University of Southern Queensland

Faculty of Health, Engineering and Sciences

The effect of wide centreline treatments on run-off-road-left incidents on rural Queensland highways and potential for a review of road shoulder width guidelines

A dissertation submitted by

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Abstract

Head-on/Cross centreline (HOCL) crashes are one of the most severe crash types and a disproportionate number of these occur on Australia's rural highways. Wide centreline treatments (WCLT) have been introduced to several major Queensland highways since 2011 to reduce the likelihood of these crashes by providing up to 1m of lateral separation between opposing traffic flows. The effectiveness of this treatment has been the focus of several Bruce Highway studies in Queensland. All studies indicated reduced HOCL crash rates suggesting the more rural highways WCLT can be applied to, the greater the number of severe crashes can be prevented. Notably, these studies also determined a large reduction in the rate of run off the road left (RORL) crash types despite hypothesising that this crash type may increase.

This study aimed to determine if the significantly reduced rate of RORL crashes could be verified on other rural highways across south-east Queensland. If so, subsequent investigations into the effect of WCLT on driver behaviour and vehicle position could be supported which may lead to further investigations into the potential use of narrower sealed road shoulders with WCLT.

The empirical Bayes (EB) approach was identified as suitably robust and able to account for component effects. The analysis used crash data from both reference and treatment sites. Reference data was used to develop safety performance functions that enabled 'predicted' crash numbers at treatment sites to be calculated. These were compared with the actual crash figures to quantify the effect of WCLT on low volume rural highway crashes, particularly on RORL events.

This study found no support to verify that WCLT reduces the RORL rate on low volume rural highways when all overtaking types are considered. Additionally, low statistical significance due to variance in the data resulted in no support for a review of associated road shoulder width guidelines. While not statistically significant, an increase in the rates of all crash types in the post-WCLT period was determined. Additionally, higher than predicted observed crash numbers were also found during both the pre- and post-treatment periods, suggesting the low volume highways studied may have a crash problem in comparison to the reference highways. As this study included all overtaking types of WCLT, the crash reduction effect of WCLT may not be influenced by low traffic volume alone but it is possible it may be influenced by a combination of contributing factors such as overtaking type and segment length. This research builds on the existing knowledge of WCLT effectiveness, indicating there may be limitations to the treatment's use.

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P. McNamara 12th October 2019

Student Number: [redacted]

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Date

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Glossary of Terms

AADT	Annual Average Daily Traffic
ATLM	Audio Tactile Line Markings
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
DTMR	Queensland Department of Transport and Main Roads (also known as TMR)
EB	Empirical Bayes
EDD	Extended Design Domain
FB	Full Bayes
FSI	Fatal and Serious Injury
HO	Head-on
HOCL	Head-On / Cross centreline
NDD	Normal Design Domain
NRSS	National Road Safety Strategy
ROR	Run Off Road
RORL	Run Off Road Left
RORR	Run Off Road Right
RRPM	Retroreflective Raised Pavement Markers
spf	Safety Performance Factor
SPF	Safety Performance Function
WCLT	Wide Centreline Treatment

Chapter 1 Introduction

1.1 Background

Of the various modes of transport employed daily in Australia, road transport is one of the most significant. For the twelve months ending 30 June 2018 there were an estimated 19 million registered vehicles on Australian roads moving various combinations of people and freight over a total 250 billion kilometres (Australian Bureau of Statistics 2019). The Australian economy, businesses and families rely heavily on the road network for the safe transit of vehicles.

As roads play such a significant role in Australia's integrated land transport system, the safety of users is a key factor in road design guidelines. Road crashes, in terms of annual economic cost to the nation, are estimated at over A$30 billion (Austroads 2019a). These costs include various human, vehicle, and other associated costs as depicted in Figure 1.1. In terms of cost to Australian lives, for the 2018 calendar year there were 1,146 road deaths in Australia, 247 of these in Queensland - the latter the same number as the previous year (Bureau of Infrastructure Transport and Regional Economics 2019). As such, road safety is recognised by the community and all levels of government as a consideration of critical significance. To enable this the various levels of government across Australia and New Zealand invest approximately A$18 billion currently on roads each year to run, maintain, improve and build their road networks (Austroads 2019b). In Australia, national and state transport authorities recognise the need for improvements to road safety and run various road safety initiatives in an effort to reduce road fatalities.

Figure 1.1 – Cost components of road crashes

Source: Department of Transport and Main Roads (2015b, p. 4)

In Australia the National Road Safety Strategy (NRSS) represents the commitment of all levels of government to an agreed set of objectives and priorities and provides an action framework to reduce the number of fatal and serious injury (FSI) crashes. The NRSS is based on the Safe System approach to improving road safety (Commonwealth of Australia 2018b). This approach (also known as Vision Zero and Towards Zero) is an international approach that places human life and health above all else on the road and that roads should be designed to protect road users from death and serious injury (Towards Zero Foundation 2019). The Safe System approach also recognises human fallibility and identifies that road users should not be penalised with death or serious injury if they make a mistake. As such, while there is promotion of compliant road usage, one of the requirements of this approach also requires that roads and roadsides are improved to minimise harm and reduce the likelihood of crashes. Subsequently, every endeavour is made to design and construct a rural highway network that caters to the needs of road users and provides a suitable degree of safety for all road users.

Austroads, the Australasian road transport and traffic agencies' peak body, incorporates this 'Towards Zero' approach in its road safety efforts. Austroads undertakes road and transport research to underpin policy development and guidelines regarding the design, construction and management of the road network and infrastructure. The Austroads Road Safety Taskforce worked together with the Commonwealth overseeing the development of the *National Road Safety Action Plan 2018-20*20 (Austroads 2019a).

The Safe System approach, particularly marketed as 'Towards Zero', a target of a future free from road deaths and serious injuries, has filtered down and been the ideology behind many strategies and programs at a state government level. Western Australia's 'Towards Zero' strategy aims to reduce serious road crashes by 40% by 2020 (Road Safety Commission 2019). Other state governments, such as Victoria, with '*Towards Zero 2016-2020 Road Safety Strategy*', and New South Wales, '*Working Towards Zero*', have similar strategies and campaigns. Like the other states and territories, Queensland's Department of Transport and Main Roads (TMR) aims to reduce casualty numbers and injury severity in crashes through innovative, cost-effective and targeted infrastructure and initiatives. Its *Safer Roads, Safer Queensland* 2015-2021 strategy marks the first time the Queensland government has committed to the *Towards Zero* vision (Department of Transport and Main Roads 2017b). One of the projects under Queensland's *Targeted Road Safety Program (TRSP)* is the *Mass Actions Initiative*. This project targets specific safety issues and funds the implementation of specific treatments to improve safety such as wide centreline treatments (WCLT) (Department of Transport and Main Roads 2018d).

Understanding road crash types, their causes and the effect of potential countermeasures enables informed allocation of road funding and the targeting of specific safety issues. In recent years the rate of road deaths in Australia has hovered at approximately 5.5 per 100 000 people. In Queensland the rate has fallen over the last 50 years to 5.01 (Department of Transport and Main Roads 2018c). This has been due to the implementation of various measures that may have seemed ambitious at first but today are widely accepted as normal, as shown in Figure 1.2. Of particular note from the national figures is that this figure is significantly higher, more than doubling to over 12 per 100 000 people, when regional and remote roads are considered alone (65% of all road deaths) - almost half of these occurring in the high speed zones i.e. speed limits ≥ 100km/h (Commonwealth of Australia 2018a). This indicates that crashes with the most severe outcomes are most likely to occur on Australia's rural highways.

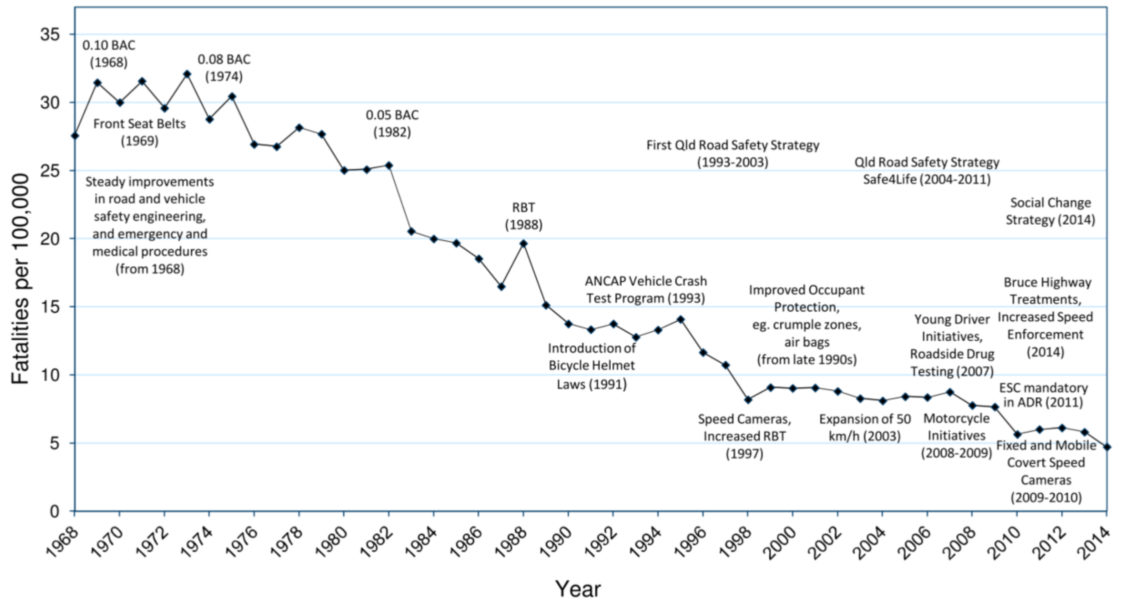


Figure 1.2 – Road fatalities per 100,000 population in Queensland: 1968-2014

Source: Department of Transport and Main Roads (2015b, p. 6)

In Queensland, like many Australian states, the challenges to address in order to progress the 'Toward Zero' vision are daunting. Much of the state's population live in urban areas. However, Queensland is a vast state requiring extensive stretches of rural highways to provide connections between isolated regional centres and to the capital city. Due to the size of the road network it is not feasible to apply physical treatments to all areas. Factors such as population growth, an aging population, and increases in vehicle ownership lead to an increase in register vehicles and traffic volumes on Queensland roads and put further pressure on the safety of the road network. Therefore, research into understanding road crash types, their causes and the effect of potential countermeasures is vital to enable the development of informed guidelines around both rural highway design and safety treatments, remedial road safety treatments and funding allocation, as Queensland continues to strive for the 'Towards Zero' vision.

Head-on and run-off-the-road crashes are among the most severe crash types. They account for less than 5% of all reported accident types (AAMI 2018; Budget Direct 2019). However, they have accounted for approximately half of all Australian road fatalities for each of the four years to 2016 as shown in Table 1.1 (Bureau of Infrastructure Transport and Regional Economics 2018a). Main Roads Western Australia identified that these crash types contributed 69% of FSI crashes on its rural high-speed state roads. It also noted that over two thirds of these crashes were not due to deliberate traffic violations (Main Roads Western Australia 2019).

As Queensland has significant lengths of rural highway and given regional and remote roads contribute to 65% of all road deaths with almost half of these in high speed zones, the identification and implementation of low-cost countermeasures are essential to the realisation of the 'Towards Zero' vision.

Table 1.1 – Fatalities from common crash sub-types in Australia

	Intersection	*Head-on*	*Single vehicle run-off road* [b]	*Total* [a,c]
2008	337	251		1,437
2009	281	287		1,490
2010	284	279		1,351
2011	286	250		1,277
2012	287	270		1,299
2013	256	210	435	1,185
2014	233	218	403	1,151
2015	245	239	410	1,206
2016	268	268	472	1,296

a Categories not mutually exclusive, nor exhaustive.
b Full national data available from 2013
c Includes all other crash types.
Source BITRE analysis of National Crash Database

Source: Bureau of Infrastructure Transport and Regional Economics (2018b, p. 15)

Road safety modelling over the past five decades has indicated that the variables of 'geometric design' and 'pavement condition' are the most important factors influencing accidents rates on rural roads, emphasised in the findings of Karlaftis and Golias (2002). In line with this, road centreline treatments are a well-supported method of reducing head-on crash types. They delineate opposing traffic lanes thereby influencing vehicle position and decreasing the likelihood of vehicles leaving their travel lane. They are frequently combined with audio-tactile line markings (ATLM). When driven on, the ATLM provide vibration and noise alerting the driver that they are straying from their lane. However, while centrelines and ATLM delineate lanes and provide audio-tactile warning, these markings provide little lateral separation between opposing traffic flows and little, if any, margin of error should drivers stray towards the oncoming traffic.

