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Bachelor of Engineering Thesis

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A REVIEW OF PAVEMENT ROUGHNESS CRITERIA FOR 110 KPH TWO-WAY TWO-LANE RURAL ROADS

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Abstract

Speed zoning of Queensland's state-controlled road network is determined in accordance with Part 4 of the Manual of Uniform Traffic Control Devices (MUTCD), a publication produced by the Queensland Department of Main Roads.

As part of the 'Additional/Desirable Criteria' for 110 kph zones, the limit for the pavement roughness count is 120 NRM (NAASRA Roughness Meter counts). Roughness counts are generally measured in 10m increments over the length of a road, and may vary widely between increments. Thus, it is not unusual for the limit to be exceeded by some segments along a road. However, since this limit is included as an additional criterion, the road manager is implicitly given some allowance in deciding whether roughness levels are excessive or not.

In the last year or so, the question has been raised of how meaningful this roughness limit is and how strictly it should be observed. To address this question, an investigation of the effect pavement roughness has on the performance of road transportation networks and the basis for applying a roughness limit specifically to 110 kph roads was undertaken. This investigation consisted of a literature review to determine current knowledge of the area, and an examination of crash and roughness data for state-controlled roads within Southern Region.

Two major aspects of a road transportation system directly affected by high pavement roughness were identified:

(a) road safety, and

(b) economic costs

Based on economic considerations, little evidence was found to support the selective implementation of a roughness limit on roads governed by a 110 kph speed limit rather than roads under a 100 kph limit, particularly for rural areas. This is simply because the likely difference in vehicle speeds under the higher speed limit is small enough to have negligible influence on pavement life, particularly in consideration of the low traffic volumes experienced by rural roads.

In terms of road safety, it is intuitive from a first-principles examination of roughness effects to expect that a network approach to managing roughness should be taken. However, an examination of road safety data leads to the probably conclusion that road safety is best managed in terms of local failure points in the system (black spots) rather than as a continuous function of system-wide parameters. Thus, there is little statistical evidence to support the use of a general limit on roughness for 110 kph two-way, two-lane rural roads.

An expansion of the data analysis to include all 110 kph two-way two-lane rural roads in Queensland is required to confirm or disprove the preliminary findings of this study before a conclusive decision can be made.

A complete review of 110 kph speed limit criteria currently being undertaken by the Department of Main Roads is expected to provide further information regarding this particular issue, among a broader range of criteria.

Contents

Introduction

Speed zoning of Queensland's state-controlled road network is determined in accordance with Part 4 of the Manual of Uniform Traffic Control Devices (MUTCD), a publication produced by the Queensland Department of Main Roads.

110 kph speed zones have been in use on Queensland roads since 1992, with extensive trials first undertaken in 1994. Around 2500km of the state-controlled road network are currently zoned as 110 kph. Some 400km of this apply to two-way four-lane divided highways in the southeast corner of the state. The remainder typically applies to two-way, two-lane undivided highways throughout rural Queensland.

As part of the 'Additional/Desirable Criteria' for 110 kph zones, the limit for the pavement roughness count is 120 NRM (NAASRA Roughness Meter counts). Roughness counts are generally measured in 10m increments over the length of a road, and may vary widely between increments. Thus, it is not unusual for the limit to be exceeded by some segments along a road. However, since this limit is included as an additional criterion, the road manager is implicitly given some allowance in deciding whether roughness levels are excessive or not.

In the last year or so, the question has been raised of how meaningful this roughness limit is and how strictly it should be observed. This thesis topic has been undertaken as a response to this question.

The objectives of this thesis, then, are

- Firstly, to investigate the effect of pavement roughness on the performance of the roads network, and attempt to determine the suitability of a roughness limit, and

- Secondly, to examine the basis for applying this limit only to roads in a 110 kph speed zone environment.

It should be noted that the Department of Main Roads is currently undertaking a much broader review of the entire criteria for 110 kph roads, with a report scheduled for completion sometime in 2003/4. The results of the DMR review are expected to be much more comprehensive than those provided in this study regarding the management of 110 kph speed zoned roads.

1   Research Approach

The objectives of this thesis are to examine what effect pavement roughness has on the performance of road transportation networks, while also considering the basis for applying a roughness limit specifically to 110 kph roads.

Efforts to address these stated objectives were directed in two broad areas:

- a literature review to determine current knowledge of the area, and

- an examination of crash and roughness data for state-controlled roads within Southern Region

The literature review was undertaken to investigate the current body of knowledge regarding (a) pavement roughness, particularly in terms of system-wide effects, and (b) the consequences of raising speed limits on Australian rural roads. Searches were conducted at the University of Queensland EPSA Library and the Department of Main Roads Central Library, in addition to use of Internet search engines. The material obtained can broadly be grouped into the following categories:

Pavement roughness:	*Speed limits:*
- Defining and measuring roughness	- Arguments for and against higher rural speed limits
- General systematic effects of roughness	- Effect on vehicle speeds
- Dynamic effects in pavement loading and damage	- Correlation with accident rates
- Correlation with free vehicle speeds	*Vehicle speeds:*
- Pavement condition and road safety	- Risk of crash involvement

Table 1.1 Literature Categories

The Literature Review section summarises the documents found in the search, and provides a discussion of the relevant findings.

The concept of the data analysis was based on the ready availability of crash data, traffic data and pavement roughness records for Queensland rural roads administered by the Department of Main Roads. While a comprehensive economic analysis of pavement roughness effects was not practicable due to the involved complexities, a simple comparison between crash rates and roughness was achievable and was expected to provide a useful result.

The decision of how best to approach the data analysis was not made until after the findings of the literature review were obtained. In short, the literature suggested that any observed effect between roughness and crash rate should be evident as either a proportional relationship or a threshold effect. Details of the actual statistical methods used to examine the data and the results obtained are provided in the Data Analysis section.

Throughout the project, regular contact was maintained with Delia Atkinson (Traffic & Road Use Management Division, Traffic Engineering and Road Safety Branch) to provide advice, feedback and generally ensure that progress was made in a positive direction.

Literature review

2 Pavement roughness

Roughness is an important quality of a road pavement from a network management perspective. If roughness can be quantified, it provides a reliable indication of the forces and displacements experienced by vehicles travelling on a particular stretch of pavement.

Historically, the aim of early attempts at measuring pavement roughness was to create an objective measure of ride quality, a subjective issue often with political implications. While research has certainly confirmed the existence of that relationship, much more attention has been given to the role that roughness plays in the overall performance of road transportation systems. With the advent of increasingly quantitative management of transportation systems, efforts have been taken to correlate the readily measurable pavement roughness with system-wide concepts fundamental to road management such as pavement deterioration, network costs, network efficiency and safety.

Conceptually, pavement roughness is a measurement of the dynamics experienced by a single vehicle. It therefore makes sense that roughness ought to influence the performance parameters of a road network, which, after all, are a summation of the conditions experienced by each individual vehicle.

2.1 Defining roughness

Paterson (1987) quotes the definition of roughness as being

> the deviations of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads and drainage. (American Society for Testing and Materials (ATSM) specification E867-82A)

There are two approaches to measuring pavement roughness. One is to directly measure the longitudinal deviations in elevation along the roadway. The other is to measure the forces/displacements experienced by a standard vehicle as it travels along the roadway, and take these values as being indicative of the pavement roughness.

In short, measurement of the road profile is the most accurate but typically the most laborious method of determining a pavement roughness statistic. Vehicle response measurements are much faster, but must be calibrated regularly to ensure accuracy (Gu, 1990).

Internationally, there is a trend towards the adoption of the International Roughness Index (IRI) as a standard measure of roughness. This is a reliable measurement derived directly from the roadway profile (Paterson 1987, p29). The IRI formula has been developed to ensure that it retains complete relevance to the three defining elements pertaining to pavement roughness (road profile, vehicle dynamics and ride quality).

Australian road authorities use the NAASRA Roughness Meter (NRM) which expresses roughness in terms of NRM counts per km. The roughness value is determined by a standardised vehicle instrumented to measure dynamic response. There is a strong linear correlation between NRM and IRI, allowing for confidence in the use of either measurement (ARRB, ARR 295; Gu, 1990).
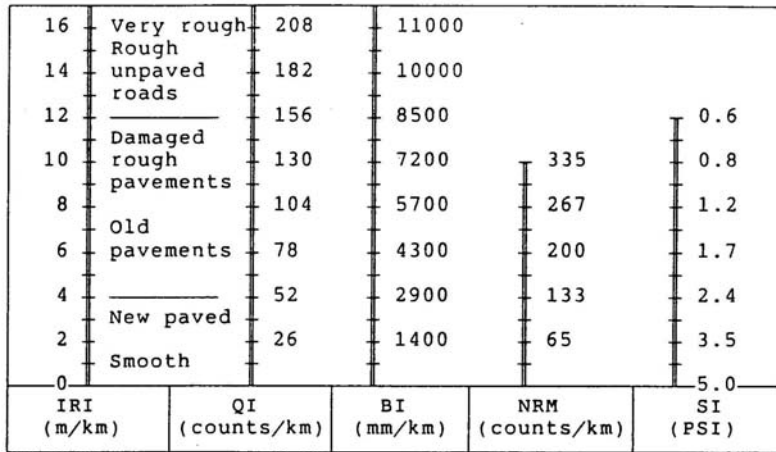
Figure 2.1 International Roughness Index and other roughness scales (from Gu, 1990)

