00-00	**965**	**616**	**41**	**112**	**25**	**11**	**6**	**12**	**5**	**92**	**37**	**8**	**0**	**90.5**	**101.2**

* Monday, 9 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	3	2	0	1	0	0	0	0	0	0	0	0	0	97.6	-
0100	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-
0200	1	1	0	0	0	0	0	0	0	0	0	0	0	84.8	-
0300	3	3	0	0	0	0	0	0	0	0	0	0	0	73.1	-
0400	11	9	0	2	0	0	0	0	0	0	0	0	0	100.9	109.1
0500	68	55	0	5	0	2	0	0	0	6	0	0	0	97.2	103.3
0600	131	87	1	14	1	2	1	1	1	13	10	0	0	89.7	98.6
0700	77	41	1	4	3	3	3	0	0	13	8	1	0	85.2	99.0
0800	119	65	8	16	2	2	2	0	0	12	12	0	0	87.2	96.5
0900	92	39	4	14	1	3	1	0	1	24	5	0	0	88.6	100.1
1000	76	48	1	8	4	0	1	1	1	5	4	3	0	88.6	99.0
1100	92	51	3	7	3	1	1	0	0	19	6	1	0	86.5	96.5
1200	111	66	2	17	2	0	2	1	0	12	9	0	0	88.3	97.2
1300	115	61	1	14	5	2	0	0	2	17	9	4	0	89.4	97.6
1400	92	61	2	8	3	1	2	1	0	5	8	1	0	92.6	100.1
1500	94	62	1	11	4	0	1	0	0	9	6	0	0	90.4	99.4
1600	125	91	3	15	3	0	0	1	0	9	3	0	0	90.7	99.4
1700	103	70	1	14	1	2	1	1	2	9	1	1	0	93.6	103.3
1800	57	42	1	4	2	1	0	1	0	3	2	1	0	91.3	101.2
1900	19	14	0	0	1	0	0	0	0	2	1	1	0	93.3	100.4
2000	14	10	0	4	0	0	0	0	0	0	0	0	0	93.0	104.8
2100	8	4	1	1	0	0	0	0	0	2	0	0	0	84.5	-
2200	5	3	1	0	0	0	0	0	0	0	1	0	0	88.4	-
2300	7	3	0	0	0	0	0	0	0	0	4	0	0	82.2	-
07-19	**1153**	**697**	**28**	**132**	**33**	**15**	**14**	**6**	**6**	**137**	**73**	**12**	**0**	**89.4**	**99.7**
06-22	**1325**	**812**	**30**	**151**	**35**	**17**	**15**	**7**	**7**	**154**	**84**	**13**	**0**	**89.5**	**99.7**
06-00	**1337**	**818**	**31**	**151**	**35**	**17**	**15**	**7**	**7**	**154**	**89**	**13**	**0**	**89.5**	**99.4**
00-00	**1423**	**888**	**31**	**159**	**35**	**19**	**15**	**7**	**7**	**160**	**89**	**13**	**0**	**89.9**	**99.7**

* Tuesday, 10 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	2	0	0	0	0	0	0	0	0	1	0	1	0	83.8	-
0100	3	2	0	0	0	0	0	0	0	1	0	0	0	67.0	-
0200	1	0	0	0	0	0	0	0	0	0	1	0	0	92.6	-
0300	2	2	0	0	0	0	0	0	0	0	0	0	0	76.7	-
0400	4	3	0	0	0	0	0	1	0	0	0	0	0	95.2	-
0500	90	59	0	5	3	1	0	0	0	13	3	6	0	90.4	100.4
0600	135	74	3	11	6	3	0	0	0	15	18	5	0	87.1	98.6
0700	151	86	2	9	7	3	2	0	0	21	18	3	0	84.9	98.3
0800	147	71	3	14	2	2	2	0	0	18	24	11	0	85.3	98.6
0900	136	78	2	8	6	2	0	1	0	21	16	2	0	85.1	98.3
1000	155	72	3	25	5	1	3	0	0	20	24	2	0	85.0	97.2
1100	135	67	2	12	7	3	1	1	1	16	21	4	0	86.7	97.9
1200	136	76	4	16	7	1	5	2	0	11	13	1	0	88.9	100.4
1300	129	76	3	11	4	3	0	3	1	18	8	2	0	87.8	99.4
1400	106	57	1	12	2	2	3	0	2	14	9	4	0	87.5	100.4
1500	102	58	0	16	2	0	2	1	0	10	10	3	0	89.9	99.0
1600	136	100	2	15	4	2	1	0	0	7	3	2	0	90.4	99.4
1700	118	83	5	13	3	1	1	2	0	8	1	1	0	93.4	101.5
1800	43	32	0	6	1	0	0	1	0	0	3	0	0	89.6	101.5
1900	25	18	0	3	0	0	0	0	0	1	3	0	0	88.5	104.4
2000	10	7	0	0	0	0	0	0	0	0	1	2	0	76.3	-
2100	9	6	1	0	0	0	0	0	0	1	1	0	0	88.3	-
2200	5	4	0	0	1	0	0	0	0	0	0	0	0	78.2	-
2300	5	1	0	0	0	0	0	0	0	3	1	0	0	77.5	-
07-19	**1494**	**856**	**27**	**157**	**50**	**20**	**20**	**11**	**4**	**164**	**150**	**35**	**0**	**87.6**	**99.4**
06-22	**1673**	**961**	**31**	**171**	**56**	**23**	**20**	**11**	**4**	**181**	**173**	**42**	**0**	**87.5**	**99.4**
06-00	**1683**	**966**	**31**	**171**	**57**	**23**	**20**	**11**	**4**	**184**	**174**	**42**	**0**	**87.4**	**99.4**
00-00	**1785**	**1032**	**31**	**176**	**60**	**24**	**20**	**12**	**4**	**199**	**178**	**49**	**0**	**87.5**	**99.4**

* Wednesday, 11 December 2013

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Cls 7	Cls 8	Cls 9	Cls 10	Cls 11	Cls 12	Mean	Vpp 85
0000	1	1	0	0	0	0	0	0	0	0	0	0	0	76.6	-
0100	4	2	0	0	0	0	0	0	0	2	0	0	0	84.7	-
0200	2	2	0	0	0	0	0	0	0	0	0	0	0	99.2	-
0300	1	1	0	0	0	0	0	0	0	0	0	0	0	97.3	-
0400	14	11	1	0	0	0	0	0	0	0	2	0	0	93.3	100.4
0500	92	65	2	9	2	0	0	1	0	9	4	0	0	95.2	104.0
0600	118	70	2	15	1	0	0	0	0	11	13	6	0	89.1	100.1
0700	130	72	4	10	3	1	1	0	2	14	18	4	1	90.3	100.8
0800	152	85	0	16	10	1	1	1	2	10	19	7	0	87.7	97.9
07-19	**282**	**157**	**4**	**26**	**13**	**2**	**2**	**1**	**4**	**24**	**37**	**11**	**1**	**88.9**	**98.6**
06-22	**400**	**227**	**6**	**41**	**14**	**2**	**2**	**1**	**4**	**35**	**50**	**17**	**1**	**89.0**	**99.4**
06-00	**400**	**227**	**6**	**41**	**14**	**2**	**2**	**1**	**4**	**35**	**50**	**17**	**1**	**89.0**	**99.4**
00-00	**514**	**309**	**9**	**50**	**16**	**2**	**2**	**2**	**4**	**46**	**56**	**17**	**1**	**90.2**	**100.8**

In profile: Vehicles = 22608 / 22806 (99.13%)

Appendix F – AADT on Downs South West Roads

Attached are the AADT volume reports for the Department of Transport and Main Roads TARS database (QDTMR 2014f).