Centreline treatment options vary from standard painted line markings to wide grassed medians. While shown to have greater safety benefits, the use of physical separation treatments such as barriers and wide medians is typically economically prohibitive on rural highways.

A low-cost method of separating oncoming flows of traffic is the wide centreline treatment, (WCLT), also referred to as a narrow painted median strip. WCLT separate opposing traffic flows by up to 1 metre and, in Queensland, are typically combined with ATLM. By providing lateral separation the WCLT targets the head-on/cross centreline (HOCL) crash event. Currently, there is no Australian Standard for WCLT application (Austroads 2018b) and treatments can be applied to new, purpose designed pavements, or by the reallocation of space on existing pavements. With respect to the reallocation of space, guidelines surround the allocation of road space and, due to the ever-increasing volumes of road and traffic data available, multi-objective optimisation can be employed to guide lane and shoulder width policies (Labi et al. 2017). This is particularly useful when site constraints mean that pavements cannot be widened so optimisation of lane and shoulder widths is required in these zero-sum situations. However, in road design, perhaps due to the relatively recent adoption of WCLT in Queensland and relatively small amount of subsequent data, considerable emphasis is given to providing lane width and sealed shoulder width (Whittaker 2012). A zero-sum situation exists in locations where WCLT may be beneficial but, due to cost-benefit, needs to be retrofitted to the existing pavement width. For accurate multi-objective optimisation to occur in this situation, a robust understanding of the effect of WCLT on HOCL, and particularly run-off-the-road-left (RORL) events is necessary.

In the past decade TMR has made increased use of WCLT along targeted sections of several Queensland rural highways. The treatment was first trialled along a 56 km section of the Bruce Highway from Cooroy north to the Wide Bay Highway. Early before-and-after studies undertaken by Whittaker (2012) and Cuckson (2016) quantified the positive safety benefit of this treatment by determining significant crash reduction values for HOCL events. Notably, they also determined significant crash reduction values for RORL events. Given that WCLT laterally separate vehicles travelling in the opposite direction and targets HOCL events, the positive RORL crash reduction rate is counter intuitive. The most recent evaluation of the effectiveness of WCLT, conducted using 8 years of control and treatment site data, also from the Bruce Highway, continued to reiterate the effectiveness of WCLT on this high volume Queensland highway, determining an FSI crash reduction of 30% for HOCL (Luy et al. 2018). Notably, a significant

FSI crash reduction factor of 24% was also determined. All injury crash reductions were found to be 33% and 21% respectively.

While the positive trend in the findings of these studies was consistent the RORL results was surprising. Harrison et al. (2015, p. 68) stated “WCLT has potentially resulted in an increase in run-off-road to left crashes”. While the findings of researchers such as Cuckson (2016) and Luy et al. (2018) found this was not the case, determining significant reductions in RORL events, they had also hypothesis that RORL rates were expected to increase.

All studies on WCLT in Queensland identified to date have focussed on treated segments of Sections 10A and 10B of the Bruce Highway. The earliest studies were constrained due to the limited time since WCLT implementation in Queensland and a lack of post-treatment data. However, Luy et al. (2018) were able to utilise 4 years pre- and 4 years post-treatment data from the Bruce Highway to increase confidence in the results. Now, with greater periods of post-treatment data available from other treated rural Queensland highway the opportunity exists to build on existing understanding of WCLT effectiveness and to determine if the counter intuitive RORL reduction occurs on lower volume rural highways.

1.2 Problem Statement

The positive effect of WCLT on RORL crash events is counter intuitive. In the previous section the importance of road safety and the safety challenges of Queensland rural highway network were highlighted. It was revealed that fatalities on rural highways are overrepresented and that HOCL and RORL crash types account for the largest percentage of these. Targeting the severe HOCL crash events, the effect of WCLT has been the focus of several studies in Queensland that have relied on data from the treated segments of Sections 10A and 10B of the Bruce Highway. All studies indicate reduced HOCL crash rates are being achieved suggesting the more rural highways that WCLT can be applied to, the greater the number of severe crashes that can be prevented. The previous researchers also demonstrated that RORL crash rates are being reduced as a result of WCLT. However, since not all existing road pavements have sufficient width there may be many rural highways that would benefit from the application of WCLT (and many lives that could be saved) but, under current guidelines, do not have sufficient width to qualify for the treatment.

When new treatments are being applied to a variety of sites it is important that the success of the treatment is reviewed to ensure the treatment’s effectiveness continues at the new locations, particularly in this instance where a counter intuitive effect is occurring. All studies on WCLT in Queensland identified to date have focussed on treated sections of the Bruce Highway. The success or otherwise of the WCLT on other rural highways is unknown.

Applying the WCLT to existing roads is far less expensive and requires far less design and construction/application time than widening a road pavement. Therefore, if the effect of WCLT can be verified to reduce the rate of RORL incidents on all highways that currently have the treatment, particularly those roads with narrower sealed road shoulders, then potential for a further investigation of acceptable minimum sealed road shoulder widths would be justified. It could lead to many more sections of highway qualifying for WCLT, in turn, resulting in the reduction of all crash types, particularly the severe HO types, and provide significant savings, both economic and human. If the rate of RORL incidents is constant or increases the potential for a review of associated road shoulder widths may not be supported. However, further investigation into the suitability of WCLT on these lower volume highways may be warranted.

1.3 Project Aims

This project aimed to investigate treatment sites across multiple two-lane two-way rural Queensland highways to quantify the effect of WCLT, particularly on RORL incidents. While the primary focus will be on RORL crash types, the study will also include head-on/cross-over-centreline and total crashes to determine revised, up-to-date crash modification factors for low volume highways.

Similar studies have been constrained by the availability of post-treatment data and/or relied on the spectrum of traffic that utilised the Bruce Highway Sections 10A & 10B. This study aimed to determine if the significantly reduced rate of RORL crash types, observed in the Bruce Highway studies of Cuckson (2016) and Luy et al. (2018), could be verified on other rural highways across south-east Queensland. If the RORL rate is always so significantly reduced, then further investigations into the effect of WCLT on driver behaviour and vehicle position could be supported. Positive results of these latter investigations may justify inquiries into the potential use of narrower sealed road shoulders with WCLT and inform the guidelines around WCLT specifications. However, if the crash rates were found to increase on the low volume rural highways then this could also stimulate further study into the suitability of WCLT on these highways and reasons for the observed effect.

It is intended that the results of this project that will build on the work of previous researchers. If statistically significant it will provide up-to-date CMFs for low volume rural Queensland highways that can be used to guide decisions in the traffic safety industry regarding the application of WCLT.

1.4 Project Objectives

To achieve the aims of this research project the following key objectives are proposed:

1. Research current world best practice with respect to WCLT application, road shoulder design, the factors that contribute in rural highway crashes, target crash types, statistical crash data analysis methods and any published data on the crash reduction effect of WCLT to date. This is to be presented in the form of a literature review.
2. Determine where research into the effect of WCLT on RORL crashes on low volume rural Queensland highways will fit within existing research and how this will build on existing knowledge and best practice.
3. Obtain and collate road and crash data for rural Queensland highways from TMR suitable for determining the effectiveness of WCLT on RORL, HOCL and TOTAL crashes.
4. Undertake statistical analysis of treatment sites, using the method identified by the Literature Review, to determine the effectiveness of WCLT on RORL, HOCL and TOTAL crashes.
5. Evaluate the analysis results with respect to the project aim and the potential implications for road shoulder widths. Develop crash modification factors (CMF) and make recommendations regarding WCLT application.

Chapter 2 Literature Review

2.1 Introduction

This literature review presents a summary of available research, guidelines and literature relevant to the project at the time of review. It explores the concepts of centreline treatments, particularly WCLT, and road shoulder design on rural highways focusing on their roles in road safety. It also explores the statistical methods used to conduct before and after crash data studies, as well as crash types and influencing factors, crashes on rural highways, and crash modification factors.

2.2 Centreline Treatments

Delineation of road pavement is provided by painted lines with the purpose of visually indicating the acceptable use of the road at that location, thereby influencing driver behaviour and improving road safety. Standard dividing line markings are typically used on sealed roads with a width greater than 5.5m (Austroads 2016b). For sealed pavements less than this width dividing lines are typically limited to locations where, due to sight distance, the conditions for a no-overtaking zone are met (Standards Australia 2011). Centrelines incorporate the use of established patterns, as set out in Australian Standard AS1742.2, such as the broken centrelines, depicted in Figure 2.2.

Figure 2.1, continuous centrelines (barrier lines) or a combination of both, as shown in Figure 2.2. These visually inform the road user as to the types of vehicle manoeuvres that are permitted for the prevailing road and environmental factors, thereby enhancing the safety of the road user. Studies to quantify the crash reduction effect of centrelines in various countries and environments have been carried out across the globe. These were each evaluated as part of a major Austroads research program which concluded that in an Australasian context the use of centrelines reduces crash rates by up to 30% (CMF of 0.70) (Austroads 2010).

Figure 2.1 – Sealed pavement with broken centreline and edge line treatment
Source: Tourism Australia (*Outback road, NT* 2019)

Painted centrelines delineate the regions of the road used by vehicles travelling in opposite directions and, in this fashion, allocate road space to the driver to reduce the risk of drivers inadvertently leaving their side of the road and suffering a head-on crash. However, typical centreline treatments do not provide significant lateral separation between opposing traffic flows. Standard dividing line markings are 100 mm wide in Queensland providing at least this width of lateral separation (Department of Transport and Main Roads 2018b). This value, in line with the preferred Austroads and Australian Standard, is larger on multilane roads and cumulatively larger where barrier lines are employed, as shown in Figure 2.2**.**

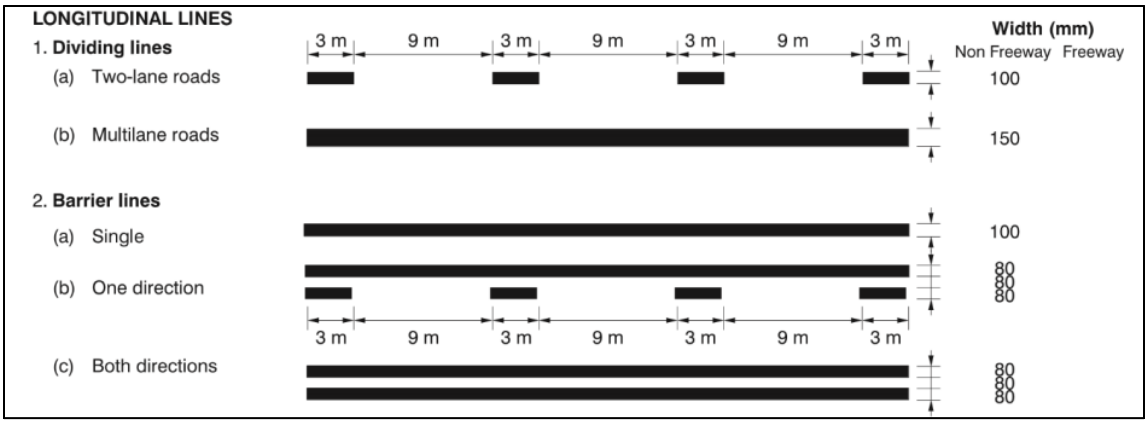


Figure 2.2 – Longitudinal centreline dimensions.

Source: Department of Transport and Main Roads (2018b, p. 10)

2.3 Edge Lines

Like centrelines, edge lines provide a visual indication to the driver of the edge of the travel lane. Typically, a 150 mm continuous painted line delineates the edge of the lane from the road shoulder, thereby influencing driver behaviour and vehicle position from road edge, improving road safety, particularly at night (Department of Transport and Main Roads 2018b). As such, aside from general delineation, they may also be used to define lane boundaries, such as cycle lanes, or to provide guidance near hazards or width transitions, such as past a traffic island (Standards Australia 2011). In Australia, edge lines are typically required for sealed pavements greater than 6.8 m, but only when centrelines are also applied (Standards Australia 2011).