Gu (1990) notes that the relationship between units of IRI (m/km) and NRM (counts/km) is given by

$$IRI = 0.072 + 0.03 * NRM \qquad (Prem, 1989)$$

2.2 General effects

Pavement roughness has long been used as an indicator of ride comfort. Generally, the correlation between a measured roughness statistic correlates well with the subjective evaluation made by road users, for instance as shown by Giummarra and Boyd (2001) in their study of road funding requirements for varying levels of ride quality.
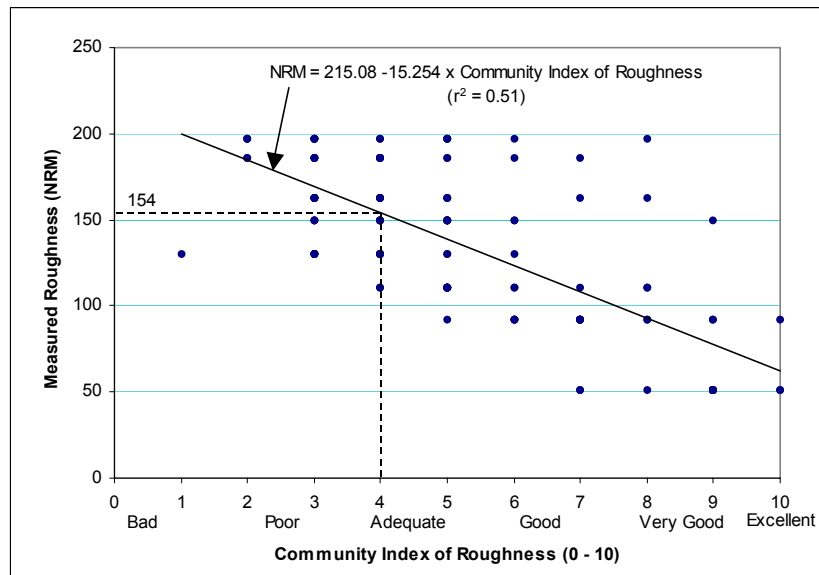
Figure 2.2 Pavement roughness and community expectation (from Giummarra and Boyd, 2001)

The National Swedish Road and Traffic Research Institute (VTI) has conducted two desktop studies of interest to this subject:

> VTI Notat 71A-2000: The significance of various road surface properties for traffic and surroundings (Anita Ihs and Georg Magnusson)

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VTI Rapport 134: The Influence of Road Roughness on the
Braking and Steering Performance of Cars: A Literature Study
(Georg Magnusson and Peter W Arnberg)

Apart from the summary, VTI Rapport 134 is entirely in Swedish. However, the summary does indicate two things:

- There is a likely relationship between pavement roughness and skid resistance of vehicles, although there is wide variation among experimental results.

- Roughness has a certain derogative effect on (a) vehicle steerability, (b) the driver's visual perception and (c) other fatigue-related effects.

VTI Notat 71A-2000 creates a broad framework for future research into the effects of road surface properties. Of interest is the creation of a matrix that relates the relative impact that various surface properties have on vehicle travel characteristics, and thus transport network effects. Pavement roughness, or unevenness, is indicated as having a broad effect across the spectrum of vehicle travel characteristics:

Significant impact:
Trafficability, comfort, vehicle wear, fuel consumption, route selection, freight damage, pavement life.

Moderate impact:
Road safety, tyre wear, tyre-road noise, pollution.

These impacts can be compared with the three direct effects of pavement roughness presented by Paterson (1987, p11):

- Disturbance of vehicle dynamics

- Increased dynamic loading on vehicles and pavement

- Adverse effect on surface drainage

These three effects each may have small to negligible effects on individual vehicles and of course vary greatly according to circumstance. However, the degree of their summed influence on the economics of a road system has been found to be clearly significant through at least four major empirical studies conducted between 1970 and 1987. Moreover, Paterson states that the total cost incurred by all vehicles due to the neglect of road maintenance typically outweighs the maintenance costs by a factor of 10 to 20 (Paterson, 1987 p13). For this reason, it is clearly understandable that much attention has been paid in recent decades to the management of pavement roughness.

Paterson provides further detail of each of these effects, particularly regarding vehicle dynamics and the subsequent impression of ride quality.

2.3   Pavement damage

It is a widely accepted assumption of traffic engineering that heavy vehicle traffic is almost entirely responsible for traffic-related pavement damage. Thus, the design loads for pavements have traditionally been based on a 'standard' single axle load, derived from the expected heavy vehicle traffic on the road. For smooth roads, the axle load of a moving vehicle is approximately constant and equal to the static axle load (i.e. when the vehicle is at rest). However, as pavement roughness increases, the vertical movements experienced by the travelling vehicle induce significant variations in the axle loads. Although the magnitude of

load variation is dependent on many factors and is difficult to predict, the advantage to be gained in pavement management through an understanding of the dynamic load phenomenon has driven considerable research in the area.

2.3.1 Dynamic tyre loads

In a comprehensive review of literature dealing with vehicle-generated road damage, Cebon summarises the dynamic effect:

> Dynamic tyre forces generate additional dynamic stresses and strains in pavements which are thought to accelerate road surface deterioration, although the mechanisms by which this occurs are not well understood. (Cebon 1989, p107)

The review considers two separate areas of investigation: (a) quantifying the dynamic load, and (b) evaluating the increase in pavement damage due to these loads.

For a predetermined pavement profile and vehicle characteristics, Cebon reports that numerical techniques are relatively accurate at modelling the dynamic wheel loads measured by a test vehicle. Furthermore, the loads generated by the test vehicle are repeatable over the same profile, which leads to the conclusion that certain points along a pavement will be subject to loads of greater magnitude.

Cebon states that these dynamic models are potentially more accurate than static models for analysing tyre forces.

It is conceivable that these modelling techniques could be used to estimate the complete loading pattern for a stretch of pavement, given the elevation profile along the wheel paths and the distribution of heavy vehicles expected along the road. From this loading pattern, predictions could then be made of pavement damage and expected road life. However, as Cebon states, the mechanisms by which roads suffer damage due to vehicle loads are not well understood.

2.3.2 Pavement damage mechanisms

Pavements are designed to be serviceable under design loads for a certain period of time, i.e. design life. A common approach to assess the incremental damage caused by loads exceeding the design load is to use a power law:

$$\frac{N_s}{N} = \left[\frac{P}{P_s}\right]^a$$

The power law is a type of fatigue law based on the assumption that N passes of an axle load P will cause the same amount of damage as N_s passes of a load P_s. For asphalt roads wearing by roughness or rutting, the value of the power a is commonly taken as 4, while for roads failing by cracking the value is 2 (ARRB, 1988). However, empirical studies have shown that the true value for pavement failure may be six or more.

Dynamic effects in this static load model are implicitly considered by use of the power a (Cebon 1989, p136). Other studies have attempted to obtain a more accurate estimation of pavement life by considering the variability of the dynamic loads.

For example, Cebon's approach is based on the assumption that accumulated pavement loading is likely to be much greater at certain points than others, based on the observed spatial repeatability of dynamic loads along a wheel path. The life of the pavement is then likely to be governed by the failure of only a small proportion of the pavement surface. Some conclusions of his research were:

- Theoretically, fatigue damage due to dynamic loads may be up to four times the damage predicted by moving static loads at the worst locations.

- Damage done by articulated vehicles was generally found to theoretically increase with speed.

- The amount of damage peaks at certain 'critical' speeds.

On relatively smooth highways, the pavement damage due to vehicles may reduce with increased speed. This can occur when the decrease in dynamic response of the road surface is outweighed by the increase in tyre load with speed. A typical illustration of his results indicates peak damage occurring at around 27 m/s (97 km/h).
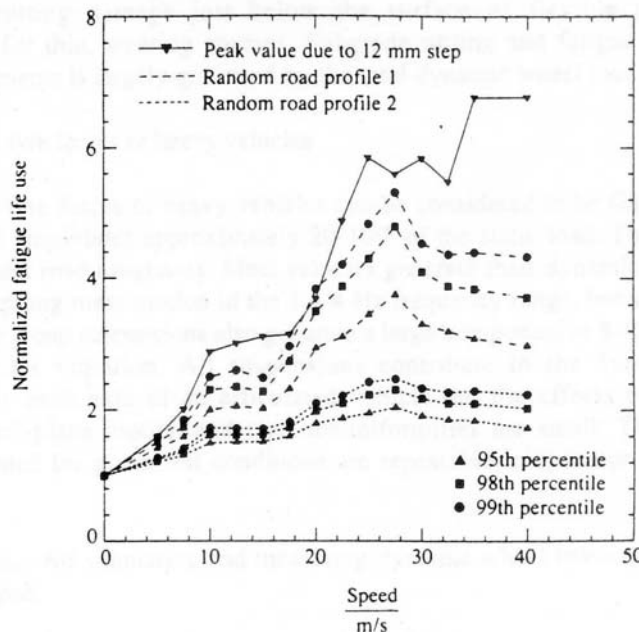
Figure 2.3 Variation of normalised theoretical fatigue damage with speed, due to one pass of a two axle vehicle model with a four-leaf tandem suspension system (from Cebon, 1989)

2.3.3 South African studies

CSIR Transportek conducted a study with the objective of determining a predictive model for dynamic loads over their road network. Their initial work found that although a full finite-element analysis of the tyre-pavement interaction was conceivable, the logistics of the exercise rendered it impractical. Instead, research was focussed on establishing an empirical relationship between the pavement loads and the expected predictors.