The both directional AADT from 2013 has been averaged in used in most of the models within this dissertation.

Traffic Analysis and Reporting System
AADT Segment Report
Road Section 36A - Balonne Highway (St George - Bollon)
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
211	0.000 km	1.500 km	55429	0.380 km	200m West of Rose St (Opp Pool)	1,245	1,403	2,648	0.68164	0.76814	1.44978	2013
211	1.500 km	5.320 km	51386	4.920 km	400m East of Mitchell - St George Road	267	260	527	0.37228	0.36252	0.73480	2013
211	5.320 km	113.270 km	50009	22.470 km	Approx 150m east of Powrunna Rd	147	147	294	5.79206	5.79206	11.58411	2013
								Totals	6.84597	6.92272	13.76869	

Road Segments Summary - Heavy Vehicles only
VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
211	0.000 km	1.500 km	55429	0.380 km	200m West of Rose St (Opp Pool)	180	14.46%	166	11.83%	346	13.07%	0.09855	0.09088	0.18944	2013
211	1.500 km	5.320 km	51386	4.920 km	400m East of Mitchell - St George Road	70	26.22%	71	27.31%	141	26.76%	0.09760	0.09900	0.19660	2013
211	5.320 km	113.270 km	50009	22.470 km	Approx 150m east of Powrunna Rd	49	33.33%	54	36.73%	103	35.03%	1.93069	2.12769	4.05838	2013
											Totals	2.12684	2.31757	4.44441	

Traffic Analysis and Reporting System
AADT Segment Report
Road Section 24A - Carnarvon Highway (Mungindi - St George)
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
211	0.000 km	10.430 km	50569	2.370 km	Approx 2km North of Mungindi	231	236	467	0.87941	0.89844	1.77785	2013
211	10.430 km	39.900 km	50416	37.020 km	5km south of Thallon	195	200	395	2.09753	2.15131	4.24884	2013
211	39.900 km	73.480 km	51406	65.600 km	Approx 300m North of Ballangarry Rd	164	169	333	2.01010	2.07138	4.08148	2013
211	73.480 km	110.820 km	50016	76.570 km	Approx 2km North of Nindigully (tube)	232	233	465	3.16195	3.17558	6.33753	2013
211	110.820 km	117.220 km	51470	111.270 km	400m North of 24A & 37A Intersection	606	618	1,224	1.41562	1.44365	2.85926	2013
211	117.220 km	118.080 km	55452	117.660 km	Approx 50m North of Marie St	1,173	1,145	2,318	0.36820	0.35942	0.72762	2013
								Totals	9.93280	10.09978	20.03258	

Road Segments Summary - Heavy Vehicles only
VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
211	0.000 km	10.430 km	50569	2.370 km	Approx 2km North of Mungindi	78	33.77%	79	33.47%	157	33.62%	0.29694	0.30075	0.59769	2013
211	10.430 km	39.900 km	50416	37.020 km	5km south of Thallon	101	51.79%	103	51.50%	204	51.65%	1.08641	1.10792	2.19434	2013
211	39.900 km	73.480 km	51406	65.600 km	Approx 300m North of Ballangarry Rd	66	40.24%	68	40.24%	134	40.24%	0.80894	0.83346	1.64240	2013
211	73.480 km	110.820 km	50016	76.570 km	Approx 2km North of Nindigully (tube)	74	31.90%	77	33.05%	151	32.47%	1.00855	1.04944	2.05799	2013
211	110.820 km	117.220 km	51470	111.270 km	400m North of 24A & 37A Intersection	125	20.63%	141	22.82%	266	21.73%	0.29200	0.32938	0.62138	2013
211	117.220 km	118.080 km	55452	117.660 km	Approx 50m North of Marie St	134	11.42%	179	15.63%	313	13.50%	0.04206	0.05619	0.09825	2013
											Totals	3.53491	3.67713	7.21205	

Traffic Analysis and Reporting System
AADT Segment Report
Road Section 341 - Chinchilla - Tara Road
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT G	AADT A	AADT B	VKT (Millions) G	VKT (Millions) A	VKT (Millions) B	Data Year
202	0.000 km	1.620 km	32653	0.470 km	Approx 470m South of Warrego Hwy	1,462	1,689	3,151	0.86448	0.99871	1.86319	2012
202	1.620 km	2.830 km	32705	1.770 km	Approx 100m South of Heeney St	1,884	1,870	3,754	0.83207	0.82589	1.65795	2012
202	2.830 km	22.486 km	32094	3.310 km	100m South of Grid at Racecourse Rd	1,407	1,433	2,840	10.09444	10.28097	20.37541	2013
202	22.486 km	43.430 km	32095	23.820 km	1.4km South of Kogan - Condamine Rd	913	912	1,825	6.97948	6.97184	13.95132	2012
202	43.430 km	68.610 km	50373	58.960 km	3km South of Upper Humbug Rd	187	190	377	1.71866	1.74623	3.46489	2012
202	68.610 km	69.660 km	51842	68.740 km	100m South of Tara - Kogan Road	454	458	912	0.17400	0.17553	0.34952	2012
								Totals	20.66313	20.99916	41.66229	

Road Segments Summary - Heavy Vehicles only
VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT G AADT	G HV %	A AADT	A HV %	B AADT	B HV %	HV VKT (Millions) G	A	B	Data Year
202	0.000 km	1.620 km	32653	0.470 km	Approx 470m South of Warrego Hwy	140	9.58%	136	8.05%	276	8.76%	0.08278	0.08042	0.16320	2012
202	1.620 km	2.830 km	32705	1.770 km	Approx 100m South of Heeney St	231	12.26%	221	11.82%	452	12.04%	0.10202	0.09760	0.19963	2012
202	2.830 km	22.486 km	32094	3.310 km	100m South of Grid at Racecourse Rd	227	16.13%	310	21.63%	537	18.91%	1.62860	2.22408	3.85267	2013
202	22.486 km	43.430 km	32095	23.820 km	1.4km South of Kogan - Condamine Rd	214	23.44%	210	23.03%	424	23.23%	1.63594	1.60536	3.24129	2012
202	43.430 km	68.610 km	50373	58.960 km	3km South of Upper Humbug Rd	30	16.04%	26	13.68%	56	14.85%	0.27572	0.23896	0.51468	2012
202	68.610 km	69.660 km	51842	68.740 km	100m South of Tara - Kogan Road	66	14.54%	57	12.45%	123	13.49%	0.02529	0.02185	0.04714	2012
											Totals	3.75035	4.26826	8.01861	