When used in combination with centrelines, studies by Miller and Moses, cited in Horberry et al. (2006) determined a 20% reduction on all accidents and a 34% reduction on single vehicle accidents, respectively, noting the effect of road markings as a continuous visual link between the driver and the driving environment. Horberry et al. (2006) emphasised this, demonstrating that enhanced road markings lowered driver workload in low visibility conditions and enabled drivers to maintain lane position and speed. Persaud et al. (2004) and Gårder and Davies (2006) quantified significant crash reduction effects from the used edge lines in combination with ATLM, the latter identifying a reduction of over 40% in run of the road crash types. Khan et al. (2015), refined this for run of the road crashes on two-lane rural highways, determining a 14% reduction when ATLM were used on edge lines on this highway type.

While the crash reduction benefit of edge lines combined with ATLM is well supported, the roads in the studies mentioned were also treated with centreline markings. A field and simulator study undertaken by Auberlet et al. (2010) found that when ATLM are applied to edge lines alone drivers shifted their vehicle position more central to the lane, away from the road edge. This driver behaviour also supports the MUTCD specification that was also reiterated in (Chandler 2016) - that edge lines are only applied only when centrelines are also applied (Standards Australia 2011), due to the lateral effect the visual cue has on drivers' lane positioning and may have on HOCL incidents. While benefits of edge lines to in reducing the rate of RORL crashes are clear, they cannot be use as a standalone treatment.

2.4 Audio Tactile Line Markings (ATLM)

ATLM can be applied to sealed pavements to alert drivers that they have strayed to the edge of their travel lane. Bahar, Wales & Longtin-Nobel (cited in Austroads 2016b, p. 9) described that when driven on, ATLM create a clearly distinguishable vibration and noise through the vehicle thereby alerting the driver and, in turn, making them effective in reducing crashes where driver distraction or drowsiness is at play. Also known as audible lines and rumble strips, ATLM are applied as either raised or grooved patterns on or near the line marking of interest, requiring no change to the pavement cross-section. As an audio-tactile treatment they provide additional benefit when visibility is otherwise low, such as at night or in heavy rain or fog, when standard paint line markings are difficult to see (Neuman et al., cited in Austroads 2016b, p. 7).

ATLM have three basic types: rolled, milled and raised. Rolled and milled designs involve the creation of an indent in the pavement surface and are suitable for all environments. Raised ATLM involve the use of raised thermoplastic ribs, such as shown in Figure 2.3. Due to their raised profile they are not suitable for snow prone environments as they are likely to be unintentionally removed during road clearing (Bahar et al. 2001).

Figure 2.3 – Raised audio tactile line markings (edge line)
Source: Allstate Linemarking Services Pty. Ltd. (Profile Thermoplastic (ATLM) n.d.)

Rolled ATLM indents can be pressed into hot asphalt using a rumble strip pattern on a roller. While it is a low cost installation method, rolled ATLM do not perform as well as milled rumble strips and may be less precisely applied due to difficulties controlling the roller's tracking, particularly near road edges (Bahar et al. 2001). Milled rumble strips, pictured in Figure 2.4, are ground into the pavement surface using a rotatory cutting head to create a precise groove in the asphalt. Modern machinery enables milled indents to be accurately applied and dimensions to be quickly adjusted to suit the required line type guidelines. While field testing has shown milled to be the most audio-tactile (Bahar et al. 2001), raised rumble strips are considered more visible in addition to their audio-tactile performance and are specified in Queensland.

Figure 2.4 – Milled audio tactile line markings (edge line)
Source: Asphalt Institute (Milled rumble strip n.d.)

In Queensland, TMR specifies the use of raised ATLM applied directly to the pavement surface on the existing painted edge lines or barrier lines (Department of Transport and Main Roads 2019a). Austroads (2016b) advise a treatment life of five years. The rib width dimension varies to match the width of the applicable continuous line type as shown in Figure 2.5 and Figure 2.6. Otherwise, the Queensland standard is for rib 50 mm long, 8 mm high spaced at 250 mm centres. When applied as part of WCLT, there is slight variation in the positioning of ribs with these applied abutting the longitudinal line markings, as can be seen in the traffic control specification in Figure 2.7.

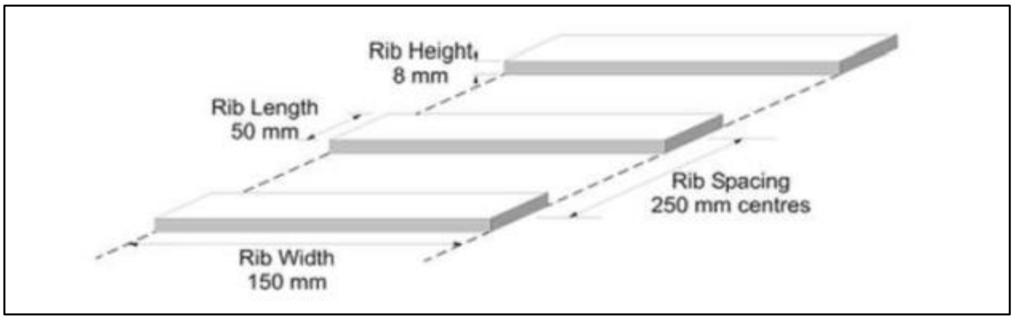


Figure 2.5 – ATLM edge line

Source: Department of Transport and Main Roads (2019a, p. 12)

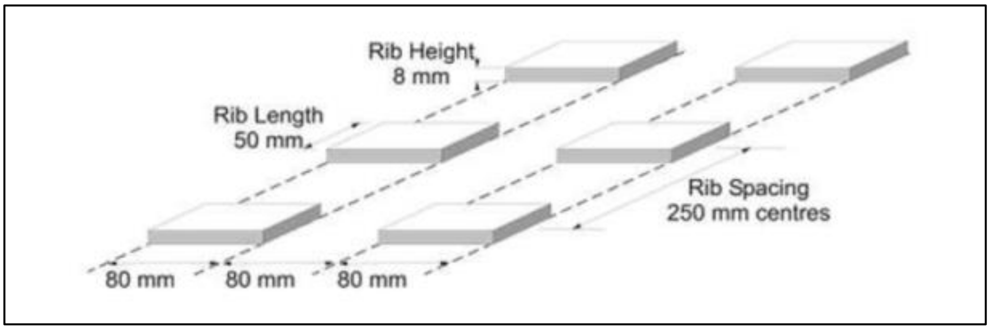


Figure 2.6 – ATLM centre double barrier lines

Source: Department of Transport and Main Roads (2019a, p. 12)

It has been found that the benefits of ATLM are not just limited to alerting drivers that they are straying from their lane. ATLM also influence driver behaviour in terms of their lane position. A field and simulator study undertaken by Auberlet et al. (2010) found that when ATLM are applied to edge lines alone drivers shifted their vehicle position more central to the lane, away from the road edge. Similarly, Auberlet et al. (2012) found that when centrelines alone were treated drivers positioned themselves further away from the road axis. These results support Queensland's guidelines for ATLM, contained in MRTS45 Road Surface Delineation, which specifies that ATML shall not be applied to centrelines where the road is too narrow and edge lines have not been marked (Department of Transport and Main Roads 2019a). However, where the road dimensions are suitable the success of ATLM in reducing accident reduction rate is clear. Persaud et al. (2004) found the use of centreline ATLM reduced all crashes by 12% and all injury crashes were estimated at 14%. Of interest, their study, which covered seven USA states and 350 km of treated roads, they found a 25 % reduction in HOCL injury accidents. If ATLM are present along both edge and centrelines the resulting in lateral position becoming more central to the lane. This supports the findings of Hatfield et al. (2009) who, suggested that application of ATLM on both edge and centreline is preferable to just applying to either alone, and TMR's specification for application to both sides of the lane when WCLT are applied, as seen in Figure 2.7.

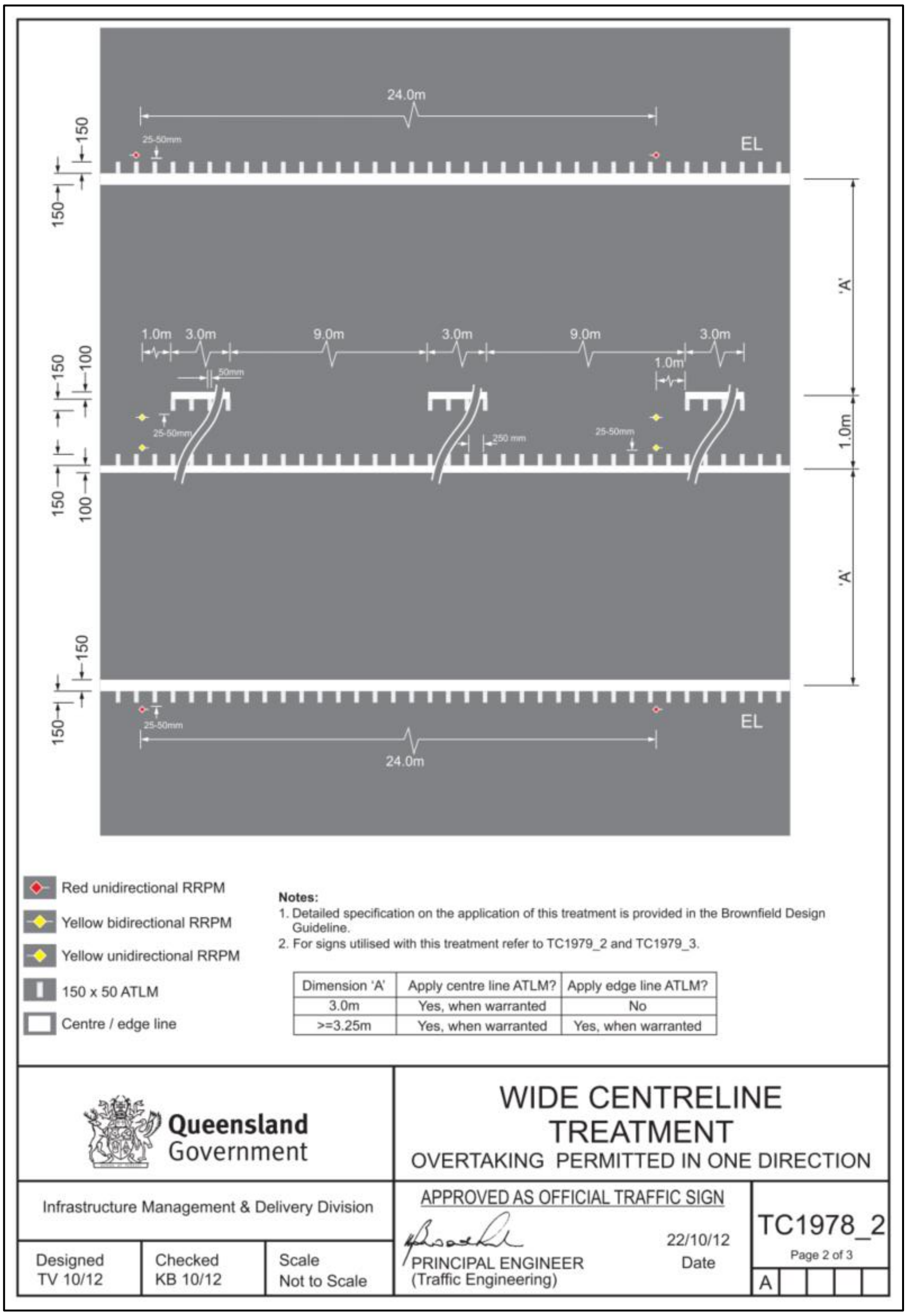


Figure 2.7 – TMR specification for WCLT with overtaking permitted in one direction
Source: Department of Transport and Main Roads (2016, p. 8)

While centrelines and ATLM delineate lanes and provide audio-tactile warning should the driver stray towards the oncoming traffic, these markings have little width, if any, and therefore provide little margin of error for drivers to recover their vehicle. However, when ATLM are used in combination with WCLT, the ATLM alerts the driver of lane departure and the WCLT provides a 1m buffer zone within which the driver has room to take corrective action after which they enter the oncoming lane. Given the success of WCLT presented by previous studies in reducing HOCL crash rates then 1m may be a wide enough buffer for the driver to take corrective action on both sides of the lane. This supports further investigation into a reduction of the required sealed shoulder width to a similar value as the wide centreline, particularly if it enables WCLT to be applied to more rural roads and highways and leads to reduced FSI crash rates on more rural roads.