The resulting model, applicable to South African conditions, provides a method of estimation for the average dynamic load and the coefficient of variation of that load:

- Avg Load [N] = 12.6 + 1.003 * GVM [N] / num. tyres on vehicle

- CoV Load [N] = 0.39 – 4.0e-7 * GVM [N] – 0.003 * Load + 0.01 * number of tyres + 0.03 * roughness [HRI] + 0.001 * speed [km/h]

   Note: the Half-car Roughness Index (HRI) is a modified version of the IRI.

The summary of the report confirms the relationships indicated by the model:

> Pavement roughness is the primary cause for moving dynamic tyre loads on pavements (Steyn & Visser, 2001).

And

> Management of pavement roughness can aid in limiting the magnitude of moving dynamic tyre loads (Steyn & Visser, 2001).

Many other studies have been undertaken to investigate tyre-pavement interaction from a theoretical perspective. An example is a submission for a Masters of Engineering published by the University of Pretoria that examines many influencing factors of dynamic loads. Of particular relevance is the section regarding the combination of road roughness and vehicle speed:

> Road roughness and vehicle speed represent the two input variables which drive dynamic wheel loading of commercial trucks. Speed affects a vehicle's pavement loading to roughness because as the speed increases, so also do the wavelengths corresponding to the bandwidth of the vehicle. Consequently, the pavement loading of the vehicle at different speeds depends on the spectral contents of the roughness in the different wave bands experienced by the vehicle. (P.E. Van Niekerk, 1992)

2.3.4   Summary

Based on the literature covered, it seems that current understanding of the tyre-pavement phenomenon allows for an accurate estimate of the magnitudes of dynamic loading to be made for a particular road profile and set of vehicle characteristics. Somewhat less is understood of the mechanism by which these loads aggravate the deterioration of a pavement. However, to expand this type of analysis to a scope that would allow for a meaningful threshold value of roughness to be determined is beyond the scope of this study.

Of interest is Cebon's finding that the magnitude of the dynamic load generally peaks at a certain vehicle speed. Whether this peak coincides with any other parameter (for example, a noticeable peak of driver discomfort) is unknown.

2.4   Free vehicle speeds

Botterill & Thoresen (1996) investigated pavement width and roughness as parameters for variation in free vehicle speeds. The study was undertaken in order to improve speed prediction models used in road planning software.

Data for the study was obtained from three sites on two-way two lane rural roads in New South Wales and Queensland, comprising one sealed road (the Newell Highway) and two unsealed roads at Roma and Gympie. By excluding vehicles travelling close to each other, the measured speeds in the data set approximate the free travelling speed for each driver, a statistic used in planning models. The results obtained from the Newell Highway data are of interest to this study, since they provide an indication of the level at which pavement roughness has a detrimental effect on driver comfort at highway speeds.

By use of linear regression and analysis-of-variance (ANOVA) tests, Botterill & Thoresen obtained a statistical measure of the effect of roughness and width across each vehicle group on vehicle speeds. To permit calculations, the median roughness statistic of the pavement at each survey site was categorised into one of three classes: 0-100, 100-130 and 130+ NRM. These roughness classes were then correlated with vehicle speed for each vehicle group, while also including pavement width as a possible predictor. Generally, the length of pavement used to obtain the roughness statistic was quite short, being somewhere between

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500 and 1000 metres. This approach was taken since the job lengths on the Newell Highway were also typically short, on average 1.6km.

By taking roughness to be the only source of variation in vehicle speeds, a significant result was obtained. However, the strength of the result was weakened when pavement widths were introduced as a parameter, suggesting that there was a high inverse intercorrelation between pavement width and roughness. This is to be expected, since relatively narrow pavement widths are usually built to a lower standard and are thus subject to higher rates of pavement deterioration. Statistically, this did present a problem since the lack of sites not demonstrating this intercorrelation of width and roughness prevented Botterill and Thoresen from fully discerning the relative contribution of the two parameters to vehicle speed variation.

Nevertheless, the result of the ANOVA test for only roughness is of interest, since a plot of speed variation against median roughness suggests a 'threshold' value of median roughness at around 130 NRM, above which vehicle speeds decrease significantly. The effect holds for both average vehicle speeds and 85th percentile vehicle speeds (the latter statistic was used to examine whether the effect was any different for vehicles travelling faster than average).
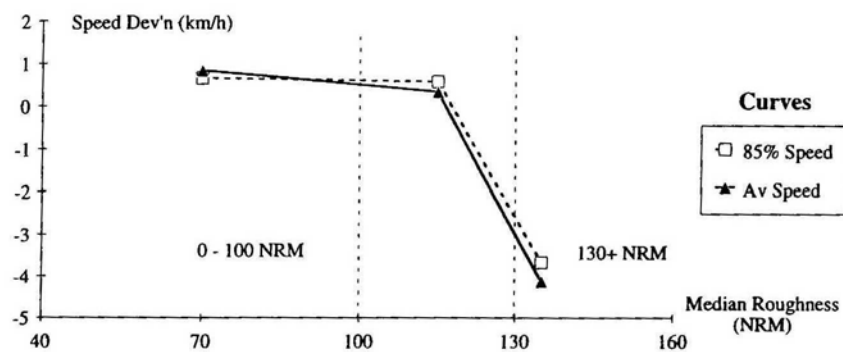

Figure 2.4 Change of speed with roughness

In summary, Botterill & Thoresen conclude that although the effect of roughness on vehicle speed is statistically significant, it is a relatively weak predictor, only accounting for up to 30% of variation. Moreover, further work on a wider data set of paved roads would be required to address issues such as the interaction between width and roughness, and the possible interfering effect of numerous roughness changes due to short job lengths on driver response (compared to large sections of pavement with uniform roughness and width).

2.5 Road safety

2.5.1 Road safety and pavement condition

Craus, Livneh & Ishai (1989) conducted an analysis of road safety with respect to road condition over the Israeli highway network. Their methodology was based on a qualitative assessment of the pavement condition that included a number of factors such as shoulder width and quality, pavement skid resistance, pavement width etc. Although these parameters are not directly related with pavement roughness, the concept of the analysis is broadly similar.

Interestingly, their conclusion was that road safety ought not to be considered as a general quality of a road system, to be correlated with system parameters such as pavement condition etc. Rather, improvements to road safety due to pavement condition should be made on a site-specific basis. This conclusion is based on two broad observations: firstly, external effects such as geometric layout and environmental trends determine the relative effectiveness

of pavement works for decreasing the crash rate at a particular location. Thus, a general recommendation for pavement condition over an entire network will not result in an optimal outcome. Secondly, economic feasibility dictates that the maintained level of pavement condition must always be a compromise. This is often best resolved by prioritising works on a site-by-site basis.

Nevertheless, Craus et al do state that by increasing the shoulders on all highways to 2m or more and ensuring that the skid resistance of the pavement surface exceeds a threshold value, an estimated 250 to 300 accidents per annum might be saved over the entire network.

2.5.2   Rural road safety

A recent publication of the Organisation for Economic Co-operation and Development (OECD) Road Transport and Intermodal Research Programme (RTR) addresses safety issues specific to rural roads (OECD, 1999). Some of the conclusions made are of particular relevance to the question of pavement roughness.

The report states that the main characteristics of the rural road safety problem may be summarised:

> As much as 80% of all accidents on rural roads fall into three categories: single vehicle accidents (especially running-off the road), head-on collisions and collisions at intersections. Single vehicle accidents constitute 35% or more of all fatal rural road accidents… Head-on collisions make up nearly 25% of all fatal accidents on rural roads. (OECD 1999, p132)

Two key factors for these accidents are given:

> Inappropriate and excessive speeds are a key factor in rural road accidents because the actual speeds on rural roads are relatively high under circumstances where these high speeds cannot be driven safely all the time and everywhere. Loss of control is also a major factor, accounting for 35% of the accidents on major rural roads and up to 60% of accidents on minor rural roads. (OECD 1999, p133.)

From these percentages, improvements made to the pavement surface that reduce the likelihood of losing control could be expected to reduce the overall number of accidents by up to 50-60%. However, there are many and various causes mentioned for loss-of-control accidents, such as driver inattention, poor tyre-pavement friction, evasive manoeuvres, poor road design (unsigned sharp curves etc) and overtaking manoeuvres. Inappropriate speed is commonly also a contributing factor to this type of accident.

With regard to the influence of pavement surface parameters on rural road safety, low tyre-pavement friction is indicated to contribute heavily towards accident rate and severity. Pavement friction is largely a function of skid resistance, but it is also adversely affected by increased roughness (of certain wavelengths) and wheel path rutting. For roughness, imperfections with wavelengths of 0.8 to 2.8m are said to have a derogatory effect on friction (OECD 1999, p38). Other research suggests that pavement roughness becomes more important in heavy vehicles accidents compared to light vehicle accidents (OECD 1999, p65).

3 Speed limits

The use of speed limits has traditionally been supported for two reasons, (a) to reduce the number and severity of accidents, and (b) to increase the efficiency of the road transportation system (Cowley 1980, p26). In summarising the main points regarding speed control to road safety, a 1973 publication of the Australian Department of Transport states the following progression:

- Accident risk increases with deviation of vehicle speed away from average.

- Accident severity increases exponentially with the speed of the accident-involved vehicle.