Traffic Analysis and Reporting System
AADT Segment Report
Road Section 426 - Chinchilla - Wondai Road
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT G	AADT A	AADT B	VKT (Millions) G	VKT (Millions) A	VKT (Millions) B	Data Year
202	0.000 km	2.520 km	32706	0.510 km	Approx 300m East of Boyd St	682	729	1,411	0.62730	0.67053	1.29784	2013
202	2.520 km	37.340 km	32553	2.940 km	Approx 400m East of Cemetry Rd	744	724	1,468	9.45572	9.20153	18.65725	2013
202	37.340 km	47.960 km	32058	28.880 km	Approx 30m West of Sullivans Rd	283	284	567	1.09699	1.10087	2.19786	2013
202	47.960 km	89.220 km	20493	49.970 km	2km North East of Jandowae Connection Rd	328	332	660	4.93965	4.99989	9.93953	2013
212	89.220 km	132.470 km	32124	108.730 km	At T Int sign on Lhs Tdist 108.73km	252	243	495	3.97814	3.83606	7.81419	2013
212	132.470 km	151.700 km	30033	149.180 km	2.3km W of Bunya Highway Td 149.18 Perm	352	347	699	2.47067	2.43558	4.90625	2013
								Totals	22.56847	22.24446	44.81293	

Road Segments Summary - Heavy Vehicles only
VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT G AADT	G HV %	A AADT	A HV %	B AADT	B HV %	HV VKT (Millions) G	A	B	Data Year
202	0.000 km	2.520 km	32706	0.510 km	Approx 300m East of Boyd St	104	15.25%	60	8.23%	164	11.62%	0.09566	0.05519	0.15085	2013
202	2.520 km	37.340 km	32553	2.940 km	Approx 400m East of Cemetry Rd	168	22.58%	165	22.79%	333	22.68%	2.13516	2.09703	4.23220	2013
202	37.340 km	47.960 km	32058	28.880 km	Approx 30m West of Sullivans Rd	113	39.93%	107	37.68%	220	38.80%	0.43802	0.41476	0.85279	2013
202	47.960 km	89.220 km	20493	49.970 km	2km North East of Jandowae Connection Rd	122	37.20%	129	38.86%	251	38.03%	1.83731	1.94273	3.78003	2013
212	89.220 km	132.470 km	32124	108.730 km	At T Int sign on Lhs Tdist 108.73km	68	26.98%	78	32.10%	146	29.49%	1.07346	1.23133	2.30479	2013
212	132.470 km	151.700 km	30033	149.180 km	2.3km W of Bunya Highway Td 149.18 Perm	71	20.17%	66	19.02%	137	19.60%	0.49835	0.46325	0.96160	2013
											Totals	6.07796	6.20429	12.28225	

Traffic Analysis and Reporting System
AADT Segment Report
Road Section 416 - Dalby - Cooyar Road
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT G	AADT A	AADT B	VKT (Millions) G	VKT (Millions) A	VKT (Millions) B	Data Year
202	0.000 km	22.140 km	32554	2.170 km	Approx 1.4km East of Oakwood Street	745	789	1,534	6.02042	6.37599	12.39641	2013
202	22.140 km	41.960 km	32104	23.470 km	Approx 1.4km East of Railway Crossing	578	492	1,070	4.18143	3.55928	7.74070	2013
202	41.960 km	58.200 km	30035	49.800 km	800m North of Maclagan Rd (Loops)	322	314	636	1.90869	1.86127	3.76995	2013
								Totals	12.11053	11.79653	23.90706	

Road Segments Summary - Heavy Vehicles only
VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT G AADT	G HV %	A AADT	A HV %	B AADT	B HV %	HV VKT (Millions) G	A	B	Data Year
202	0.000 km	22.140 km	32554	2.170 km	Approx 1.4km East of Oakwood Street	123	16.51%	130	16.48%	253	16.49%	0.99398	1.05054	2.04452	2013
202	22.140 km	41.960 km	32104	23.470 km	Approx 1.4km East of Railway Crossing	81	14.01%	69	14.02%	150	14.02%	0.58598	0.49917	1.08514	2013
202	41.960 km	58.200 km	30035	49.800 km	800m North of Maclagan Rd (Loops)	66	20.50%	52	16.56%	118	18.55%	0.39122	0.30824	0.69946	2013
											Totals	1.97118	1.85794	3.82912	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 421 - Dalby - Jandowae Road
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
202	0.000 km	1.370 km	32707	0.350 km	350m North of Int Warrego & Jondowae Rd	1,197	1,336	2,533	0.59856	0.66807	1.26663	2013
202	1.370 km	24.400 km	32057	12.820 km	750m North of Karingal- Apunya Rd	509	513	1,022	4.27863	4.31225	8.59088	2013
202	24.400 km	47.410 km	32116	38.540 km	Approx 1.6km South of Warra-Marnhull Rd	373	379	752	3.13270	3.18309	6.31578	2013
								Totals	8.00988	8.16341	16.17329	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
202	0.000 km	1.370 km	32707	0.350 km	350m North of Int Warrego & Jondowae Rd	203	16.96%	247	18.49%	450	17.77%	0.10151	0.12351	0.22502	2013
202	1.370 km	24.400 km	32057	12.820 km	750m North of Karingal- Apunya Rd	93	18.27%	126	24.56%	219	21.43%	0.78175	1.05915	1.84090	2013
202	24.400 km	47.410 km	32116	38.540 km	Approx 1.6km South of Warra-Marnhull Rd	67	17.96%	63	16.62%	130	17.29%	0.56271	0.52911	1.09182	2013
											Totals	1.44597	1.71178	3.15775	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 340 - Dalby - Kogan Road
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
202	0.000 km	19.292 km	30019	6.140 km	Approx 6.1km West of Warrego Hwy	773	797	1,570	5.44314	5.61214	11.05528	2013
202	19.292 km	47.682 km	32010	34.060 km	Approx 2km East of Breamar Ck Bridge	748	764	1,512	7.75104	7.91684	15.66787	2013
								Totals	13.19418	13.52897	26.72315	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
202	0.000 km	19.292 km	30019	6.140 km	Approx 6.1km West of Warrego Hwy	231	29.88%	296	37.14%	527	33.57%	1.62660	2.08431	3.71091	2013
202	19.292 km	47.682 km	32010	34.060 km	Approx 2km East of Breamar Ck Bridge	254	33.96%	273	35.73%	527	34.85%	2.63204	2.82892	5.46096	2013
											Totals	4.25864	4.91323	9.17187	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 313 - Gatton - Clifton Road
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
202	0.000 km	5.890 km	32070	1.000 km	200m North of Wells Rd	593	471	1,064	1.27486	1.01258	2.28744	2013
202	5.890 km	26.757 km	30023	11.900 km	50m North of Ridleys Rd (loops)	407	400	807	3.09990	3.04658	6.14648	2013
202	26.757 km	43.697 km	32561	34.287 km	300m North of horse Trough Ck	444	480	924	2.74530	2.96789	5.71318	2013
202	43.697 km	59.207 km	50539	53.017 km	Approx 120m East of Neds Gully Bridge	472	481	953	2.67206	2.72301	5.39508	2013
202	59.207 km	60.877 km	50538	59.620 km	Approx 400m West of Spring Creek Rd	499	502	1,001	0.30417	0.30599	0.61016	2013
202	60.877 km	62.677 km	55410	62.397 km	Approx 40m South of Edward St - Clifton	953	792	1,745	0.62612	0.52034	1.14646	2013
								Totals	10.72240	10.57640	21.29880	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
202	0.000 km	5.890 km	32070	1.000 km	200m North of Wells Rd	85	14.33%	66	14.01%	151	14.19%	0.18274	0.14189	0.32463	2013
202	5.890 km	26.757 km	30023	11.900 km	50m North of Ridleys Rd (loops)	75	18.43%	64	16.00%	139	17.22%	0.57123	0.48745	1.05869	2013
202	26.757 km	43.697 km	32561	34.287 km	300m North of horse Trough Ck	111	25.00%	111	23.12%	222	24.03%	0.68632	0.68632	1.37265	2013
202	43.697 km	59.207 km	50539	53.017 km	Approx 120m East of Neds Gully Bridge	111	23.52%	98	20.37%	209	21.93%	0.62839	0.55479	1.18318	2013
202	59.207 km	60.877 km	50538	59.620 km	Approx 400m West of Spring Creek Rd	74	14.83%	74	14.74%	148	14.79%	0.04511	0.04511	0.09021	2013
202	60.877 km	62.677 km	55410	62.397 km	Approx 40m South of Edward St - Clifton	82	8.60%	139	17.55%	221	12.66%	0.05387	0.09132	0.14520	2013
											Totals	2.16766	2.00689	4.17455	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 4144 - Gatton-esk Road

Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT G	AADT A	AADT B	VKT (Millions) G	VKT (Millions) A	VKT (Millions) B	Data Year
202	0.000 km	17.770 km	32646	1.960 km	150m South of Orchard Rd	1,175	1,194	2,369	7.62111	7.74434	15.36545	2013
207	17.770 km	39.870 km	32025	17.780 km	100m North of Gatton - Esk Bdy	621	651	1,272	5.00930	5.25129	10.26059	2013
								Totals	12.63041	12.99564	25.62604	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT G AADT	HV AADT G HV %	HV AADT A AADT	HV AADT A HV %	HV AADT B AADT	HV AADT B HV %	HV VKT (Millions) G	HV VKT (Millions) A	HV VKT (Millions) B	Data Year
202	0.000 km	17.770 km	32646	1.960 km	150m South of Orchard Rd	159	13.53%	184	15.41%	343	14.48%	1.03128	1.19343	2.22472	2013
207	17.770 km	39.870 km	32025	17.780 km	100m North of Gatton - Esk Bdy	60	9.66%	54	8.29%	114	8.96%	0.48399	0.43559	0.91958	2013
											Totals	1.51527	1.62902	3.14430	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 35A - Moonie Highway (Dalby - St. George)

Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT G	AADT A	AADT B	VKT (Millions) G	VKT (Millions) A	VKT (Millions) B	Data Year
202	0.000 km	3.660 km	32631	0.530 km	Approx 500m South of Warrego Hwy	3,192	3,113	6,305	4.26419	4.15866	8.42285	2013
202	3.660 km	11.000 km	30018	3.850 km	Approx 100m West of Watts Rd (Loop)	1,383	1,271	2,654	3.70520	3.40514	7.11033	2013
202	11.000 km	50.370 km	32053	17.440 km	1km East of Broadwater Rd	1,088	1,016	2,104	15.63461	14.59997	30.23459	2013
202	50.370 km	113.530 km	50013	111.670 km	2km East of Moonie (tube)	320	305	625	7.37709	7.03129	14.40838	2013
202	113.530 km	184.520 km	50097	114.660 km	Approx 1km West of Moonie	219	223	442	5.67459	5.77823	11.45282	2013
202	184.520 km	211.960 km	51367	185.580 km	Approx 1km West of Westmar	180	182	362	1.80281	1.82284	3.62565	2013
211	211.960 km	293.750 km	51382	292.200 km	1.5km East of Carnarvon Hwy	261	265	526	7.79172	7.91114	15.70286	2013
								Totals	46.25021	44.70726	90.95747	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT G AADT	HV AADT G HV %	HV AADT A AADT	HV AADT A HV %	HV AADT B AADT	HV AADT B HV %	HV VKT (Millions) G	HV VKT (Millions) A	HV VKT (Millions) B	Data Year
202	0.000 km	3.660 km	32631	0.530 km	Approx 500m South of Warrego Hwy	396	12.41%	342	10.99%	738	11.70%	0.52902	0.45688	0.98589	2013
202	3.660 km	11.000 km	30018	3.850 km	Approx 100m West of Watts Rd (Loop)	333	24.08%	349	27.46%	682	25.70%	0.89214	0.93501	1.82715	2013
202	11.000 km	50.370 km	32053	17.440 km	1km East of Broadwater Rd	244	22.43%	241	23.72%	485	23.05%	3.50629	3.46318	6.96947	2013
202	50.370 km	113.530 km	50013	111.670 km	2km East of Moonie (tube)	105	32.81%	91	29.84%	196	31.36%	2.42061	2.09786	4.51847	2013
202	113.530 km	184.520 km	50097	114.660 km	Approx 1km West of Moonie	56	25.57%	54	24.22%	110	24.89%	1.45104	1.39921	2.85025	2013
202	184.520 km	211.960 km	51367	185.580 km	Approx 1km West of Westmar	58	32.22%	64	35.16%	122	33.70%	0.58090	0.64100	1.22190	2013
211	211.960 km	293.750 km	51382	292.200 km	1.5km East of Carnarvon Hwy	78	29.89%	89	33.58%	167	31.75%	2.32856	2.65695	4.98551	2013
											Totals	11.70856	11.65008	23.35864	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 3501 - Roma - Southern Road

Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT G	AADT A	AADT B	VKT (Millions) G	VKT (Millions) A	VKT (Millions) B	Data Year
211	0.000 km	1.600 km	40512	1.340 km	1.34km South of Warrego Hwy	245	234	479	0.14308	0.13666	0.27974	2013
211	1.600 km	10.800 km	40403	2.770 km	1.2km South of Geoghegan Street	162	156	318	0.54400	0.52385	1.06784	2013
211	10.800 km	49.020 km	40511	21.680 km	3.77km South of Hope Creek (RPC 3)	48	44	92	0.66961	0.61381	1.28343	2013
								Totals	1.35669	1.27432	2.63101	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT G AADT	HV AADT G HV %	HV AADT A AADT	HV AADT A HV %	HV AADT B AADT	HV AADT B HV %	HV VKT (Millions) G	HV VKT (Millions) A	HV VKT (Millions) B	Data Year
211	0.000 km	1.600 km	40512	1.340 km	1.34km South of Warrego Hwy	66	26.94%	34	14.53%	100	20.88%	0.03854	0.01986	0.05840	2013
211	1.600 km	10.800 km	40403	2.770 km	1.2km South of Geoghegan Street	34	20.99%	33	21.15%	67	21.07%	0.11417	0.11081	0.22499	2013
211	10.800 km	49.020 km	40511	21.680 km	3.77km South of Hope Creek (RPC 3)	10	20.83%	11	25.00%	21	22.83%	0.13950	0.15345	0.29296	2013
											Totals	0.29222	0.28412	0.57634	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 86A - Surat Dev Road (Surat - Tara)

Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
211	0.000 km	52.910 km	40353	11.050 km	11.05km East of Int Carnarvon Hwy	94	102	196	1.81534	1.96984	3.78518	2012
202	52.910 km	63.420 km	50378	61.000 km	3km west of Glenmorgan	75	74	149	0.28771	0.28388	0.57159	2012
202	63.420 km	119.300 km	51364	87.600 km	1km east of Meandarra - Talwood Road	104	105	209	2.12120	2.14160	4.26281	2012
202	119.300 km	142.670 km	50025	121.210 km	Approx 2km East of The Gums	137	135	272	1.16862	1.15156	2.32017	2013
202	142.670 km	145.240 km	51348	144.970 km	100m east of Rail Xing to Steel Yards	319	316	635	0.29924	0.29642	0.59566	2012
202	145.240 km	147.510 km	55448	147.310 km	200m East of Wilson St-Opp Train Quarter	424	570	994	0.35131	0.47227	0.82358	2012
202	147.510 km	147.860 km	55449	147.560 km	Approx 50m East of Tara Chinchilla Rd	974	901	1,875	0.12443	0.11510	0.23953	2011
								Totals	6.16785	6.43067	12.59852	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
211	0.000 km	52.910 km	40353	11.050 km	11.05km East of Int Carnarvon Hwy	25	26.60%	31	30.39%	56	28.57%	0.48280	0.59868	1.08148	2012
202	52.910 km	63.420 km	50378	61.000 km	3km west of Glenmorgan	23	30.67%	24	32.43%	47	31.54%	0.08823	0.09207	0.18030	2012
202	63.420 km	119.300 km	51364	87.600 km	1km east of Meandarra - Talwood Road	30	28.85%	29	27.62%	59	28.23%	0.61189	0.59149	1.20338	2012
202	119.300 km	142.670 km	50025	121.210 km	Approx 2km East of The Gums	36	26.28%	36	26.67%	72	26.47%	0.30708	0.30708	0.61416	2013
202	142.670 km	145.240 km	51348	144.970 km	100m east of Rail Xing to Steel Yards	78	24.45%	69	21.84%	147	23.15%	0.07317	0.06473	0.13789	2012
202	145.240 km	147.510 km	55448	147.310 km	200m East of Wilson St-Opp Train Quarter	71	16.75%	85	14.91%	156	15.69%	0.05883	0.07043	0.12925	2012
202	147.510 km	147.860 km	55449	147.560 km	Approx 50m East of Tara Chinchilla Rd	97	9.96%	103	11.43%	200	10.67%	0.01239	0.01316	0.02555	2011
											Totals	1.63439	1.73763	3.37202	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 86B - Surat Dev Road (Tara - Dalby)

Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
202	0.000 km	0.050 km	55450	0.040 km	40m South of Rail Xing (Opp Amenities)	663	723	1,386	0.01210	0.01319	0.02529	2012
202	0.050 km	2.150 km	55451	0.760 km	150m East of Day Street Rail Access	351	359	710	0.26904	0.27517	0.54422	2012
202	2.150 km	40.390 km	51585	2.480 km	200m East of Cambridge Crossing Rd	312	319	631	4.35477	4.45247	8.80725	2012
								Totals	4.63591	4.74084	9.37676	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
202	0.000 km	0.050 km	55450	0.040 km	40m South of Rail Xing (Opp Amenities)	83	12.52%	119	16.46%	202	14.57%	0.00151	0.00217	0.00369	2012
202	0.050 km	2.150 km	55451	0.760 km	150m East of Day Street Rail Access	80	22.79%	76	21.17%	156	21.97%	0.06132	0.05825	0.11957	2012
202	2.150 km	40.390 km	51585	2.480 km	200m East of Cambridge Crossing Rd	65	20.83%	68	21.32%	133	21.08%	0.90724	0.94912	1.85636	2012
											Totals	0.97008	1.00954	1.97962	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 3402 - Tara - Kogan Road

Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
202	0.000 km	34.800 km	50372	1.740 km	1.7km from Chinchilla Tara Rd Int.	141	148	289	1.79098	1.87990	3.67088	2012
202	34.800 km	43.030 km	32143	42.090 km	970m South of Dalby-Kogan Rd	116	122	238	0.34846	0.36648	0.71494	2012
								Totals	2.13944	2.24638	4.38582	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
202	0.000 km	34.800 km	50372	1.740 km	1.7km from Chinchilla Tara Rd Int.	14	9.93%	13	8.78%	27	9.34%	0.17783	0.16513	0.34295	2012
202	34.800 km	43.030 km	32143	42.090 km	970m South of Dalby-Kogan Rd	26	22.41%	26	21.31%	52	21.85%	0.07810	0.07810	0.15621	2012
											Totals	0.25593	0.24323	0.49916	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 324 - Toowoomba - Cecil Plains Road
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
202	0.000 km	2.670 km	32078	1.770 km	100m West of Eyers St.	6,728	6,812	13,540	6.55677	6.63863	13.19541	2012
202	2.670 km	5.860 km	32014	4.480 km	500m West of Moores Rd	2,778	2,333	5,111	3.23456	2.71643	5.95099	2012
202	5.860 km	12.120 km	32664	10.040 km	800m West of Omara Road	1,178	1,152	2,330	2.69161	2.63220	5.32382	2012
202	12.120 km	30.960 km	32062	14.720 km	100m West of Brimblecombe	939	948	1,887	6.45713	6.51902	12.97614	2012
202	30.960 km	59.920 km	32081	44.960 km	200m East of Ruhle Rd	259	256	515	2.73773	2.70602	5.44376	2012
202	59.920 km	74.840 km	32082	72.300 km	50m Est Condamine Rv Nth Bch	186	185	371	1.01292	1.00747	2.02039	2012
202	74.840 km	78.780 km	32083	75.720 km	800m West of Horrane Rd	233	236	469	0.33508	0.33939	0.67447	2012
								Totals	23.02581	22.55917	45.58498	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
202	0.000 km	2.670 km	32078	1.770 km	100m West of Eyers St.	1,269	18.86%	1,463	21.48%	2,732	20.18%	1.23670	1.42577	2.66247	2012
202	2.670 km	5.860 km	32014	4.480 km	500m West of Moores Rd	835	30.06%	693	29.70%	1,528	29.90%	0.97223	0.80689	1.77913	2012
202	5.860 km	12.120 km	32664	10.040 km	800m West of Omara Road	282	23.94%	237	20.57%	519	22.27%	0.64434	0.54152	1.18586	2012
202	12.120 km	30.960 km	32062	14.720 km	100m West of Brimblecombe	149	15.87%	151	15.93%	300	15.90%	1.02461	1.03837	2.06298	2012
202	30.960 km	59.920 km	32081	44.960 km	200m East of Ruhle Rd	73	28.19%	78	30.47%	151	29.32%	0.77164	0.82449	1.59613	2012
202	59.920 km	74.840 km	32082	72.300 km	50m Est Condamine Rv Nth Bch	59	31.72%	52	28.11%	111	29.92%	0.32130	0.28318	0.60448	2012
202	74.840 km	78.780 km	32083	75.720 km	800m West of Horrane Rd	72	30.90%	71	30.08%	143	30.49%	0.10354	0.10211	0.20565	2012
											Totals	5.07438	5.02233	10.09670	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 18C - Warrego Highway (Dalby - Miles)
Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
202	0.000 km	1.210 km	32633	0.740 km	100m East Of Rail X-ing	4,968	4,937	9,905	2.19412	2.18043	4.37454	2013
202	1.210 km	5.600 km	32647	5.000 km	Approx 600m East of Dalby - Kogan Rd	2,921	2,876	5,797	4.68046	4.60836	9.28882	2013
202	5.600 km	25.115 km	30040	10.730 km	300m East of Yaralla Wheat Rd (Perm)	1,998	1,970	3,968	14.23170	14.03226	28.26396	2013
202	25.115 km	45.195 km	30076	30.980 km	5.8km West of Warra - Canaga Ck Rd	2,345	1,996	4,341	17.18697	14.62908	31.81606	2013
202	45.195 km	72.055 km	32047	49.740 km	Approx 600m West of Wolski Rd	2,169	1,966	4,135	21.26466	19.27447	40.53913	2013
202	72.055 km	79.045 km	32654	78.420 km	Approx 600m East of Carmichael St	3,008	2,574	5,582	7.67446	6.56717	14.24164	2013
202	79.045 km	80.175 km	32702	79.790 km	Approx 300m West of Copper St	3,399	3,218	6,617	1.40192	1.32726	2.72918	2013
202	80.175 km	81.255 km	32648	81.090 km	150m East of Chinchilla - Wondai Rd	3,933	4,071	8,004	1.55039	1.60479	3.15518	2013
202	81.255 km	83.155 km	32048	81.830 km	Eastern End of Charlies Creek Bridge	3,153	3,058	6,211	2.18661	2.12072	4.30733	2013
202	83.155 km	106.355 km	30020	83.250 km	150m West of Auburn Rd (Tube)	2,232	2,161	4,393	18.90058	18.29935	37.19992	2013
202	106.355 km	126.745 km	40047	123.200 km	WiM Site Miles 3.35km East of Int 26C	2,268	2,100	4,368	16.87925	15.62894	32.50818	2013
								Totals	108.15112	100.27283	208.42395	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
202	0.000 km	1.210 km	32633	0.740 km	100m East Of Rail X-ing	1,243	25.02%	1,207	24.45%	2,450	24.73%	0.54897	0.53307	1.08204	2013
202	1.210 km	5.600 km	32647	5.000 km	Approx 600m East of Dalby - Kogan Rd	836	28.62%	952	33.10%	1,788	30.84%	1.33956	1.52544	2.86500	2013
202	5.600 km	25.115 km	30040	10.730 km	300m East of Yaralla Wheat Rd (Perm)	650	32.53%	628	31.88%	1,278	32.21%	4.62993	4.47323	9.10316	2013
202	25.115 km	45.195 km	30076	30.980 km	5.8km West of Warra - Canaga Ck Rd	781	33.30%	676	33.87%	1,457	33.56%	5.72411	4.95454	10.67864	2013
202	45.195 km	72.055 km	32047	49.740 km	Approx 600m West of Wolski Rd	757	34.90%	718	36.52%	1,475	35.67%	7.42155	7.03920	14.46075	2013
202	72.055 km	79.045 km	32654	78.420 km	Approx 600m East of Carmichael St	868	28.86%	747	29.02%	1,615	28.93%	2.21457	1.90586	4.12043	2013
202	79.045 km	80.175 km	32702	79.790 km	Approx 300m West of Copper St	803	23.62%	855	26.57%	1,658	25.06%	0.33120	0.35264	0.68384	2013
202	80.175 km	81.255 km	32648	81.090 km	150m East of Chinchilla - Wondai Rd	1,090	27.71%	1,012	24.86%	2,102	26.26%	0.42968	0.39893	0.82861	2013
202	81.255 km	83.155 km	32048	81.830 km	Eastern End of Charlies Creek Bridge	925	29.34%	849	27.76%	1,774	28.56%	0.64149	0.58878	1.23027	2013
202	83.155 km	106.355 km	30020	83.250 km	150m West of Auburn Rd (Tube)	820	36.74%	878	40.63%	1,698	38.65%	6.94376	7.43490	14.37866	2013
202	106.355 km	126.745 km	40047	123.200 km	WiM Site Miles 3.35km East of Int 26C	776	34.22%	718	34.19%	1,494	34.20%	5.77526	5.34361	11.11887	2013
											Totals	36.00009	34.55020	70.55029	

Traffic Analysis and Reporting System

AADT Segment Report

Road Section 18E - Warrego Highway (Roma - Mitchell)

Traffic Year 2013

Road Segments Summary - All Vehicles

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	AADT			VKT (Millions)			Data Year
						G	A	B	G	A	B	
211	0.000 km	2.200 km	40539	1.090 km	30m West of Feather Street (Roma)	3,202	3,151	6,353	2.57121	2.53025	5.10146	2013
211	2.200 km	5.500 km	40540	7.320 km	1.76km West of Currey Street (Roma)	573	563	1,136	0.69018	0.67813	1.36831	2013
211	5.500 km	63.580 km	40041	39.910 km	3.13km West of Massey Lane (Mt Abud)	527	513	1,040	11.17198	10.87519	22.04717	2013
211	63.580 km	86.400 km	40410	74.980 km	2.42km East of Little Amby Ck	505	480	985	4.20630	3.99806	8.20436	2013
211	86.400 km	87.350 km	40527	85.980 km	30m East of Abut (A) Maranoa River	633	593	1,226	0.21949	0.20562	0.42512	2013
								Totals	18.85915	18.28726	37.14642	

Road Segments Summary - Heavy Vehicles only

VKT totals are calculated only if traffic class data is available for all sites.