2.5 Sealed Road Shoulders

Road shoulders have two functional purposes – structural and traffic. Structurally, they provide lateral support to the layers of the road pavement. In terms of traffic function, they play several important roles. These include providing clearance from lateral obstructions, providing a trafficable area in the case of an emergency, and providing a firm refuge for stopped vehicles. Also, just as WCLT provide a buffer to the right of the travel lane for vehicles to correct their course should they begin to cross the centreline or run off the road right, RORR, a defined road shoulder provides this same buffer to the left. Run off the road (ROR) incidents involving a single vehicle are one of the most common lane departure crash types (Chandler 2016). Rural roadsides are hazardous and, in the absence of a shoulder, once a vehicle leaves the travel lane it is more likely to hit a fixed object, overturn or overcorrect. In turn, road shoulders play a role in the Safe System approach to road design, recognising that drivers are fallible and should a vehicle begin to run off the road left the shoulder provides an initial recovery area free from obstructions (Austroads 2016a, p. 48).

Road shoulders are strips of sealed and/or unsealed land running parallel to the road lane edge. Sealed road shoulders are typically covered with a flexible pavement layer while unsealed shoulders consist of gravel or grass (Vic Roads 2019). When constructed they maintain the pavement crossfall profile from the road crown to the road verge, as shown in Figure 2.8. This directs runoff away from the road pavement, reducing maintenance costs (Austroads 2016a). Sealed shoulders provide the largest safety benefit, by 20-30% compared to unsealed (Vic Roads 2019), as they deliver the greatest opportunity for a vehicle to re-enter the travel lane. This is achieved by the road shoulder properties, such as gradient, level, materials and surface type, maintaining consistency with the sealed lane pavement properties (Chandler 2016). These characteristics of sealed shoulder enable greater braking and steering control than if unsealed, thereby improving safety for vehicles should they leave the travel lane for any reason.

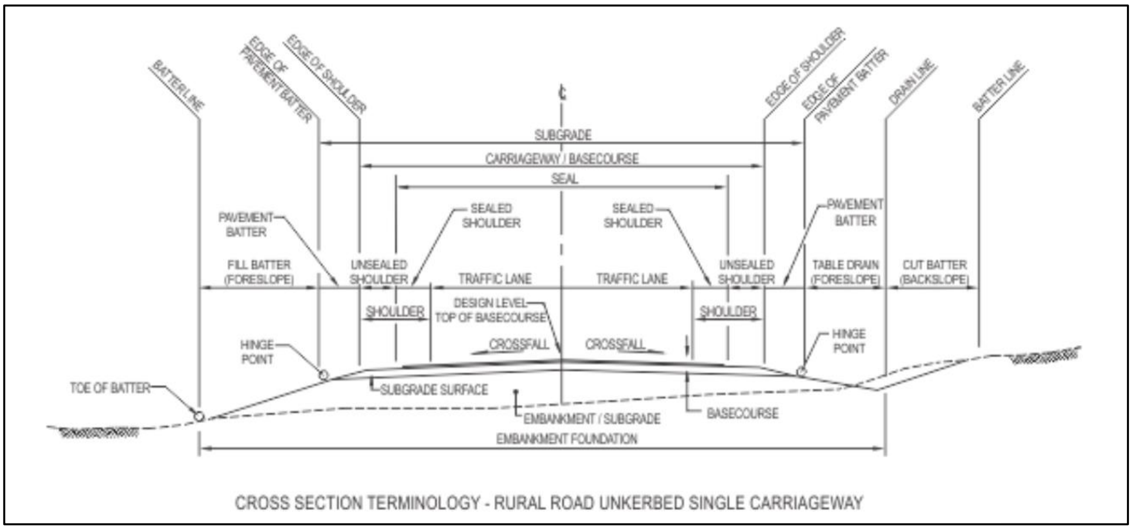


Figure 2.8 – Typical rural road cross section and terminology
Source: (Main Roads Western Australia 2019)

Road shoulder delineation and width contribute to road user safety. The role and effect of delineation is clear. Delineation of the shoulder from the designed traffic lane is achieved by the application of continuous edge lines to the sealed pavement. As described in Section 2.3, these painted lines may be combined with ATLM to provide visual and, if necessary, audio-tactile guidance, thereby improving road safety (Queensland Government 2018). For rural high speed roads in Western Australia the combined use of sealed shoulders and ATLM edge lines have been shown to have substantial 43-67% effect on the reduction of HOCL/ROR crash types, depending on the formation of the existing carriageway (Main Roads Western Australia 2019). As discussed by Chandler (2016), when ATLM treated edge lines are combined with suitable road shoulder widths and/or a forgiving roadside, should a vehicle begin to depart from the lane to the left, drivers may have opportunity to return to their lane safely and avoid a crash.

The exact effect of road shoulder width on safety is complex. Shoulder width is measured laterally from the traffic lane edge out to the usable road edge. Wide shoulders provide several advantages to drivers. These include space for a vehicle to pull up clear of the travel lane (a width of at least 2.5 m is required, as shown in Table 2.1), space to redirect a vehicle that has departed the travel lane, space to avoid an errant vehicle, and greater sight distance on the inside of horizontal curves (Austroads 2016a). A positive relationship between safety benefit and increases in width is well supported globally for freeway and divided road crash occurrences where traffic speeds and volumes are high. This trend was consistently found in studies into wider road shoulders (Gitelman et al. 2019). However, freeways and divided road configurations are not like two-lane rural roads and highways as there is physical separation from on-coming traffic.

Table 2.1 – Minimum sealed shoulder widths for various functions

Function of shoulder	Minimum sealed width (m)
Lateral support of pavement	0.5
Control of moisture or on outside of curves	1.0
Initial recovery area	0.5
Discretionary stopping Cars Trucks	 2.5 3.0
Bicycle demand	2.0/3.0

Source: Austroads (2016a, p. 50).

The findings of studies of shoulder widths on two-lane rural roads do not follow such a consistent trend. Evidence suggests that beyond 1.5 to 2.0 m the improvement to safety does not change significantly (Austroads 2016a). A study of 3594 two-lane rural road sections in Israel by Gitelman et al. (2019) found an increase in associated crash risk for medium shoulders, of 1.8-2.4 m for sealed shoulders and over 1 m for unpaved shoulders. They emphasised that these widths are not recommended for use. Their findings also concluded that wide shoulders, widths of 3 m, and narrow shoulders, below 1 m, were associated with the lowest crash risks. Mecheri et al. (2017) investigated how lane width, shoulder width, and road cross-sectional allocation on two-lane rural roads affects driver behaviour. Their simulator study found that participants positioned their vehicles further away from the road and lane centre when road shoulders widths were at least 0.50 m – a finding also reported by Ben-Bassat and Shinar (2011) and Bella (2013). This supports another advantage of road shoulders – that the presence of road shoulders increases driver comfort (Austroads 2016a). In the presence of no other road treatments, drivers will position their vehicle further away from the oncoming lane when wider shoulders, above 0.5 m, are present. In doing so they realise more lateral separation to avoid HOCL events and enjoy greater width to recover if they begin to stray from their lane to the left. However, from these previous findings it is proposed that if the lane width is in excess of that required for initial recovery but not wide enough to enable the whole vehicle room to stop then the width may be wide enough to induce driver comfort and negatively affect driver safety if it leads to speeding and driver inattention. This would be what ITE-TSC (2009) describes as 'road security' – the subjective perception of road safety that, in some cases, may be detrimental to road safety if it leads the driver to be less cautious.

Guidelines around road shoulder types and widths depend on the road typology. In Queensland, TMR's Road Planning and Design Manual (RPDM) provides guidance for desired lane, shoulder widths and sealed shoulder widths, as shown in Table 2.2 for single carriageway rural road design. This guide shows a degree of flexibility in both lane and shoulder widths as there are several factors that can influence the acceptability of a pavement's cross section. These include elements such as expected vehicle types, proximity of adjacent slopes or batters, proximity of lateral obstructions and other road design features such as safety barriers (Department of Main Roads 2005).

Table 2.2 – Minimum single carriageway rural road widths (m)

Design AADT	**250 – 400**	**400 – 1000**	**1000 – 2000**		**2000 – 4000**			**> 4000**		
Road Carriageway Type(1)	All	All	L	N	L	N	H	L	N	H
Lane Width	3.00	3.25	3.50	3.50	3.50	3.50	3.25	3.50	3.50	3.25
Shoulders	1.00	1.00	1.00	1.25	1.00	1.50	1.50	1.50	1.75	1.75
Wide Centre Line Treatment							1.00			1.00
Carriageway(2)	8.00(4)	8.50	9.00	9.50	9.00	10.00	10.50	10.00	10.50	11.00
Cycling(3)						P	P	P	P	P

Notes:

(1) Road Carriageway formation type
L – Low embankments (i.e < 1.0 m) on lower order roads where batter slopes do not exceed 1V:4H
N – nominal road values
H – Higher order roads requiring a 1.0 m wide centre line treatment and 3.25 m wide lanes

(2) Full width of seal required

(3) A "P" in these columns indicates cross sections generally considered suitable for "Priority cycle routes" in rural areas. Refer to Section 4.8 for further details

(4) Where a road is subject to the State Strategic Road Investment Strategy, the interim seal width is to be applied is 8.0 m with allowance for a vision seal width of 9.0 m.

Source: Department of Transport and Main Roads (2018a, p. 59)

While Austroads noted that beyond 1.5 to 2.0 m the improvement to safety does not change significantly, their Guide to Road Design suggests that wherever possible rural road shoulders should be 1.5 to 2.0 m wide, and up to 2.5 to 3.0 m wide where expected traffic volumes and speeds are higher (Austroads 2016a, p. 49). This suggested width goal has practical and safety advantages, such as allowing vehicles to stop or maintenance vehicles to operate creating no or only partial traffic lane obstruction. However, these goals are more suitable for new road, major remedial or road widening designs where the costs of earthworks and pavement construction for the wider design are reduced due to economies of scale. They are not suited to otherwise low-cost rehabilitation works or minor works involving cross-section reallocation paint-only treatments such as WCLT, where providing wider sealed shoulders would increase costs significantly.

The minimum required sealed shoulder width specified by Austroads for various shoulder functions are set out in Table 2.1. This table notes that a minimum seal shoulder of 0.5 m is functionally acceptable structurally, for the lateral support of pavements, and in terms of traffic safety as an initial recovery area, the key concern for ROR events. Table 2.2 provides pavement width guidelines based on the Annual Average Daily Traffic (AADT). Depending on traffic volume it identifies the minimum road shoulder widths as 1.50 to 1.75 m on higher order where a WCLT has been applied. The table indicates that the extra 1.0 m of pavement width required to apply the WCLT is gained by reducing the width of the two lanes by 0.25m and constructing a 0.5m wider total pavement. However, road shoulder width remains unchanged at 1.5m, corresponding to the minimum rural road shoulder guideline, and appears to not consider any crash reduction benefit of WCLT on RORL events.

2.6 Wide Centreline Treatments (WCLT)

WCLT have been introduced on several major Queensland highways since 2010 with the purpose of reducing vehicle crash rates, particularly the most severe crash type that occurs on Australian rural highways, the head-on (HO)/Run-of-road-right (RORR) or HOCL event (Connell et al. 2011). As discussed in Section 2.2, typical centreline markings provide no lateral buffer distance between opposing lanes of traffic. Even with the additional application of ATLM to the centreline the noise and vibration only occur as the vehicle crosses the lane threshold so there is no margin of error should a vehicle stray from their lane toward the oncoming traffic. These outcomes are not in line with the Safe System approach adopted across Australia as states and territories endeavour to achieve their 'towards zero' targets - that road users are fallible but at the same time identifies that they should not be penalised with death or serious injury if they make an error. From 2007 to 2013 cross centreline crashes in Queensland accounted for over 30% of all FSI road events. HOCL events accounted for 26% of these on Queensland's high speed roads (speed limits at or above 80km/h) with driver inattention and fatigue thought to be significant contributing factors (Harrison et al. 2015, p. 63). In Australia every endeavour is made to design and construct a 'forgiving' rural highway network that caters to the transport needs of road users and ensures the force limits of the human body are not exceeded in collisions (Commonwealth of Australia 2018b). This approach identifies that roads that roads and roadsides should be improved and designed to minimise harm and reduce the likelihood of crashes.