- The objective of speed controls is to reduce variance in the distribution of vehicle speeds. In particular, maximum speed limits are used to reduce the number of vehicles travelling at excessively high speeds.

- Thus, significant reductions in accidents and fatalities may be achieved by the imposition of speed limits. (Cumming & Croft 1973, p72)

For this reason, the speed limit is typically determined by the 85th percentile of free vehicle speeds, under the assumption that the 85th percentile is a good indication of the speed seen to be reasonable by most drivers. However, consideration for increased road safety as well as economic performance has led to the adoption of lower speed limits in the last few decades. (The introduction of a 55mph general highway limit in the USA during the energy crisis of the 1970's is one of the most prominent examples of this type of policy).

3.1 Comparing 100 kph and 110 kph limits

A 1980 review of Australian rural speed limits clearly affirmed that while general limits varied between the states as 100kph or 110kph, little work had been conducted in Australia to substantiate either of these values (Cowley 1980, p25). Moreover, a lack of available data prevented any meaningful economic analysis from being undertaken for this purpose.

However, based on the results of various studies and the exercise of engineering judgement, Cowley presented the following summary of arguments for and against both speed limits:

100 kph limit	*110 kph limit*
For:	For:
- 'safe' and in line with worldwide trends;	- realistic in terms of driver compliance;
- generally restrictive;	- realistic in terms of enforcement;
- probably suitable for both day and night driving.	- consistent across network; i.e. would not require speed zoning at higher levels.
Against:	Against:
- safety benefits possibly short-term only;	- not restrictive nor in line with worldwide trends;
- probably requires an increase in enforcement of, say 10%;	- probably no safety benefits;
- high standard roads and freeways might require to be zoned at a higher limit.	- probably requires a lower limit for night driving.

Of the two, Cowley supports the adoption of 110 kph as a general rural speed limit, with a differential limit of 90 kph for heavy vehicles, omnibuses, towed caravans, and all night driving. However, the development of heavy vehicles since 1980 may well have annulled the requirement for a differential limit.

Cowley's reckoning of a 110 kph limit as being more reasonable in terms of driver compliance and thus enforcement is based on the results of a survey of free vehicle speeds across mainland Australia conducted in 1978/79. Broadly, the survey found that average vehicle speeds for cars (i.e. 50th percentile speeds) ranged from 90 to 100 kph, while 85th percentile speeds varied from 100 to 110 kph. Notably, there was no correlation of these values with the prevailing speed limit (either 100 or 110 kph, depending on the state or territory). This observation can be explained by the general premise that drivers will mostly ignore a speed limit that is seen to be unreasonable for the prevailing conditions. Thus, Cowley concludes that a limit of 110 kph is likely to be more inclusive of the 85th percentile drivers nationwide, based on this 1978/79 speed data.

A more recent assessment of higher rural speed limits by Donald & Cairney (1997) found that in general an increase in speed limit does lead to an increase in average vehicle speeds, and vice versa. The writers do acknowledge that most of the studies quoted are from international sources with much different traffic trends and compositions than Australian rural highways, undermining the usefulness of direct comparisons. Nevertheless, based on these observed trends, anecdotal evidence and their engineering judgement, Donald & Cairney suggest that an increase in speed limit from 110 to 120 kph on rural roads in Western Australia would lead to a likely increase in average traffic speeds of between 3 to 5 kph. Although for many drivers raising the limit simply 'legalises' the speed at which they previously drove at, the writers point out that some drivers will always tend to drive over the speed limit regardless of how high it is. These observations are likely to also hold true for the increase on Queensland rural highways from 100 to 110 kph.

3.2 Speed limit and road safety

In the same report, it is shown that the trends in road safety with speed limit changes are not as well defined. The results of many European cases are quoted, of which most report that reductions in speed limit correlate with declines in fatality rates, at least in the short-term. Two instances are quoted in which an increase in speed limit was associated with (a) in the Netherlands, a reduction in fatality rate, and (b) in five states of the USA, a reduction in variance and dispersion of vehicle speeds but with no significant change in accident rate. It is worth noting that the Netherlands change was accompanied by a concerted effort to heavily police the new limits.

A similar review of trends in road safety following changes in speed limit on Victorian roads provided

> clear evidence that reducing speed limits can lead to reduction in casualty crashes in both urban and rural environments. (Pirrotta & Szwed, 2001)

Moreover,

> when speed limits are raised casualty crashes increase, and while improved road design and construction standards may be able to mitigate this increase they cannot be eliminated. (Pirrotta & Szwed, 2001)

One of the studies mentioned in the report is of particular interest because it specifically documents the changes in crash rate due to increasing and subsequently decreasing the limit

from 100 to 110 kph on both urban and rural freeways. The change (expressed as a percentage change of crashes per km) pertaining to rural highways over the measured period (3 years either side of changing the speed limit) was an increase of 15% and a decrease of 17% corresponding to the increase and decrease in limit respectively. Because the freeways considered are all four-lane divided highways, these results are not directly applicable to rural Queensland highways. However, the overall trend discerned by Pirrotta and Szwed is a positive correlation between speed limit reductions and road safety. This trend is consistent with the results of similar international studies mentioned in their review.

It is worth noting that other studies have failed to detect such significant relationships between speed limit and road safety (for example, a US Department of Transportation report cited at http://www.ibiblio.org/rdu/p-sl.html).

While not being directly relevant to this thesis, a paper by Waller (2002) is of interest for introducing an issue that is generally overlooked in the other studies. The paper is a summary of the main parameters to be considered in the selection of a suitable national speed limit for the US highways. Of the many points Waller raises, the changing demographics of drivers due to an increasingly aging population is mentioned as being perhaps the most significant issue in setting speed limits. The unavoidable loss of driving proficiency that occurs with age is reflected in the increase of crash risk per mile driven for drivers in their late 50's to 60's, continuing to their 70's and older (NHTSA, 2000 and Peck and Romanowicz, 1993/94 cited in Waller, 2002).

3.3   Vehicle speed and road safety

It is generally a well-acknowledged fact that there is a strong relationship between individual vehicle speed and accident severity. More recently, the connection between vehicle speed and the risk of accident involvement has also been established by studies both in Australia and overseas.

A recent study conducted by the Road Accident Research Unit of Adelaide University clearly established that

> in rural out of town areas, the risk of involvement in a casualty crash increases greater than exponentially with increasing free travel speed. (Kloeden, Ponte & McLean, 2001)

Their study was based on a detailed investigation of 83 case vehicles involved in 76 casualty crashes occurring in 80 kph or greater speed limit zones in rural areas within 100km of Adelaide. The case vehicles were chosen to eliminate causes of accident that would negate free travelling speed being a reasonable factor (eg. blood alcohol level, medical condition). The investigation of each crash site was thorough enough to ensure that enough information was collected so that the free travelling speed of each vehicle prior to the crash could be determined.

Each crash investigated was reconstructed using computer modelling to determine the likely free travelling speed of the each case vehicle. For comparison, the speeds of 10 other vehicles similar to the case vehicle and subject to the same conditions (location, direction, time of day etc) were measured at each crash site. From this information, the risk of crash involvement as a function of travelling speed could be determined, in terms of both absolute speed and relative speed. To facilitate the combination of data from different sites, the data set used was based on the relative speeds of the case vehicles to the average rather than absolute speeds.

In summary, the relative risk of involvement in a casualty crash as a function of variance in travelling speed was plotted as follows:
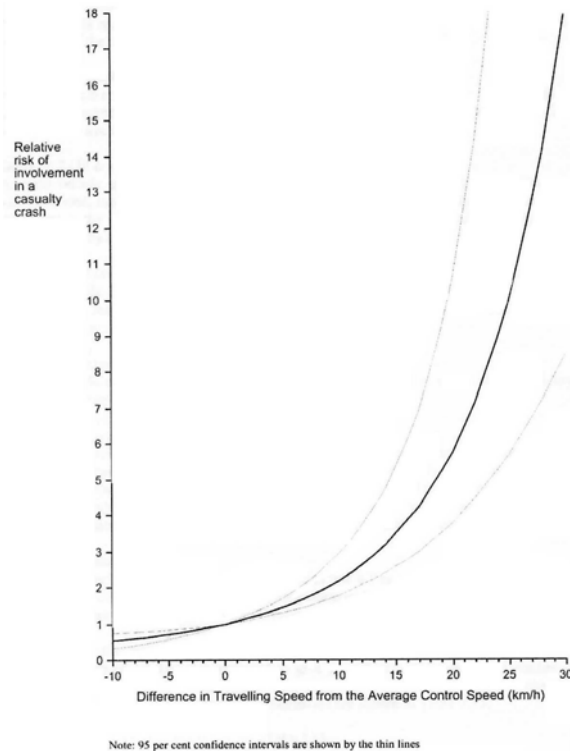
Figure 3.1 Differences between the travelling speed and average control speed against the risk of involvement in a casualty crash relative to travelling at the control speed (from Kloeden, Ponte & McLean 2001)

As shown, the authors found a strong increase in risk for drivers travelling above average speed. No correlation could be made for drivers travelling below average speed, a finding that apparently contradicts much earlier studies conducted in the United States such as those by Solomon (1964), Cirillo (1968) and the Research Triangle Institute (1970). However, as the authors discuss in their report, the findings of these earlier studies may be biased due to the assumptions inherent in the methodology used.