Region	Segment Start TDist	Segment End TDist	Site	Site TDist	Description	HV AADT						HV VKT (Millions)			Data Year
						G		A		B					
						AADT	HV %	AADT	HV %	AADT	HV %	G	A	B	
211	0.000 km	2.200 km	40539	1.090 km	30m West of Feather Street (Roma)	834	26.05%	509	16.15%	1,343	21.14%	0.66970	0.40873	1.07843	2013
211	2.200 km	5.500 km	40540	7.320 km	1.76km West of Currey Street (Roma)	171	29.84%	188	33.39%	359	31.60%	0.20597	0.22645	0.43242	2013
211	5.500 km	63.580 km	40041	39.910 km	3.13km West of Massey Lane (Mt Abud)	157	29.79%	166	32.36%	323	31.06%	3.32827	3.51907	6.84734	2013
211	63.580 km	86.400 km	40410	74.980 km	2.42km East of Little Amby Ck	189	37.43%	153	31.87%	342	34.72%	1.57424	1.27438	2.84862	2013
211	86.400 km	87.350 km	40527	85.980 km	30m East of Abut (A) Maranoa River	203	32.07%	183	30.86%	386	31.48%	0.07039	0.06346	0.13385	2013
											Totals	5.84857	5.49208	11.34065	

Appendix G – Comparison Crash Rate

This table is used to compare the calculated crash rate to determine if a safety review is required, from Part 4 of the MUTCD.

Table 17: Comparison crash rate for rural roads (Queensland Government 2014a, p55).

Table E2 TYPICAL COMPARISON CASUALTY CRASH RATES (AVERAGE) FOR ROADS IN URBAN ENVIRONMENT

Urban Typical Average Casualty Crash Rates (*10^4 ERU per 10^8 VKT)

Type of Road	ADT Band (veh/day)	Speed Zone (km/h)					
		40-50	60	70-80	90	100	110
Motorways and Freeways	>30,000	308.5	308.5	308.5	308.5	308.5	308.5
Highways	0 - 1,000	633.8	633.8	633.8	502.1	502.1	502.1
	1,001 - 3,000	633.8	633.8	633.8	502.1	502.1	502.1
	3,001 - 10,000	525.8	525.8	525.8	509.7	509.7	509.7
	10,001 - 20,000	383.8	383.8	383.8	601.2	601.2	601.2
	20,001 - 30,000	-	374.5	374.5	372.3	372.3	372.3
	>30,000	-	374.5	374.5	372.3	372.3	372.3
Arterial and Sub-Arterial Roads	0 - 1,000	509.2	509.2	509.2	-	-	-
	1,001 - 3,000	509.2	509.2	509.2	-	-	-
	3,001 - 10,000	509.2	509.2	509.2	319.7	319.7	319.7
	10,001 - 20,000	467.2	467.2	467.2	319.7	319.7	319.7
	20,001 - 30,000	332.2	332.2	313.5	319.7	319.7	319.7
	>30,000	-	252.6	252.6	319.7	319.7	319.7
Trunk Collector Roads and Collector Roads	0 - 1,000	-	1,494.4	1,494.4	1,652.3	1,652.3	-
	1,001 - 3,000	995.9	995.9	769.4	1,652.3	1,652.3	-
	3,001 - 10,000	524.2	524.2	561.8	544.2	544.2	-
	10,001 - 20,000	497.3	497.3	462.7	544.2	544.2	-
	20,001 - 30,000	329.2	329.2	282.5	544.2	544.2	-
	>30,000	-	352.0	352.0	-	-	-
Local Roads	0 - 1,000	2,125.2	1,956.5	1,956.5	-	-	-
	1,001 - 3,000	1,241.7	1,189.6	1,189.6	-	-	-
	3,001 - 10,000	779.6	856.7	856.7	-	-	-
	> 10,000	585.1	585.1	-	-	-	-

Appendix H – 1km and 100m segment models

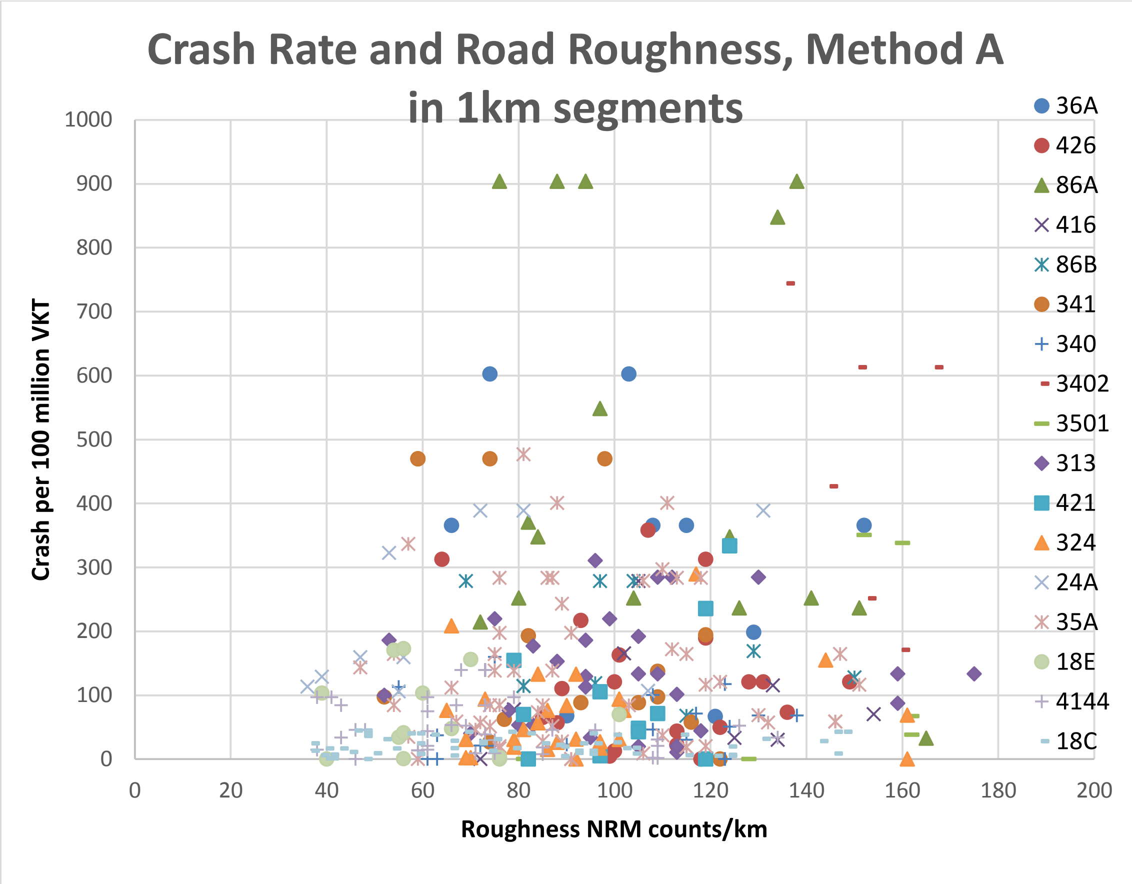

Figure 58: Crash rate and roughness using Method A in 1km segment lengths.