One method of improving margin of error for the cross-centreline events includes creating a buffer zone between opposing flows of traffic using WCLT. WCLT involve applying a narrow painted median strip, typically one metre wide, to a new or existing road with the purpose of increasing lateral distance between vehicles travelling in opposite directions (Lilley 2012). The median 'buffer' zone improves the margin for error by providing drivers with extra time to react and take appropriate corrective action should they stray towards the oncoming traffic and cross into this median area, as shown in Figure 2.9. This ability to improve the margin for errors has led to

WCLT being introduced on several major Queensland highways since 2010 with the purpose of reducing vehicle crash rates, particularly the most severe crash type that occurs on Australian rural highways, the HOCL event (Connell et al. 2011).

Figure 2.9 – Example of WCLT (overtaking permitted) retrofitted on a road pavement
Source: Thomason (2018)

2.6.1 WCLT application in Queensland - General

Appendix F of TMR's Austroads Design Guide Supplement to Part 3 provides state-wide guidance on the utilisation of WCLT. It notes that WCLT are a viable option for reducing crash potential on 10 m and 10.5 m sealed carriageways. The guideline also points out that while lane and shoulder widths may need to be reconfigured for WCLT to be applied, the potential benefit of applying the treatment must be weighed carefully against any change in potential ROR and cyclist crash events (Department of Transport and Main Roads 2018a),.

A lateral buffer of 1 m has been determined as the optimal for WCLT in high speed zones. This is reflected by the guidelines provided by Austroads (2016b) and the Department of Transport and Main Roads (2018a). Both set out the that 2 km should be the minimum length of WCLT application and identify that for high speed zones, such as two lane rural highways, a width of 1.0 m is applied, as shown in Table 2.3. Other widths are listed dependent on posted speed and are based on providing similar recovery times/travel times across the treatment. The 1 m width for high speed zones is based on earlier research, such as that by Levett et al. (2009) who evaluated the effects of five different centrelines/WCLT widths on the Pacific and New England Highways. Their report concluded that the benefits of painted medians on crash incidence and severity are maximised when they are at least 1.0 m wide and incorporate ATLM.

Table 2.3 – Guidelines for WCLT Dimensions and ATLM Application

Posted Speed	WCLT(1)	ATLM
90 km/h and greater	1.0 m	Yes
70 – 80 km/h	0.8 m	No(2)
60 km/h	0.6 m	No

Notes to Table:

1. WCLT is width between the centres of the lines at either side of the treatment.
2. ATLM to be applied if section is immediately adjacent to a 90 km/h or higher speed zone (transitioning drivers between high and low speed zones) or there is a history of fatigue related crashes.

It is important to note that the WCLT widths above are based on providing similar travel times across the treatment. Other factors such as driver behaviour and driver's perception to determine when a vehicle will not return to the correct side of the road has not been considered and further research is required.

Source: Department of Transport and Main Roads (2018a, p. 63)

TMR specify the incorporation of both ATLM and retroreflective raised pavement markers (RRPM), the specifications for WCLT (overtaking permitted both directions), TC1978_1 is shown in Figure 2.10. ATLM are to be positioned on the outside the line markings defining the travel lane and the RRPM, included to supplement visual guidance in low light, are spaced in pairs every 24 m within the median area of the treatment. In sections where overtaking is allowed in both direction the RRPM pair are staggered, as shown in Figure 2.10.

WCLT can be applied to existing roads very cheaply, particularly as a paint-only project where road reallocation involves reducing the shoulder width, providing one of the most cost-effective ways for road agencies to reduce crash rates (Harrison et al. 2015, p. 65). While initial installation of WCLT in Queensland did not allow overtaking, current TMR specifications incorporate established line marking patterns and standards that drivers recognise, such as broken or continuous lines, as shown in Figure 2.11 and Figure 2.12, respectively. Traffic control signage is also utilised to inform drivers of acceptable use of the road, as shown in Figure 2.13.

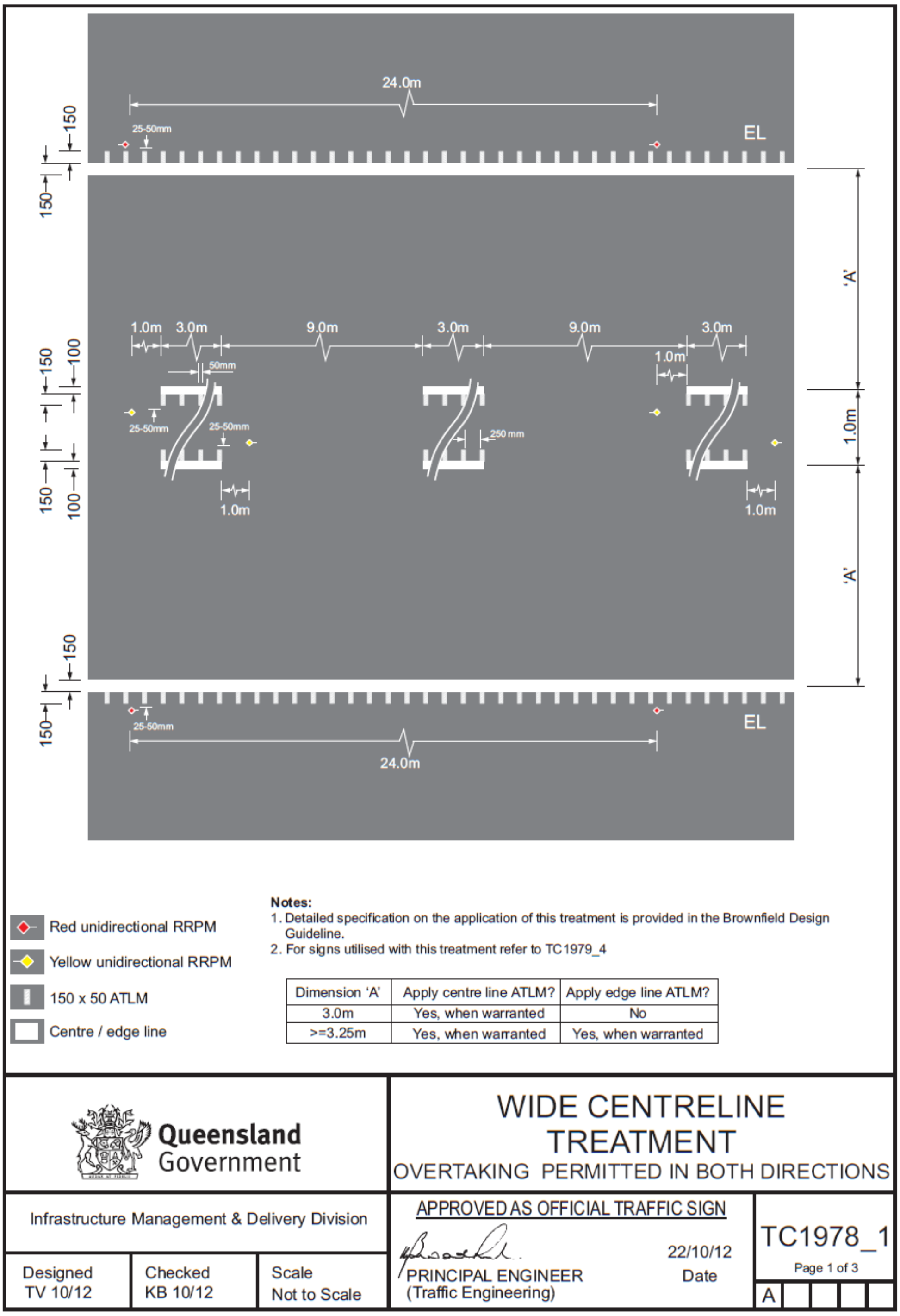


Figure 2.10 – Specification TC1978_1 for WCLT (overtaking permitted both directions)
Source: Department of Transport and Main Roads (2016, p. 7)

WCLT can be applied to existing roads very cheaply, particularly as a paint-only project where road reallocation involves reducing the shoulder width, providing one of the most cost-effective ways for road agencies to reduce crash rates (Harrison et al. 2015, p. 65). While initial installation of WCLT in Queensland did not allow overtaking, current TMR specifications incorporate established line marking patterns and standards that drivers recognise, such as broken or continuous lines, as shown in Figure 2.11 and Figure 2.12, respectively. Traffic control signage is also utilised to inform drivers of acceptable use of the road, as shown in Figure 2.13.

Figure 2.11 – WCLT – 'overtaking permitted one direction' markings
Source: Transport for NSW in Austroads (2016b, p. 10)

Figure 2.12 – WCLT – 'no overtaking permitted' markings on purpose-built road pavement.
Source: Department of Transport and Main Roads (2017a, p. 1)

Figure 2.13 – WCLT Information signs TC1979_1 to TC1979_4
Source: Department of Transport and Main Roads (2015a, p. 2).

Not all rural highways can accommodate WCLT. New road pavements can be designed to ensure adequate road cross-section width to allow for the treatment, design lanes, and the road shoulder width required under current guidelines. However, in terms of existing roads, early applications of WCLT in Queensland have occurred at locations identified as having sufficient existing sealed pavement width to accommodate the treatment, design lanes, and shoulder widths (Harrison et al. 2015, p. 64), as shown in Figure 2.9 where evidence of the removed centre line to incorporate the WCLT can be seen. However, since not all existing pavements have sufficient width under current guidelines there may be many high-speed rural roads or highways that would benefit from the application of WCLT if road shoulder constraints were reduced.

2.6.2 WCLT application on Queensland Rural Two Lane, Two Way Roads

Neuman et al. cited in Austroads (2016b) identified that WCLT installation may be achieved by narrowing lane and shoulder widths. However, the study also noted that the existing pavement geometry must allow trucks and buses sufficient space from the travel lane sides after narrowing. As shown in Table 2.4 and Table 2.5 while the suitable width of the WCLT is dependent on the signed speed of the road, the minimum lane width and minimum shoulder width are dependent on AADT volume and the size of vehicles that need to be accommodated on the given road. Note that the normal design domain (NDD) shown in Table 2.4, sets out the criteria and specifications that must be met or exceeded for all new works and wherever practical. The extended design domain (EDD) shown in Table 2.5, sets out the lower specifications than the NDD that should only be adopted when context-sensitivity demands it and it can be defended on engineering grounds and operating experience (Main Roads Western Australia 2018).

Table 2.4 – Normal design domain cross section for a WCLT – two lane, two-way roads

Design AADT	Vehicle routes	Sealed Shoulder (2)(3)(4) (m)	Lane Width (1) (m)	WCLT (m)	Total Seal Width (m) (6)
2000 - 4000	All vehicles up to B double	1.75	3.25	Refer Table 3-F 1 for width	11.0
	Type 1 Road Train	1.50	3.50		
	Type 2 Road Train	1.25	3.75		
> 4000	All vehicles up to B double	1.75	3.25		11.0(5)
	Type 1 Road Train	1.50	3.50		
	Type 2 Road Train	1.25	3.75		
	All vehicles up to B double	2.00	3.25		11.5
	Type 1 Road Train	1.75	3.50		
	Type 2 Road Train	1.5	3.75		

Source: Department of Transport and Main Roads (2018a, p. 62)

Note: Table 3-F 1 referred to in the WCLT column is Table 2.3 in this report.