The study continues by using the crash reconstruction program to determine the hypothetical reduction in crash severity that would occur if the case vehicles were assumed to be travelling at a lower speed. The entire study provides compelling evidence that unnecessarily high travelling speeds have a significant detrimental effect on the safety of rural highways.

Another recent, much broader study conducted by the Transportation Research Laboratory (TRL) in the UK sought to relate average road speeds to accident frequency with respect to the type and condition of the road. The statistical data used in the study was obtained through a European Union research project and covered two to three hundred stretches of road. The significance of the results was that statistical models were produced for a variety of road types and conditions, providing an important tool for the development of speed management strategies. Moreover, having such clear evidence of the relationship between speed and accident risk may provide the basis for a change in the public attitude toward speed in a similar fashion to that of driving while under the influence of alcohol.

While the results obtained are not directly applicable to Australian rural conditions, the study does confirm the distinct trend of increased casualty accident rate with average traffic speed.

4　Discussion

4.1　Roughness

i. Roughness is generally used to describe pavement condition with a single numeric parameter. There are numerous methods of calculating roughness. The NAASRA Roughness Meter used by Australian road authorities is accurate and efficient and correlates well with community perceptions of driver comfort as well as international standards of roughness measurement.

ii. Based on consultation, the maximum level of roughness for a road to be deemed adequate by the community is in the range of 130 to 160 NRM, depending on speed. Measurements of free travelling vehicles at highway speeds indicate a threshold awareness level of about 120 to 130, above which vehicle speeds begin to reduce implying a noticeable driver reaction.

iii. Roughness is the main factor for dynamic loading and thus accelerated pavement damage and deterioration. Vehicle speed has a less significant effect on dynamic loading. Notably, for a given profile, the damage suffered by the pavement often exhibits a peak at a certain vehicle speed. Above this speed, the pavement damage suffered decreases.

iv. An Israeli study found little evidence to link pavement condition with road safety on a system-wide basis. Rather, situations where pavement condition is detrimental to road safety are generally confined to specific locations (ie 'black spots').

However, based on a 'first-principles' consideration of the influence road roughness has on vehicle travel behaviour, it could be expected that high levels of roughness will impair a driver's capability, and in summation, the overall safety of a road. Conversely, lower levels of roughness could be expected to aid the driver in operating at full capability. Nevertheless, no literature exists to confirm such an effect.

4.2　Speed limits

v. There is clear evidence that compared to similar roads zoned at 100 kph, the average vehicle speed will increase for traffic on roads zoned at 110 kph. Less clear is whether the variation of the speed distribution increases or not under the higher limit.

vi. As a direct result of the rise in vehicle speeds, accident severity may be expected to increase. The likelihood of an increase in accident frequency is less well defined in terms of absolute speed, being linked more to the degree of variation in the traffic speed distribution.

vii. Higher speed limits demand greater driver control and awareness. For an aging population, the level of control demanded becomes progressively harder to achieve.

4.3　Summary

In terms of road safety, it can be deduced that a limit on pavement roughness at the threshold level of driver awareness may be expected to help mitigate the increased risk of accident on roads under a higher speed limit.

From a pavement management perspective, there is less evidence to support a particular limit on pavement roughness for 110 kph roads since the likely rise in vehicle speeds will result in a relatively small increase in pavement damage.

Data Analysis

5   Approach

In order to determine whether the conclusions derived from the literature review regarding road safety were in fact observable, a trial analysis of data obtained from rural highways in Southern Region was undertaken.

The concept of the analysis was to determine whether there is any evidence of a relationship between roughness and crash rate. Such a relationship was expected to be proportional in nature, with a threshold value below which no effect would be observed.

The main statistical difficulty in attempting this kind of analysis is the relative scarcity of accidents along rural roads, due to the relatively low traffic volumes on these roads. In comparison, pavement roughness measurements are obtainable along the entire length of a road in almost any increment length (a minimum of 10m for NRM counts). Thus, to make a useful comparison, these two variables need to be expressed over a common length of road.

To obtain a statistically useful data set, it was decided to adopt an approach by which each road was divided into segments of around 20km, each segment having a roughly uniform roughness distribution. Then over a period of a few years, enough accidents could be expected to accumulate to calculate a meaningful crash rate for each segment (number of crashes per traffic volume and segment length). This crash rate value can then be correlated against a roughness parameter for the same segment. The two roughness parameters considered were (a) the average roughness count and (b) the percentage of counts exceeding 120 NRM for each segment. The average roughness count was expected to be more useful in determining whether a proportional relationship exists, while the percentage parameter was intended for examining any possible threshold effects.

The threshold value of 120 NRM corresponds to the limit specified in the MUTCD for 110 kph speed limits.

5.1   Data requirements

The data set used was derived from roads within Southern Region. The main reason for this was to begin the analysis with a data set small enough to try different approaches easily. It was thought that this might also minimise possible interfering factors due to regional differences, while ensuring that a result meaningful for Southern Region could be obtained. Originally, it was intended to extend this analysis to include all of Queensland, however this did not eventuate due to time constraints.

5.1.1   Roads included

The highways included in the 110 kph data set were the Landsborough Hwy (13A & 13B), Warrego Hwy (18C & 18D), Mitchell Hwy (23B), Gore Hwy (28B) and Moonie Hwy (35A). To provide a comparison data set of 100 kph roads, the 17C as well as the sections of the above highways zoned at 100 kph were used.

5.1.2   Crash statistics and traffic volume

Crash data and traffic volume data for each road over the past five years (January 1997 to June 2002) was provided by Wayne Dale (QT) and Michael Szymanowski (QT), respectively.

The five year period was chosen as being a reasonable compromise between having enough crashes to obtain a meaningful crash rate and obtaining a uniform data set in terms of changes to the road environment, traffic composition etc.

For the accidents on the 110 kph highways, detail was provided of the crash date, nature of the crash, the prevailing weather and lighting conditions, crash severity (based on injury outcome) and speed zone. This accommodated a degree of control in selecting the crashes to be included in the crash rate calculation. However, this detail was not available for the 100 kph roads due to time constraints.

5.1.3   Roughness

The roughness data used in the analysis was provided by Emma Hutchinson (Roads Information Officer, Roads Information Branch, DMR) in tabular form. The tables provided the following information in 10m increments along each road:

- NRM count
- date of NRM survey
- start and end chainages
- pavement width
- number of lanes
- speed limit

Data for the most recent survey was obtained for each road. This was early 2002 for most of the roads, except for the 23B and 35A, which were last surveyed in early 2001.

It was realised later that this would lead to possible inaccuracies in correlating these roughness values against a crash rate averaged over the past five years. For example, it is meaningless to associate a crash occurring in 1997 with roughness data for 2002, particularly if a reseal or reconstruction of the road had occurred between these dates. However, time constraints prevented annual records of roughness data for the past five years being obtained from Emma and implemented into the data set to remove these errors.

5.2   Creating the data set

In creating the data set used in the analysis, the following process was used:

a) Each road was divided into segments of around 20 to 40 km based loosely on a graphical inspection of the roughness distribution, job history and location of accidents for each road. At this stage, data for the 110 kph section of the 23B was discarded since there were only two recorded crashes on that road.

b) Pavement roughness statistics were acquired for each segment (average and standard deviation of NRM counts as well as the binned distribution of counts from 10 to 200 NRM, each bin being 10 NRM wide).

c) Traffic volume and crash statistics were acquired for each segment.

The average crash rate for the previous five years was calculated for each segment using the formula:

$$\text{crash rate} \;=\; \frac{10^3 \;\times\; \text{number of crashes}}{\text{segment length} \;\times\; \text{AADT}}$$

Both the number of crashes and the AADT (annual average daily traffic) were taken over the entire five year period. It was intended that the crashes included in the calculation could be selected based on details such as the type of crash, environmental conditions, crash severity and governing speed limit as provided in the crash records. Regrettably, this could not be done for the crashes on the 100 kph roads since sufficient detail was not provided in time.

The calculated crash rate could be plotted against the pavement roughness parameters for each segment to graphically observe any relationship.

Furthermore, the segments could be grouped into categories based on the roughness parameters, and the average crash rates for these grouped segments compared using histograms to assess possible threshold effects.

The plots and histograms obtained are included in Section 6 (Graphs) in Figures 6.1 through 6.8.

6   Graphs

Figures 6.1 and 6.2 show crash rate plotted against average roughness for segments in 110 and 100 kph zoned roads, respectively.