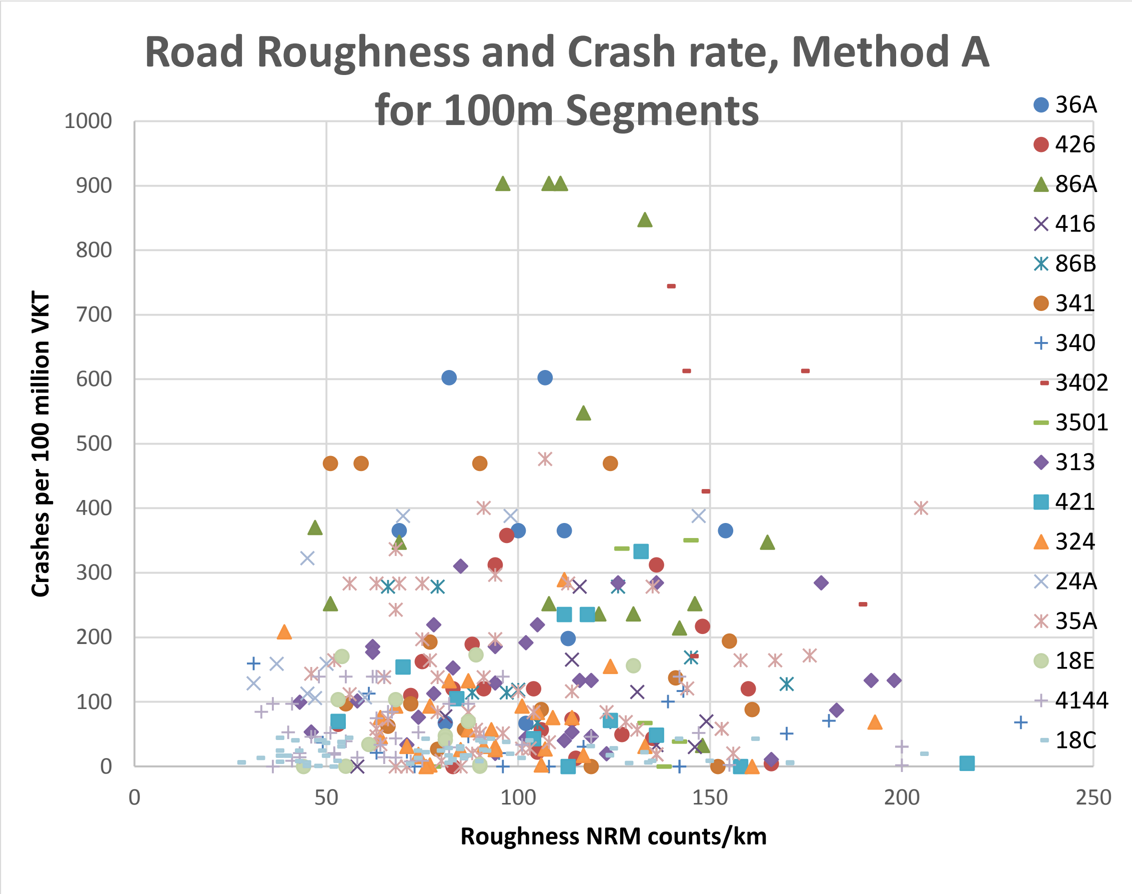

Figure 59: Crash rate and roughness using Method A in 100m segment lengths.

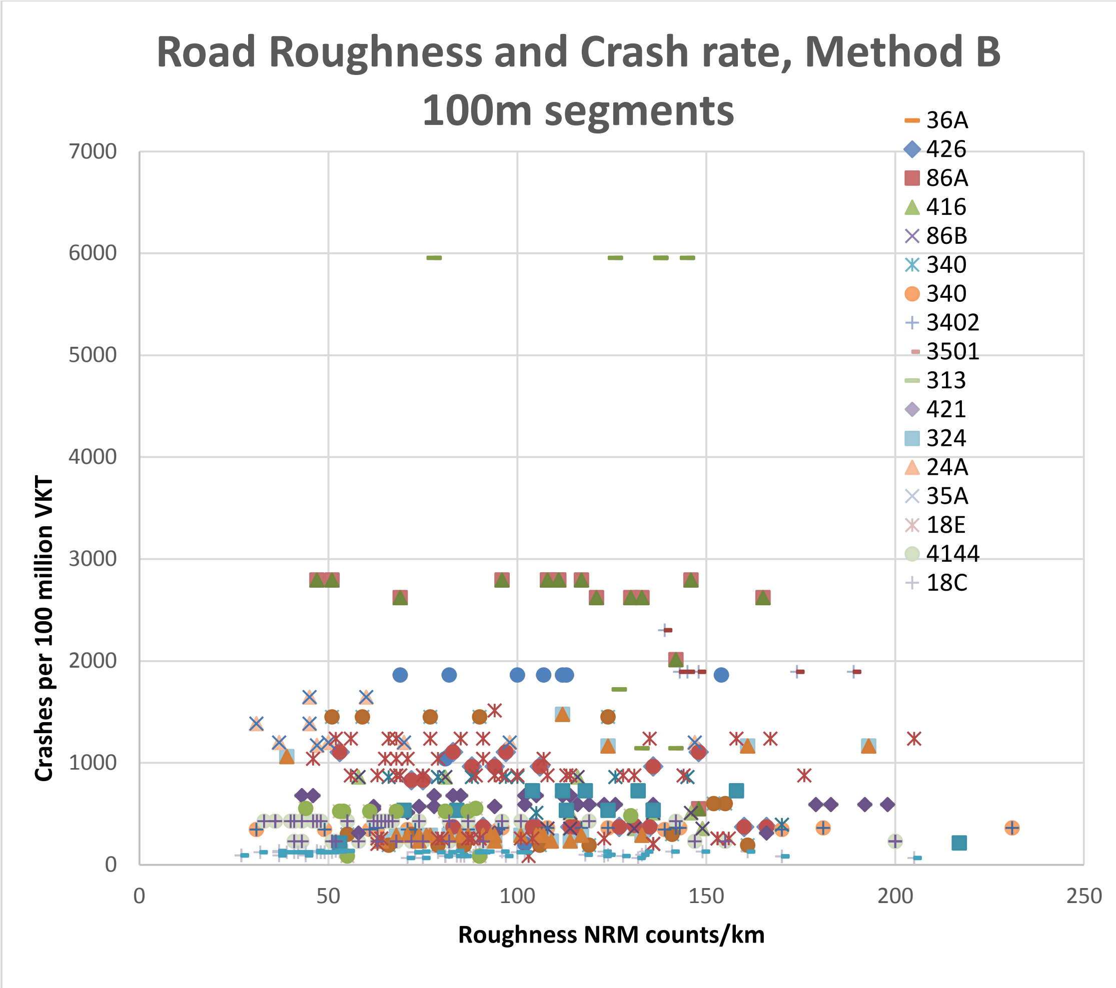

Figure 60: Crash rate and roughness using Method B in 100m segment lengths.