Table 2.5 – Extended design domain cross section for a WCLT – two lane, two-way roads

Design AADT	Vehicle routes	Sealed Shoulder (2)(3)(4) (m)	Lane Width (1) (m)	WCLT (m)	Total Seal Width (m) (6)
2000 - 4000	All vehicles up to B double	1.25	3.25	Refer Table 3-F 1 for width	10.0
	Type 1 Road Train	1.00	3.50		
	Type 2 Road Train	1.00	3.75		10.5
> 4000	All vehicles up to B-double	1.25	3.25		10.0(5)
	Type 1 Road Train	1.00	3.50		
	Type 2 Road Train	1.00	3.75		10.5(5)
	All vehicles up to B-double	1.50	3.25		10.5
	Type 1 Road Train	1.25	3.50		
	Type 2 Road Train	1.25	3.75		11.0

Source: Department of Transport and Main Roads (2018a, p. 62)

Note: Table 3-F 1 referred to in the WCLT column is Table 2.3 in this report.

The cumulative effect of narrowing lanes and narrowing shoulders limits the recovery time a driver has from when the vehicle first begins to move toward the lane sides. However, with ATLM providing noise and vibration to alert drivers and Table 2.1 setting out 0.5 m as the minimum sealed shoulder required as an initial recovery area there is reason to consider whether the minimum sealed shoulder could be reduced for the various traffic volume categories set out in Table 2.4 and Table 2.5. It may also be that benefits of applying WCLT could also see the breadth of traffic volumes to which these tables specify are extended to rural two lane, two-way roads with AADT < 2000 may outweigh the disbenefits. However, as the purpose of road shoulders Is not limited to initial recovery, Neuman et al. cited in Austroads (2016b) also advise in ensuring the narrowing of road shoulders does not increase the risk of FSI incidents with objects nor remove adequate protection for vehicles that have needed to pull over.

2.6.3 Crash reduction support for WCLT

As WCLT laterally separate vehicles travelling in the opposite direction, it would be expected that the HO crash reduction rate figure would be the highest. Since the implementation of WCLT, crash studies have been carried out by Whittaker (2012), Cuckson (2016), and Harrison et al. (2015), to determine the success of reducing cross centre line crashes. These studies, particularly Whittaker's, were constrained by the limited amount of post-WCLT traffic data available and all relied heavily on traffic data from the Bruce Highway. Cuckson's (2016) study endeavoured to build on previous work, utilising a more robust approach when analysing the Bruce Highway data with the empirical Bayes method. Additionally, the study sort to investigate the effect of WCLT on the Sunshine Motorway, D'Aguilar Highway and Glass House Mountains Road. However, it noted inconclusive results on these additional highways due to the limited time since the WCLT application and a subsequent lack of post-treatment data.

From these early Bruce Highway studies, while the effect of WCLT on HOCL crash reduction stood out due to crash severity involved in these events, the overwhelming trend in Cuckson's results was that, with more available data, the WCLT crash reduction rates including all data up to 2016 were much lower than originally determined by Whittaker in 2012, with one exception – the RORL crash type. For RORL events, Whittaker's corrected 2012 reduction of 38% increased to a 50% reduction when including the data up to 2016 in Cuckson's report. Not only was this change in the result of the earlier study the opposite to all other crash type reduction trends but, at 50%, also stands out as being reduced significantly more than HOCL crash types at approximately 25% (Harrison et al. 2015; Cuckson 2016). The most recent study into the effect of WCLT on the Bruce Highway, by Luy et al. (2018), found the reduction between crash types was not so different from the earlier cited studies. Luy et al. (2018), using eight years of control and treatment site data and employing the empirical Bayes method, concluded that for straight road sections with WCLT there were reductions of 33% for all HOCL injury crashes and a 30% reduction of HOCL FSI crash types. Notably, the RORL reduction was still substantial with reductions of 21% for all injury crash types and a 24% reduction in FSI crash types. Given that WCLT laterally separate vehicles travelling in the opposite direction, the counterintuitive effect of WCLT on the rate of RORL crash types is significant and is proposed to be related to drivers' perception of risk in WCLT road sections and their subsequent driving behaviour.

2.7 Driver Perception of Risk

Driver comfort and perception of the driving environment influences driver behaviour and should be considered in road design. In a simulator study of driver perception of roadside configurations of rural two-lane roads Bella (2013) found that driver speed was higher when shoulders were present. The study also found lateral position was affected by shoulder width. Vehicle position was to the left of the lane when narrow (0.50 m) shoulders were present but shifted to the right side of the lane when wider shoulders (1.20 and 3.00 m) were employed. These findings reiterated some of the conclusions of Ben-Bassat and Shinar (2011), whose study into the effect of shoulder width, guardrail and roadway geometry noted shoulder width had a similar, significant effect on speed and lane position.

In the absence of other treatments wider shoulders may reduce crash risk. However, this may be due to driver's adopting a lane position further from the oncoming lane and, thereby, requiring more shoulder width to recover should they begin to drift toward the road edge. In the presence of treatments that reduce HOCL risk, such as WCLT, a narrow road shoulder may be appropriate as the risk of RORL events may also be reduced by drivers adopting a lane position that is more central or to the right of centre.

In terms of the effect of WCLT on drivers' lane positioning, the initial findings of a New Zealand trial by Burdett (2011) identified that while a 1 m WCLT increased the lateral separation of vehicles by 0.60 m on average. This suggests that while the lateral separation was increased, drivers were positioned further to the right of centre within their lane, perhaps perceiving the road edge as a greater risk due to a perceived decrease in HOCL risk provided by the WCLT buffer.

Burdett (2011) also found the WCLT had no significant effect on drivers' speed choice. This latter finding was in contrast to the previous investigation findings of Neuman et al. cited in Austroads (2016b) and of a more recent driving simulator and road study conducted by Charlton and Starkey (2016). Charlton and Starkey (2016) investigated the relationship between drivers' perception of risk on rural roads and the speed they chose to drive at. They found that drivers selected lower speeds on narrow roads and had a higher associated perception of risk. They also found that WCLT markings were associated with higher perceptions of risk and lower speed choices. These results were magnified in high traffic conditions.

The RORL result observed in the studies by Cuckson (2016) and Luy et al. (2018) suggests the effect of WCLT may extend beyond simply increasing the lateral distance between vehicles in opposing lanes. The treatment may also contribute to an overall safety effect on driver behaviour. Recent papers focussing on driver behaviour indicate there may be a connection. In response to significant numbers of single vehicle ROR crashes in the European Union between 2004-2013, Mecheri et al. (2017) investigated the effects of lane and shoulder widths. They identified strong trends in drivers' in-lane positioning in response to road reallocations, including lane narrowing, without generating behaviours that would adversely affect safety. They also noticed that drivers positioned the vehicle further from the road and lane centre when shoulders were at least 0.50 m. Haghighi et al. (2018) determined that crash type is strongly influenced by a road's geometric features and identified narrow road shoulders as one of the key features associated with lowering the risk of severe crash occurrence. The findings from both studies suggest that the positive overall effect WCLT may have on driver behaviour and subsequent reductions in crash rates, particularly on the shoulder side of the lane, may not be so unexpected.

2.8 Fatigue and speed on rural highways

Highways are typically designed to enable efficient, high-speed travel. As a result, and given the significant distances between regional towns, rural Queensland highways may stretch out over considerable distances with minimal geometric changes while carrying low traffic volumes. This creates a repetitive, low-stimulus environment that Farahmand and Boroujerdian (2018) state can lead to loss of concentration and have detrimental effects on drivers' performance. Their study into the effect of road geometry on driver fatigue found road design had a significant effect on lane positioning and time on task. More complex road geometry placed more demand on the driver, required more active driving and resulted in significantly improved mental engagement.

The effect of action demand on drivers was also seen by Ahlström et al. (2018) in a study into the road environment and how it affected the development of driver sleepiness. It was found that stimulating environments may help a driver mask fatigue, but the visual load is not as important as driver action in countering fatigue. While WCLT provide increased lateral separation to reduce the likelihood of HOCL events, the long, reasonably straight stretches of low volume rural Queensland highways places a low level of demand on the driver.

In terms of the outcomes of the Bruce Highway studies, it suggests that the combination of hills, on and off ramps to frequent towns, and a higher traffic volume to increase the perception of risk along Sections 10A and 10B may place a higher demand on the driver, thereby helping counter fatigue. In terms of this investigation into the effect of WCLT, the traffic volumes will be much lower, segments will be longer, the distance between towns will be longer and the roads flatter. As a result, fatigue and lack of driver concentration may play a greater role in crash rate. In terms of comparable highways, this study will require segments from low volume highways with minimal changes in vertical or horizontal direction.

Speed is also recognised influence on crash events and, particularly, on crash severity (Ma et al. 2015). The NSW Government reported that 42% of all fatalities from 2008 to 2010 were attributable to speeding (Moorena et al. 2014). More recently, in Queensland inappropriate speed resulted in 20% of the 2017 road toll (Queensland Government 2019). Greater speeds require greater stopping distances but additionally involve increased distances travelled during a driver's reaction time which may lead to insufficient recovery time and space for those incidents where the driver response does not involve braking. WCLT guidelines, shown in Table 2.3, reflect this understanding, providing greater width in association with higher speed. Most WCLT on rural Queensland highways are within 100 km/h posted speed limits. To enable a fair investigation any WCLT segments with posted speeds within 90km/h of this will require crash modification factors to enable crash modelling to account for the change in speed. Any WCLT within 80km/h zones will be considered too different to the 100km/h limit and will be excluded.

2.9 Crash Types and Data

In Queensland, road crash data is maintained by TMR to enable analysis and inform road safety initiative development. To qualify for TMR's Road Crash database, an incident must be reported to the Queensland Police Service, have resulted in a person being killed or injured, and involve the movement of at least one road vehicle (Department of Transport and Main Roads 2018f).

TMR uses a system for classifying crash type called DCA (Definitions for Coding Accidents) that is based on the vehicle movements prior to the incident. A DCA number is applied to all reported crashes and number coding is applied based on the nature and type of crash (Austroads 2015). The crash types of interest for studying the effectiveness of the WCLT are HO, RORR and RORL events (Whittaker 2012; Harrison et al. 2015; Cuckson 2016; Luy et al. 2018). These crash types are identified in the TMR DCA codes as 201, 701, 702, 703 and 704 as shown in the Table 2.6 below (Austroads 2015).

Table 2.6 – Standard accident-type codes for DCAs in Australia

Code	Vehicles from opposite directions	Off path when on straight road	Crash Type
201	Head on		HO
701		Left off carriageway: out of control	RORL
702		Right off carriageway: out of control	RORR
703		Left off carriageway: hit object/animal	RORL
704		Right off carriageway: hit object/animal	RORR

Source: Extracted from Austroads (2015, p. 87)

While code 201 is the code for pure head-on collision events, DCA codes 702 (off carriageway to right) and 704 (right off carriageway into object) are included as these movements involve crossing the centreline and are ones that could result in a head-on incident. Additionally, it is noted that the DCA codes presented in Austroads (2015, p. 87) for crashes 'off path on curve' do not differentiate between left or right movements off the road. Without this information any crashes on curves recorded within selected road segments could not be allocated as either HOCL or RORL events without speculation. Instead crash codes 801 to 804, covering vehicles leaving their lane on curves, have been excluded from both categories and included in the research as 'OTHER' to avoid assumptions. In turn, this study's findings can only be directly applied to straight sections of road.

Therefore, in this study, 'HOCL' events include the codes for HO and both RORR crash types, 201, 702 and 704. 'RORL' events include both codes 701 and 703. All other crash types along the selected road sections have been classified as 'OTHER'. Finally, 'TOTAL' represents the sum of these three crash groups.

2.10 Analysing & Evaluating Treatment Effectiveness

2.10.1 Observational Studies

The number of accidents and the severity of these accidents are considered the subjective measures of road safety (ITE-TSC 2009). Crashes are rare and random events that typically involve the convergence of events that are influenced be a number of contributing facts, such as visibility, driver attention, road design and speed (AASHTO 2010). They cannot be simulated so observational studies are required. Observational studies come in two forms: 'before and after' and 'cross-sectional'. The latter is used for comparing treatment types with one another while a before and after study is focused on the safety implications of a single treatment, such as WCLT in this investigation (ITE-TSC 2009). As crashes have is no single cause, there is no single road safety countermeasure. However, countermeasures are designed for target accidents that are directly related. The target accidents for this study have been identified in Section 2.9. Any countermeasure may have drawbacks as well as contribute benefits, some of which may be unknown or unforeseen. Therefore, in evaluating treatment effectiveness before and after studies are used to determine crash rate reduction.