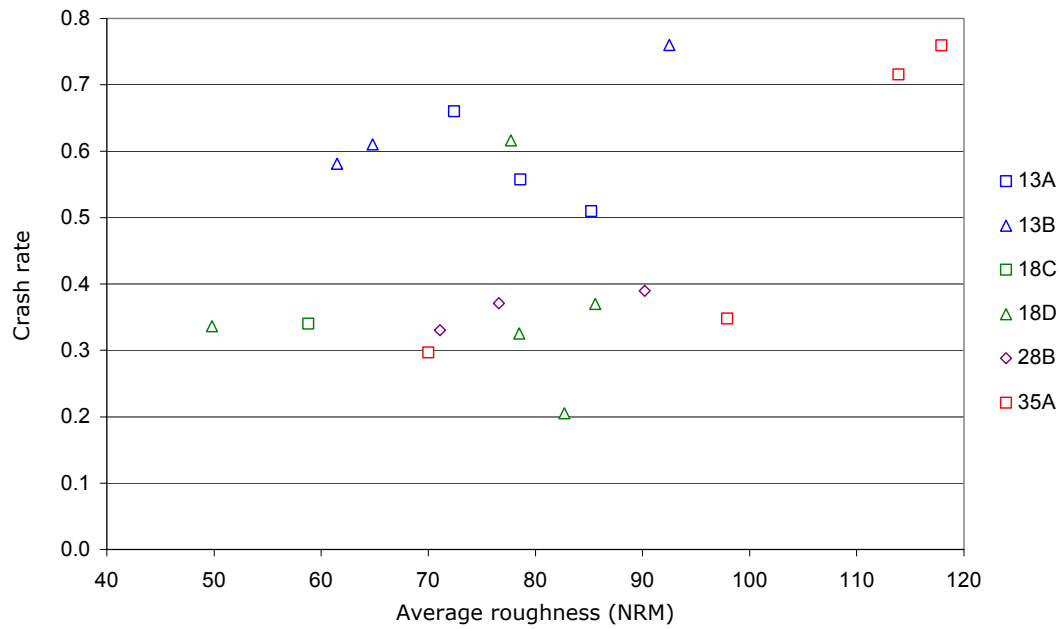*Figure 6.1 Crash rate with average roughness, 110 kph roads*
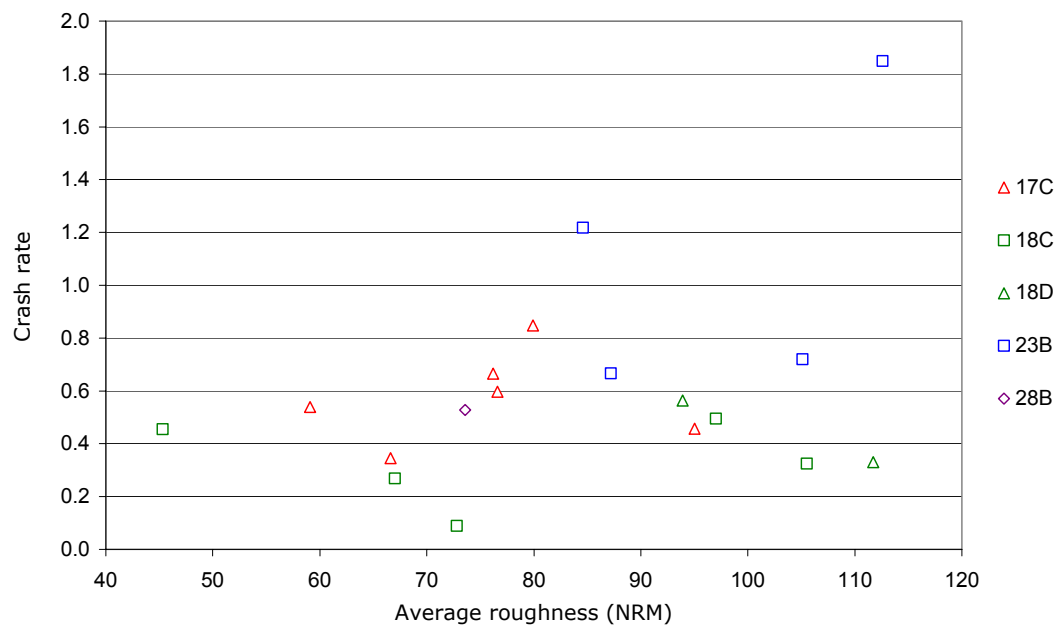
Figure 6.2 Crash rate with average roughness, 100 kph roads

19

Figures 6.3 and 6.4 show crash rate plotted against threshold percentage for segments in 110 and 100 kph zoned roads, respectively.
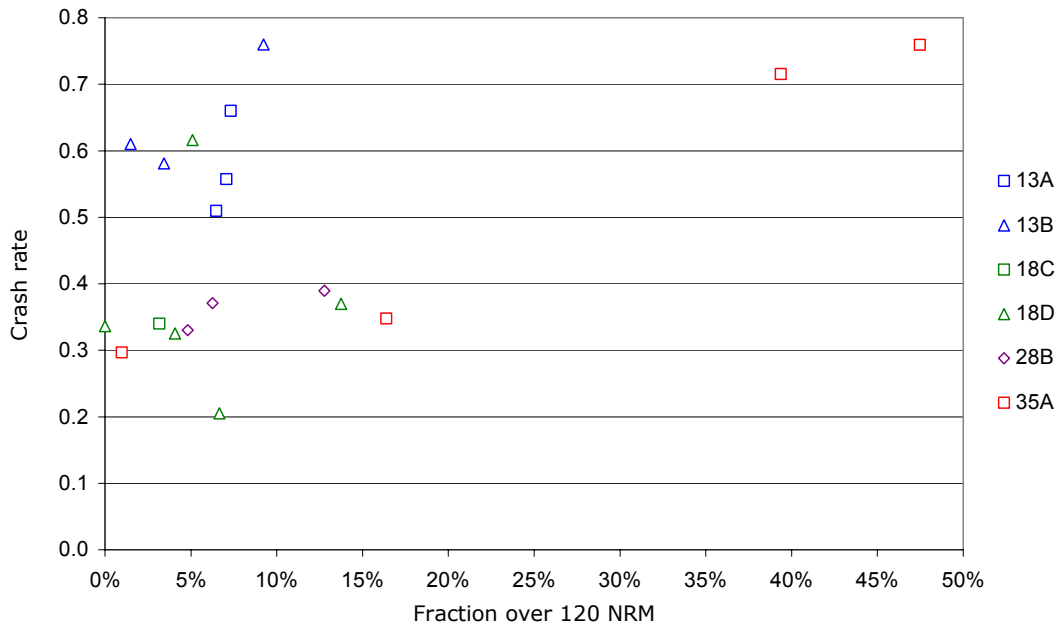
Figure 6.3 Crash rate with fraction of segment over 120 NRM, 110 kph roads
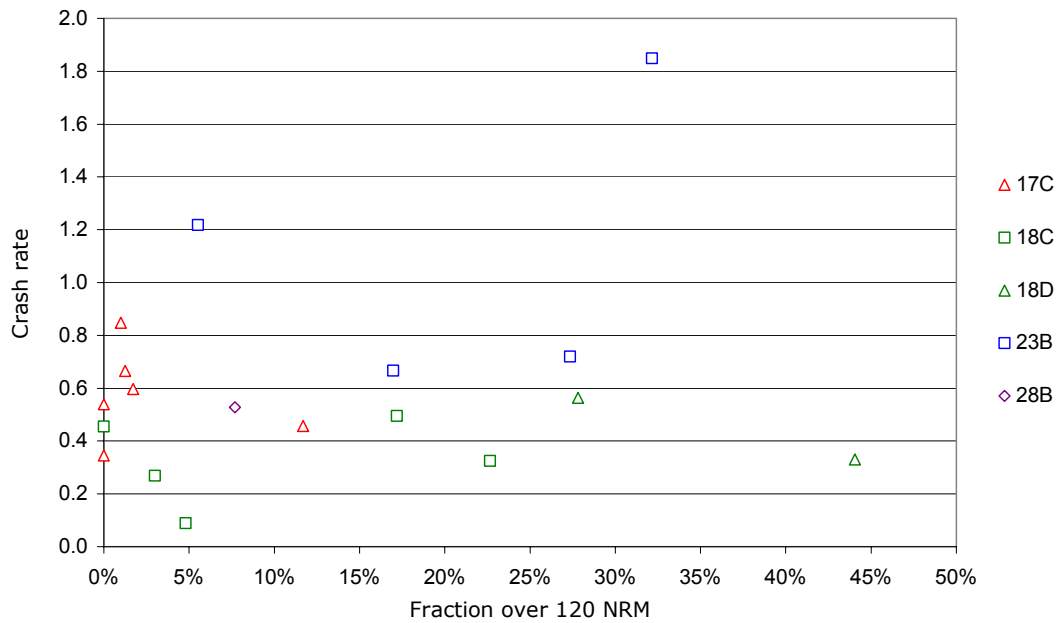
Figure 6.4 Crash rate with fraction of segment over 120 NRM, 100 kph roads

Figures 6.5 and 6.6 show histograms of average crash rate for the segments collected in each of the average roughness bins.
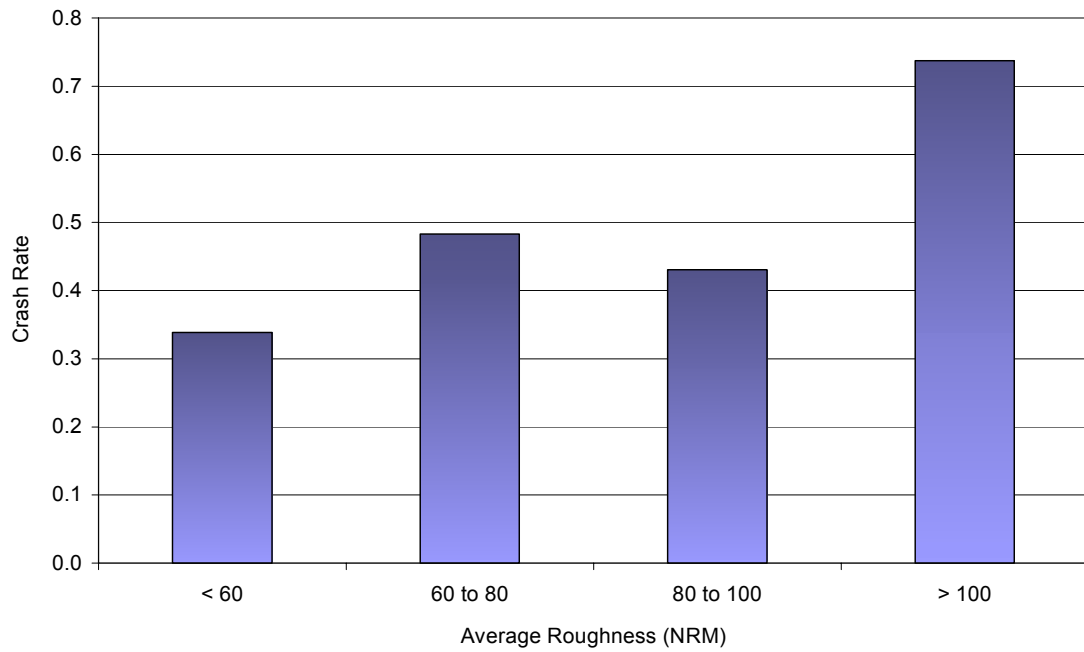
Figure 6.5 Average crash rate for roughness bins, 110 kph roads
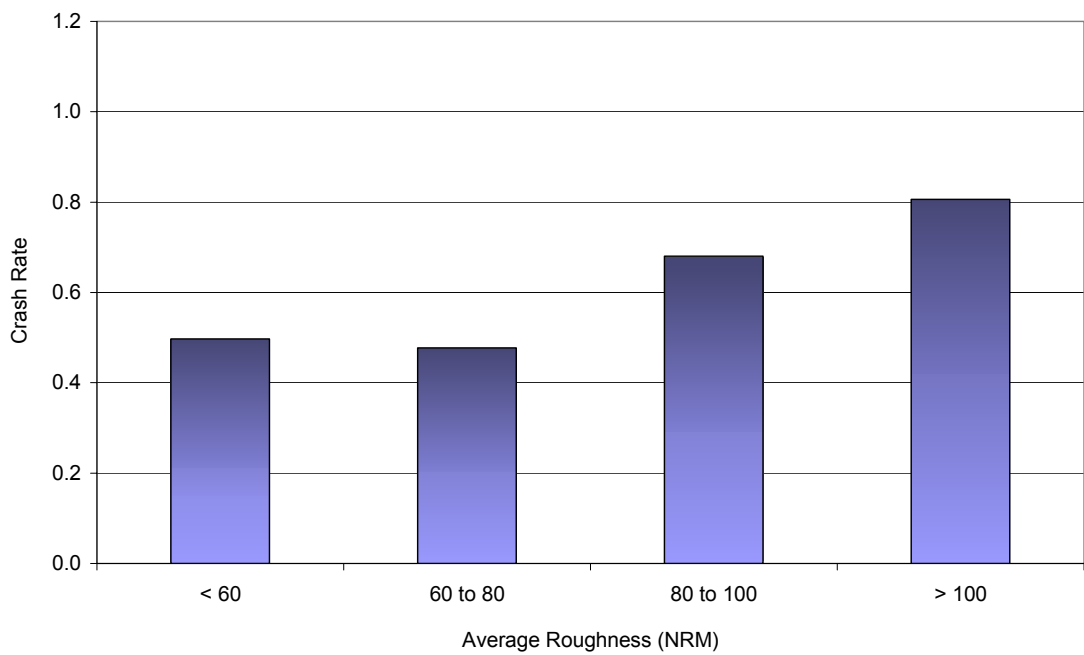
Figure 6.6 Average crash rate for roughness bins, 100 kph roads

Figures 6.7 and 6.8 show histograms of average crash rate for the segments collected in each of the threshold percentage bins.

Figure 6.7 Average crash rate for percentage bins, 110 kph roads

Figure 6.8 Average crash rate for percentage bins, 100 kph roads

7   Analysis

7.1   Graphical results

From the graphical results obtained, some relationship can be observed between crash rate and roughness. However, a large amount of variance is evident in the plots of crash rate with roughness, which obviously is due to a number of uncontrolled factors.
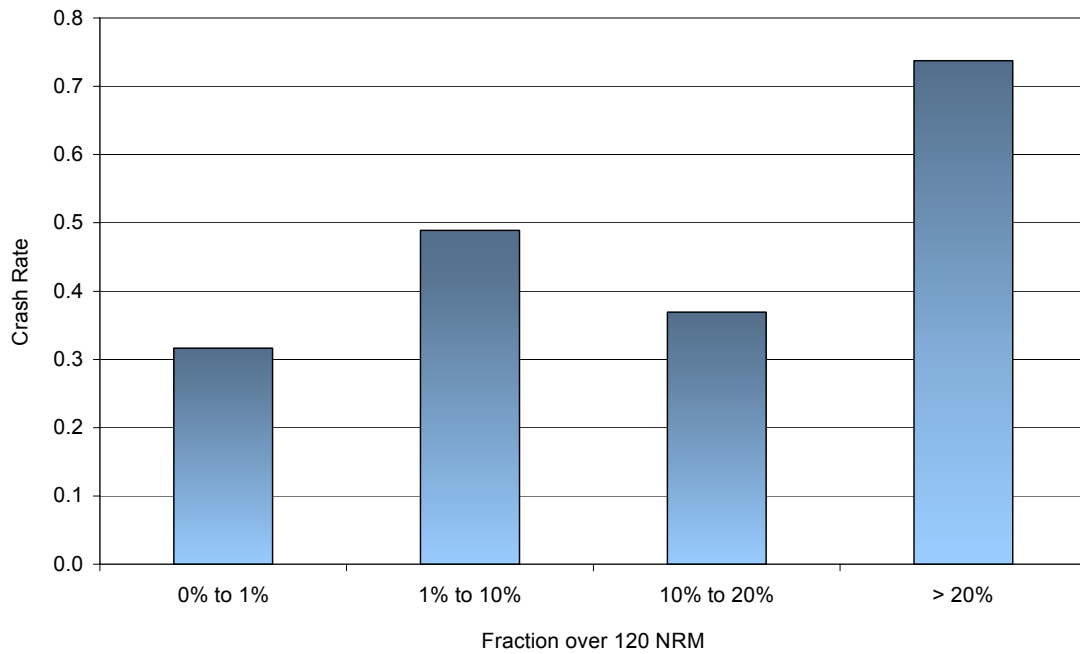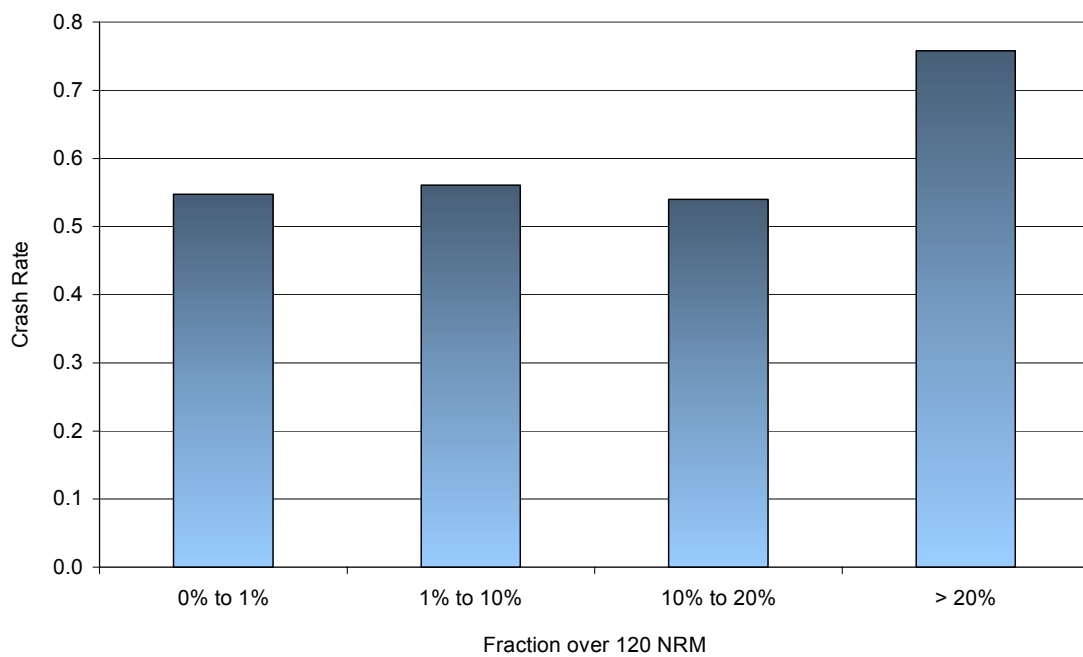
7.1.1   110 kph graphs

From the 110 kph data, there seems to be a qualitative regional factor for some of the roads considered. For instance, for an average roughness of below 100 NRM, the crash rate for the 13A/B is generally much higher than that of the 18C/D, 28B or 35A (Figure 6.1).

Three of the five roads display some increase in crash rate with average roughness. The increase is particularly pronounced for the segments taken from the 35A. The two segments from the 35A with large roughness and crash rate are taken from chainages of 60-90 km and 90-112 km along that highway. For the plot of crash rate with percentage over threshold (Figure 6.3), the distinction between the two outlying values and the remaining segments becomes even more pronounced. These two values are what drive the large increase in average crash rate for the highest roughness categories in the two histograms (Figures 6.5 and 6.7).