In before and after studies factors that may influence the performance of the treatment may change over time and cannot be controlled. These are collectively known as casual factors of which there are two groups. Both groups need to be accounted for to ensure an assumption that all parameters are constant does not invalidate the results (ITE-TSC 2009). The first group are those factors that are recognised and can be explained by models. The second group are not recognisable but still have to be accounted for in a valid before and after investigation. From these two groups of factors any safety performance change over time, i.e. from the 'before' to the 'after' period, can be separated into four component effects: treatment, exposure, trend, and random (ITE-TSC 2009).

2.10.2 Treatment Effect

The treatment effect is the net change in safety performance of the road due to the treatment alone i.e. isolated from the other component effects (ITE-TSC 2009). Therefore, an understanding of the other casual components is required, enabling the safety performance of the road had no treatment been applied to be determined and thereby, knowing the target crash type, facilitating a comparison with the safety performance as a result of treatment.

2.10.3 Exposure Effect

As accidents are rare and random, the exposure effect is related to traffic volume. While the relationship between accident probability and traffic volume is not purely linear (Qin et al. 2005; AASHTO 2010) as the number of vehicles utilising a treatment section of road increase, the greater the probability that one may have an accident becomes. The effect could be important if the treatment changes the capacity of the road. However, in this study WCLT do not alter the AADT of the road.

2.10.4 Trend Effect

The effect of trend is caused by factors that are not recognised, understood or measured but may change between the 'before' and 'after' period, such as conditions (road, weather, vehicle, enforcement) or composition (vehicle types, drivers). In this instance, sites selected have consistent AADT total load distribution spectrums and have had the treatment for several years, thereby reducing effects due to trend.

2.10.5 Random Effect

A phenomenon known as regression to the mean bias causes the random effect. There is a chance for regression to the mean bias to particularly influence safety performance results. This is due safety treatments typically being applied at sites with a higher than usual number of accidents. This may be short term but lead to a treatment being applied and subsequent studies being carried. In the 'after' period the number of accidents appears to fall. However, statistically it would be expected to fall without treatment anyway as the accident rate trends back towards the longer term, historical rate (ITE-TSC 2009).

2.11 Analysis Methods

Previous studies evaluating the benefits of road pavement treatments such as those focussing on WCLT have used a before-and-after method of analysis. The objective of this approach is to compare known crash figures recorded prior to the treatment with the number of crashes that it is expected would have occurred in the time period after the treatment had the treatment not actually been applied. Whittaker (2012, p. 33) identifies factors such as crash types, the suitability of comparison sites, the duration of post-treatment traffic data available and the treatment type as those that most influence the results when studying road treatments. Khan et al. (2015) identifies four types of before-and-after methods: the simple (Naïve) before-and-after analysis, the comparison group (CG) analysis, the empirical Bayes (EB) analysis and the full Bayes (FB) analysis.

2.11.1 Simple (Naïve) before-and-after analysis

The Naïve before-and-after analysis is the simplest of the four techniques. It compares known crash figures recorded prior to the treatment with known crash figures recorded after the treatment. It assumes that the relationship between factors is linear and that the crash data follows a Poisson distribution before using the difference in crash figures to assess the safety benefit of the treatment (Khan et al. 2015). However, this method is affected by the random, trend and exposure factors, discussed in Section 2.10, inherent in road crash data. When these are combined with this method's limitations to address bias caused by regression to the mean it leads to conclusions that are inaccurate and misleading (Shen & Gan 2003). Therefore, this method is not recommended and is not used in this study.

2.11.2 Comparison group (CG) analysis

The CG analysis method accounts for various causal factors that change with time (Khan et al. 2015). This is achieved by comparing the treatment site to a comparison group of untreated sites with similar geographic and traffic characteristics (Khan et al. 2015; Cuckson 2016). Crash data from these sites is used to estimate the expected crashes during the after period had no treatment been applied. Using this method can result in better estimates of the after-period crashes, thereby improving the analysis and conclusions. However, the accuracy of the CG analysis relies on the degree of similarity between the treated and selected untreated comparison sites. Also, like the Naïve before-and-after analysis, CG analysis accuracy is limited by its inability to address regression to the mean bias (Khan et al. 2015), so it is not used in this study.

2.11.3 Empirical Bayes (EB) analysis

Developed by Hauer (1997) and Hauer et al. (2002) for estimating safety, the EB method addresses the limitations of the Naïve and CG Methods by accounting for the external casual factors of exposure, trend and regression to the mean bias (Khan et al. 2015). This enables the effectiveness of road safety treatments to be estimated with more confidence. The EB method is a more complex method of analysis, recognising that crash counts are not a road's only measure of safety and estimating the expected crash numbers at the treatment site had no treatment been applied. This is achieved by considering the crash trend at the site pre-treatment and the trends at non-treated 'reference' comparison sites (Persaud et al. 2010; Khan et al. 2015). The EB analysis method is the most commonly utilised and accepted statistical approaches for before-and-after evaluations of road safety treatments, particularly in safety performance studies since the publishing of the Highway Safety Manual in 2010 (Kitali & Sando 2017). However, the EB approach also has some inherent methodological and statistical limitations, such as the assumption that any unknown factors will affect the reference sites in the same way the treatment site is influenced (Sacchi & Sayed 2015). Regression-to-the-mean can also be problematic unless treatment site and reference group have matching crash occurrence and there are practical difficulties in achieving this (Gross et al. 2010). To use this method every effort would be required to identify control group segments with similar geometric characteristics, lengths, features and traffic volumes. Reviews of previous WCLT studies in Australia to date have all employed the EB approach.

2.11.4 Full Bayes (FB) analysis

Considered a more complex version of the EB method, the FB analysis method has some strengths over the EB method. It provides more detailed inference, better integrates tasks and better accounts for uncertainty in the data used (Persaud et al. 2010; Sacchi & Sayed 2015; Kitali & Sando 2017). This is achieved by generating a distribution of likely values that is combined with the treatment site specific crash trend data that can then be used to create an estimate of the expected crashes at the treatment sites had treatment not been applied. This estimate is used for comparison instead of using crash trend information from similar sites as used in the EB method (Khan et al. 2015). This also makes the FB method more attractive in situations where sufficient comparison site data is difficult to acquire, when sample sizes are small or the target crash type is rare (Gross et al. 2010).

The FB approach has not been used by previous studies to evaluate WCLT due to the complexity of the methodology required and the comparable results determined by the EB approach (Persaud et al. 2010, p. 38). Therefore, this study will also employ the EB method. Additionally, it will provide consistency of approach for comparison of studies and results where applicable.

2.12 Crash Modification Factors

Crash Modification Factors, CMF, which globally may also be referred to as the Accident Modification Factors, AMF (AASHTO 2010) are the measure of treatment effectiveness (Austroads 2015). They are used to describe the long-term benefits expected to result from the implementation of a road safety feature by indicating the expected remaining crashes. CMF provide a quantitative measure that enable transport professionals to evaluate treatments and assumptions, compare safety benefits of different treatment types at various locations, and develop cost-effective strategies (Gross et al. 2010).

CMF are determined by expressing the expected average crash frequency with the treatment as a fraction of the expected average crash frequency without the treatment and are the complimentary event to Crash Reduction Factors, CRF. The CRF is the traditional measure used and is expressed as a percentage (AASHTO 2010; Austroads 2015). If a treatment has a successful effect on safety the CMF will be a value less than 1.00 and the CRF will be greater than zero. For example, a CMF of 0.76 would correspond to a CRF of 24%. Austroads (2015) suggests that CRF for various crash severities are valuable but recognises that this can be limited by available data. In this study data on all crash types was accessible.

2.13 Project Value

The literature review identified that the effect of WCLT may extend beyond simply increasing the lateral distance between vehicles in opposing lanes and reducing HOCL crash rates. It may also contribute to an overall safety effect on driver behaviour and, subsequently, RORL crash events. WCLT were introduced to target one of the most severe crash types, the HOCL event, yet evidence shows RORL events, on treated sections of the Bruce Highway, are being significantly reduced (Cuckson 2016; Luy et al. 2018). This counter intuitive finding may be influenced by drivers' perception of risk and subsequent lane positioning. However, these factors may work against drivers on longer, lower volume segments of highway. As the subject WCLT segments of previous studies into the effect of WCLT were all from Sections 10A and 10B of the Bruce Highway, the effect of WCLT on low volume rural highways should also be determined, particularly with respect to RORL crash types. By doing so, this study adds to the literature on the effect of WCLT, improving understanding of the extent of the treatment's suitability.

The literature review identified the empirical Bayes method as a suitable before and after study analysis approach. Less complex than the full Bayes method but providing comparable results, it offers the additional benefit of providing consistency of analysis methodology with the previous Bruce Highway studies. The study analyses the effect of WCLT on low volume highways, particularly the effect on RORL events, and evaluates the potential for further studies and opportunities arising from the results.

Further evidence of the effect of WCLT on RORL crashes is particularly important. This is not the target crash type of the treatment. However, despite being hypothesised by previous studies to be negatively affected, RORL events were found to receive a large crash reduction benefit. If the significantly reduced rate of RORL incidents found on the Bruce Highway also found on other treated subject roads, then potential may exist for a review of associated road shoulder width guidelines. This may involve subsequent investigations into the effect of WCLT on driver behaviour and vehicle positioning. Depending on the results of these studies, trials or simulator studies using narrower road shoulders with WCLT might be supported. Success of these trials may provide the necessary evidence to revise the guidelines around WCLT specifications and the required road shoulder, enabling WCLT to be applied to rural highways that do not meet current existing pavement width guidelines.

Current Queensland specifications detail 1.0 m wide shoulders are to be provided on a 10.0 m or 10.5 m EDD carriageway and 1.25 m shoulders on an 11.0 m NDD carriageway (Department of Transport and Main Roads 2018a), as shown in Table 2.4 and Table 2.5. Should support for narrower road shoulders be found, the opportunity to apply WCLT and potential to reduce crash rates on roads with narrower existing pavement width will be available. This would potentially save lives, as well as provide fiscal savings due to cost reductions in areas such as accident clean-up and emergency services costs. Findings of an increase in RORL events will still be of value as this will justify a revision of WCLT CMF and the highway parameters for which WCLT is suitable. Therefore, the effect of WCLT on the rate of RORL incidents needs to be verified.

Chapter 3 Methodology

3.1 Introduction

From the literacy review it was established that for this study into the effectiveness of a single road safety treatment a before-and-after observational study was required. Treatment target crash types and available data for HOCL and RORL events were determined and limitations on what data could be collected were ascertained. From the various known before-and-after study approaches, the empirical Bayes approach was selected to enable causal factors, such as exposure, trend and random effects to be accounted for in the statistical analysis. Crash Modification Factors were then calculated as the measure of treatment effectiveness before being converted to Crash Reduction Factor form – the traditional crash reduction study form.

3.2 The Empirical Bayes Method

While the method was originally proposed by Hauer in 1997, the Highway Safety Manual sets out the accepted method for applying the empirical Bayes (EB) before-and-after approach to estimate and evaluate the safety effectiveness of a treatment (AASHTO 2010).

The safety effect of a treatment is calculated by finding the difference between the expected/predicted number of crashes had no treatment been applied, $N_{expected,T,A}$ (or for simplicity, E_A), and the sum of the observed/actual crashes in post-treatment period, $N_{observed,T,A}$ (or O_A).

$$Safety\ effect = N_{expected,T,A} - N_{observed,T,A} = E_A - O_A \qquad \text{Eqn. 3-1}$$

However, it is more commonly described as a ratio of the observed number of crashes after treatment compared to the expected number had no treatment been applied. It is in estimating the number of crashes expected had no treatment been applied, that the empirical Bayes approach is utilised.

3.2.1 Data and Safety Performance Functions

First, data on a large group of reference/control sites that are similar to the treatment sites is required. The size of the control group must be sufficient to reduce the chance of any bias in the estimates of the number of crashes expected had no treatment been applied. In their study to determine the optimal ratio of control to treatment sites in matching studies, Linden and Samuels (2013) identified that a ratio of 4:1 results in the lowest statistical bias. While a higher ratio could be used, there is no statistical benefit gained though they noted that for longitudinal studies a larger ratio may be beneficial.