7.1.2   100 kph graphs

The plots of the segments from the 100 kph data show little evidence of a relationship between roughness and crash rate (Figures 6.2 and 6.4). The one large value from the 23B can probably be considered an outlier, since segments of similar roughness along the 18C/D do not display such an increase in crash rate relative to other segments on the same road. This single value largely drives the threshold effect observable in the histograms (Figures 6.6 and 6.8).

The presence of outliers in the data does conform to the conclusions of Craus et al as mentioned in the literature review[1]. However, as mentioned previously[2], a significant possibility of error in the data collection may explain these outlying data points instead.

7.2   Statistical tests

To quantitatively test the statistical significance of these findings, two methods were used:

- Linear regression of crashes with average roughness.

- Hypothesis testing of the equality of means for grouped segments above and below a threshold value.

All of the tests were conducted using the data analysis add-in functions available in Microsoft Excel.

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[1] Craus et al (1989) conducted a study of road safety as a function of pavement condition over the Israeli highway system. In short, their findings were that road safety can only be considered to be affected by location-specific deficiencies in road condition ("black spots") rather than generic, system-wide parameters.
[2] Refer Section 5.1.3

7.2.1   Linear regression

The first regression tested the following model:

sum crashes = f (traffic volume, segment length, average roughness count, speed limit)

Regression Statistics	
Multiple R	0.829034651
R Square	0.687298453
Adjusted R Square	0.628568009
Standard Error	0.479371067
Observations	37

ANOVA

	df	SS	MS	F	Significance F
Regression	4	16.66759395	4.166898488	18.13298428	7.199E-08
Residual	33	7.583288443	0.229796619		
Total	37	24.25088239			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
aadt	0.001038174	0.000134956	7.692673232	7.38142E-09	0.000763603	0.001312744
seg length	0.043706491	0.007943088	5.50245613	4.1853E-06	0.027546145	0.059866837
avg NRM	0.00450428	0.00437939	1.028517783	0.311186386	-0.004405662	0.013414223
speed limit	-0.004169272	0.004494819	-0.927572911	0.360364153	-0.013314057	0.004975513

Table 7.1 Results of Regression A

The results shown in Figure 7.1 indicate that the model is moderately strong as a predictive tool, with an R^2 value of around 0.65. In addition, both the average roughness count and the governing speed limit are found as not being significant, with p-values exceeding 0.3.

A second regression tested the model:

crash rate = f (average roughness count, speed limit)

Since the crash rate calculation implicitly accounts for traffic volume and segment length, this model was expected to provide a more detailed look at the effect of roughness.

Regression Statistics	
Multiple R	0.363651541
R Square	0.132242443
Adjusted R Square	0.078877942
Standard Error	0.28914688
Observations	37

ANOVA

	df	SS	MS	F	Significance F
Regression	2	0.445941124	0.222970562	2.666923197	0.083967746
Residual	35	2.92620713	0.083605918		
Total	37	3.372148254			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
avg NRM	0.006873393	0.002577669	2.666514573	0.01152398	0.00164044	0.012106347
speed limit	-0.000234729	0.002055006	-0.114222938	0.909713808	-0.004406618	0.003937161

Table 7.2 Results of Regression B

The results shown in Figure 7.2 suggests that the average roughness count may be a significant factor for crash rate, with a p-value of less than 2%. However, the R^2 value for the model is only around 10%, indicating that it is almost useless as a predictive tool. It is concluded that neither of the regression models are particularly useful for determining a relationship between pavement roughness and road safety.

7.2.2   Threshold effects

The histograms shown in Figures 6.7 and 6.8 indicated that a strong threshold effect was evident for segments with more than 20% of pavement roughness counts exceeding 120 NRM. Figures 6.5 and 6.6 displayed a similar effect in terms of average roughness, with a threshold value of 100 NRM.

To test the significance of this threshold, the segments for each speed limit set were grouped into two categories based on the percentage exceeding 120 NRM: from 0 to 20%, and > 20%. These two samples were then tested under the hypothesis that the average crash rates for the two populations were equal, using two-sided t-tests. This test was done separately on each of the speed limit data sets, in order to observe whether the threshold value ought to be applied only to one limit or both.

The tabulated results obtained for these tests are shown in Tables 7.3 through to 7.6. In short:

(a) For 110 kph roads, there is strong evidence to suggest that the average crash rates across the 20% threshold are not equal (p-value = 0.000). The difference in crash rates between the two groups is given as at least 0.1916 (and at most 0.3886) at the 95% confidence interval, representing a percentage increase of at least 40% (and at most 80%).

(b) For 100 kph roads, there is not enough evidence to disprove the hypothesis that the average crash rates across the 20% threshold are equal (p-value = 0.338).

Thus, for the data set used, the analysis does provide a statistical basis for stipulating that not more than 20% of the roughness counts over a given road segment should exceed 120 NRM.

However, it should be noted that the sample size used in this analysis is very small; of the 19 segments in the 110 kph roads data set, only the two segments from the 35A fall into the >20% roughness category. Since these two segments are from the same road and are geographically close, it cannot conclusively be asserted that the high roughness parameter is causing this increase in crash rate. Other possible factors may include road geometry, traffic type and speed distributions as well as the proportion of traffic travelling at night, none of which has been investigated as part of this thesis. A larger data set that enables these other factors to be controlled would be required for this apparent effect of pavement roughness on crash rate to be conclusively established.

The method was repeated using the average count for each segment as the roughness parameter and a threshold value of 100 NRM. This provided almost exactly the same results as the previous threshold test, because the division of the segments by the chosen threshold value was almost the same. This can be seen by comparing the location of values between Figures 6.1 and 6.3 and similarly between Figures 6.2 and 6.4. Thus, the data set provides no basis for distinction between the two roughness thresholds considered.

Speed limit = 100 kph

Group Statistics[a]

	F2	N	Mean	Std. Deviation	Std. Error Mean
RATE	0% to 20%	13	.5516	.2767	7.675E-02
	> 20%	5	.7578	.6324	.2828

a. LIMIT = 100.00

Table 7.3 Group statistics, 100 kph roads

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RATE	Equal variances assumed	3.200	.093	-.987	16	.338	-.2062	.2088	-.6488	.2364
	Equal variances not assumed			-.704	4.602	.516	-.2062	.2931	-.9795	.5672

a. LIMIT = 100.00

Table 7.4 Independent samples test, 100 kph roads

Speed limit = 110 kph

Group Statistics[a]

	F2	N	Mean	Std. Deviation	Std. Error Mean
RATE	0% to 20%	17	.4474	.1562	3.789E-02
	> 20%	2	.7375	3.182E-02	2.250E-02

a. LIMIT = 110.00

Table 7.5 Group statistics, 110 kph roads

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RATE	Equal variances assumed	5.455	.032	-2.557	17	.020	-.2901	.1134	-.5294	-5.07E-02
	Equal variances not assumed			-6.583	9.793	.000	-.2901	4.407E-02	-.3886	-.1916

a. LIMIT = 110.00

Table 7.6 Independent samples test, 110 kph roads

Conclusions

8   Summary

There are potentially two major aspects of a road transportation system directly affected by high pavement roughness:

(c) road safety, and

(d) economic costs

Although pavement maintenance is a continual expense for road authorities, the large proportion of economic costs is incurred by road users through mechanisms such as vehicle wear and inefficiencies in travel. The magnitude of the possible costs to the economy requires road authorities to actively manage the pavement condition of road networks. In light of this, a system-wide limit on pavement roughness seems to be a reasonable measure to take. However, a review of literature regarding pavement damage provides little evidence to support the selective implementation of such a limit on roads governed by a 110 kph speed limit over roads under a 100 kph limit, particularly for rural areas. This is simply because the likely difference in vehicle speeds under the higher speed limit is small enough to have negligible influence on pavement life, particularly in consideration of the low traffic volumes experienced by rural roads.

In terms of road safety, it is intuitive from a first-principles examination of roughness effects to expect that a network approach to managing roughness should be taken. Instead, the major finding of only other comparable data study[3] is that road safety is best managed in terms of local failure points in the system (black spots) rather than as a continuous function of system-wide parameters. While excessive pavement roughness may certainly be a factor at some of these black spots, over the entire system no overall trend of safety with roughness will be evident.

The results of the data analysis are somewhat inconclusive:

(a)   There is little statistical evidence of a proportional relationship of roughness with crash rate.

(b)   Statistical tests of a threshold effect do provide an apparent basis for applying a roughness limit to 110 kph roads, although an examination of the underlying data shows that this result is driven by a very small number of observations. Subsequently, the possibility that this perceived threshold effect is caused by an accumulation of other factors cannot be discounted.

Thus, despite the apparent support for a roughness limit, it seems most probable that the data does conform to the findings of the Israeli study. A further expansion of the data set would be required to validate this conclusion.

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[3] Craus et al (1989)

9   Conclusion

Notwithstanding the conclusions obtained from a first-principles consideration of pavement roughness effects, there is little statistical evidence to support the use of a general limit on roughness for 110 kph two-way, two-lane rural roads.

10   Recommendations

An expansion of the data analysis to include all 110 kph two-way two-lane rural roads in Queensland is required to confirm or disprove the preliminary findings of this study before a conclusive decision can be made.

A complete review of 110 kph speed limit criteria currently being undertaken by the Department of Main Roads is expected to provide further information regarding this particular issue, among a broader range of criteria.

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