Next, a regression model is fitted to the control group data with the purpose of calculating the safety performance factors (spf) for variables that may influence crash frequency such as traffic volume. This step is undertaken using regression analysis software. To model yearly crash frequencies the standard method involves applying a negative binomial distribution with a log link to a generalised linear model (AASHTO 2010). This process is known as calibration. The resulting spf parameter estimates are used as coefficients in a safety performance function (SPF) for each crash type. The calibrated SPF, shown in general form as Eqn. 3-2, are mathematical models that can be used to calculate the average crash frequency for a segment based on comparable sites. To account for additional factors on the treated road segments that may influence crash frequency, such as reduced speed limit, crash modification factors (CMF) may also be included in the model. To account for the difference in speed limit Gross et al. (2010) recommended the use of results from surrogate measure studies to determine the CMF for applicable segments. Th calibrated SPF models provide an additional information source for the EB process to help account for regression-to-the-mean, time trends and AADT changes (Gross et al. 2010). The SPF models estimate the number of crashes that would have been on the treated road segment per year ($N_{spf,rs}$) based on comparable sites.

$$\mathrm{N_{spf\,rs}} = \mathrm{CMF} \times \mathrm{e}^{[\alpha+(\beta_1\times \mathrm{L})+(\beta_2\times \mathrm{AADT})]} \qquad \text{Eqn. 3-2}$$

Where, L = segment length

α, β_1 and β_2 = spf parameters

These values for each year are summed to determine the *predicted before* ($N_{predicted,T,B}$) and *predicted after* ($N_{predicted,T,A}$) periods for later stages of the process. For simplicity these will be referred to as P_B and P_A, respectively.

3.2.2 EB Estimation of Expected Crash Frequency (before)

P_B is then used to determine the weighted expected number of crashes at the treatment site in the before period ($N_{expected,T,B}$ or E_B). This is done by weighing the observed number of crashes at the treatment site ($N_{observed,T,B}$ or O_B) and P_B by the complimentary weighting factors, w_1 and w_2.

$$E_B = w_1 \times O_B + w_2 \times P_B \qquad \text{Eqn. 3-3}$$

Where,

$$w_1 = \frac{P_B}{P_B + 1/k} \qquad \text{Eqn. 3-4}$$

$$w_2 = \frac{1}{k(P_B + 1/k)} \qquad \text{Eqn. 3-5}$$

k = the overdispersion parameter of the negative binomial distribution created earlier in the regression model during the SPF calibration process.

3.2.3 EB Estimation of Expected Crash Frequency (after, no treatment)

An adjustment factor, *R*, the ratio of the predicted SPF estimates P_A and P_B is calculated to account for any effect of any differences in the length of the before and after periods on non-time related variables such traffic volume.

$$R = P_A/P_B \qquad \text{Eqn. 3-6}$$

The number of crashes expected had no treatment been applied, ($N_{expected,T,A}$ or E_A) is then calculated using Equation 3-7.

$$E_A = E_B \times R \qquad \text{Eqn. 3-7}$$

3.2.4 The Treatment Effectiveness

The overall treatment effectiveness can be calculated in the form of an odds ratio of the observed number of crashes compared to the expected number, shown as Equation 3-8. A safety improvement provides a value < 1.

$$OR' = O_A/E_A \qquad \text{Eqn. 3-8}$$

However, Hauer, cited in AASHTO (2010), noted that this basic odds ratio estimate of effectiveness is potentially biased. An adjusted method, shown as Equation 3-9, is recommended as it provides a more reliable, unbiased estimate of treatment effectiveness, θ.

$$\theta = \frac{OR\prime}{1+\left[\frac{Var(E_A)}{E_A{}^2}\right]} \qquad \text{Eqn. 3-9}$$

Where, $Var(E_A) = R^2 \times E_B \times w_1$ Eqn. 3-10

Next, the overall unbiased safety effectiveness, *CMF*, can be calculated as a percentage change in the frequency of crashes.

$$CMF = 100 \times (1 - \theta) \qquad \text{Eqn. 3-11}$$

3.2.5 Estimating the Precision of the Treatment Effectiveness

This final stage is utilised to determine whether the *CMF* is statistically significant. This is determined by first estimating its precision of the unbiased estimate of treatment effectiveness, θ.

The variance of θ is calculated as follows:

$$Var(\theta) = \frac{\theta^2\left[\frac{1}{O_A}+\frac{Var(E_A)}{{E_A}^2}\right]}{1+\left[1++\frac{Var(E_A)}{{E_A}^2}\right]} \qquad \text{Eqn. 3-12}$$

This variance is then employed to calculate the standard error (the precision of the unbiased estimate of treatment effectiveness, θ) using Equation 3-13.

$$SE(\theta) = \sqrt{Var(\theta)} \qquad \text{Eqn. 3-13}$$

Next, the *CMF*'s standard error is calculated as:

$$SE(CMF) = 100 * SE(\theta) \qquad \text{Eqn. 3-14}$$

Finally, comparing the absolute value of the quotient of the *CMF* over its standard error enables the statistical significance of the estimated safety effectiveness to be revealed and criteria-based conclusions to be drawn.

3.3 Data collection

The raw data for this study was collected from the Queensland Government Data Portal and by application to TMR. Other data sources included NearMap, Google Street View and the Route Planner application from Ride with GPS. These were utilised to provide current and historical satellite imaging of the subject highways for comparison purposes and to verify geometric information such as pavement widths, gradients, intersections, speed limits and road alignments. Google Earth was utilised to precisely locate crash sites from the Portal data co-ordinates and match these to highway road segments. An example of a data request submitted to TMR is provided in Appendix B.

3.3.1 Crash Data

The Queensland Government Data Portal hosts the road crash dataset from TMR for all reported Queensland crashes from 1 January 2001. It includes all fatal, hospitalisation, medical treatment, minor injury and property damage crashes and, at the time of project data collection, was complete for all years through to 30 June 2018. The dataset includes all Queensland roads so crash data from all roads with WCLT are captured. The dataset was downloaded in digital .csv spreadsheet form enabling it to be filtered by variables such as highway, speed limit, and year. Appendix C shows an extract from the dataset which is updated annually and freely available from the Queensland Government Data Portal. Due to the vast amount of data contained in the file on over 321,000 crashes in Queensland since 2001 the full dataset has not been included with this report.

As the crash data is one of the cornerstone elements on which the results of this study depend, all care was taken manage, transfer and utilise data in the analysis process. However, it is noted that the dataset was extracted from the Queensland Road Crash Database and the accuracy of this database relies on the level of detail and accuracy of reporting and transposing at the time of the crash investigation. Due to practical limitations this study assumed the collected road and crash datasets are validated as true and accurate for all years through to 30 June 2018.

3.3.2 WCLT segment selection for Treatment Group

In this study a treatment site or segment is defined as a length of two-lane, two-way highway in a 90-100 km/h speed zone where the WCLT has been applied and is the exclusive treatment. Following on from this definition, and as the purpose of WCLT is to reduce the rate of HOCL events, road segments that incorporated features that could otherwise influence safety or crash type were avoided. This was done by splitting segments, if required, by removing a transition length of 100 m either side of the influencing feature. This transition length was selected as at 100 km/h, and allowing for a comfortable lateral shift of 0.6 m/s as used by the WCLT tapers (Department of Transport and Main Roads 2017a), a distance of 60 m would allow for a 1.2 m lateral adjustment in vehicle position in response to any feature. The length of 100m provides addition buffer length and time to remove the influence of the feature.

Road segments selected for later analysis were essentially homogenous, as prescribed by Section C.5 the Highway Safety Manual (AASHTO 2010). They were reasonably straight segments of two-lane highway that required no advised change to speed, and were uninterrupted by major intersections with channelised treatments, road furniture or changes in cross-section configuration. This same practice was applied to the selection of control segments.

Table 3.1 – South east Queensland highways with WCLT

Road ID	Highway Name	Towns	WCLT Completion Date
150B	Sunshine Motorway	Maroochydore-Peregian	March 2013
17B	Cunningham Highway	Brisbane-Warwick	June 2015
17C	Cunningham Highway	Warwick-Inglewood	June 2018
18B	Warrego Highway	Toowoomba-Dalby	November 2017
18C	Warrego Highway	Dalby-Miles	November 2017
22C	New England Highway	Warwick-Wallangarra	January 2016 and July 2018
25B	Mt Lindesay Highway	Beaudesert-Palen Creek	January 2017
28B	Gore Highway	Millmerran-Goondiwindi	February 2015
40A	D'Aguilar Highway	Caboolture-Kilcoy	July 2015
42A	Brisbane Valley Highway	Ipswich-Harlin	June 2015

Source: Extracted from Department of Transport and Main Roads (2019c)

As WCLT have been applied to several rural highways this study was able to analyse multiple treatment sites across the south east Queensland (including the Darling Downs region). In response to an information request to TMR, a data file of all two-lane highways with WCLT applied in south east Queensland, excluding the Bruce Highway, was provided in digital .csv spreadsheet form. This included details such as highway name and ID, segment start and end chainages, and completion date. Table 3.1 shows a summary of that file identifying the treated highways and their treatment completion dates. Due to practical limitations an extract of the supplied WCLT location file has been included as Appendix D.

3.3.3 Segment selection for Control Group

As discussed in Section 3.2, in order to calculate the safety effect of a treatment the number of crashes expected had no treatment been applied needs to be estimated. To do this the empirical Bayes (EB) approach is utilised. However, it involves several stages. The first, set out in Section 3.2.1, requiring the identification of road segments with similar characteristics to the treatment group but without the WCLT to first develop a safety performance function (SPF). This is done by fitting a regression model the crash data from the selected control sites.

As a one-to-one pairing of treatment and comparison segments is not required in the Bayesian approaches differences in the number of treatment and control segments is inconsequential. Similarly, the control group segments do not need to be exactly the same. This would be impractical, if not impossible. However, the control group segments do need to be similar to the treatment segments as they affect the regression model. The larger and more closely matching the control segments' characteristics are to the treatment group segments', the more accurately other factors that may influence the rate of crashes will be allowed for. These factors, such as driver assist features in cars, traffic volumes and speed limits, may affect vehicle safety beyond the effect of the treatment. The EB method accounts for these through the developed regression model. Therefore, suitable control segment selection enables a greater ability to remove the influence of the component effects of exposure, trend, and regression to the mean discussed in Section 2.10. In turn, the regression model is able to more accurately estimate the 'after' period crash numbers.

In this study, to be comparable to roads that have had WCLT applied the control road segments had to have a two-lane, two-way cross section and a similar function and environment to the treatment group highways. They were identified as highways in Queensland that provided links between rural centres, with a total pavement width of 10 - 11m and a similar AADT to the treatment sites. Highways from which control sites were selected with a summary of their data are tabulated below in Table 3.2.

Table 3.2 – Queensland highways from which control sites were identified

Road ID	Highway Name	Towns
10B	Bruce Highway*	Gympie - Maryborough
10C	Bruce Highway*	Maryborough - Gin-Gin
17B	Cunningham Highway*	Brisbane - Warwick
18C	Warrego Highway*	Dalby - Miles
22B	New England Highway	Toowoomba - Warwick
28A	Gore Highway	Toowoomba - Millmerran
42A	Brisbane Valley Highway	Ipswich - Harlin

* Highway also contains sections with wide centreline treatment applied.

3.3.4 Limitations of Timeframes

While it is recommended in Exhibit 9-7 of the Highway Safety Manual (AASHTO 2010) for three years of post-treatment crash data to be collected, the recency of treatment application meant not all treatment locations had data for this timeframe. This limitation in the data available may influence the results by increasing component effects. As a result, there may be value in a further study into WCLT effectiveness when additional post treatment data is available.

Additionally, in a response to a request for data on the start and end date of WCLT application to treatment sites TMR records were limited to the date of completion. As a result, the exact construction time period was unknown. Construction and/or application of any treatment occurs over a period and throughout this time period the roadworks area is typically under control of a Traffic Management Plan. Immediately after new roads or features are opened for use a short amount of time is required for traffic to become used to the road/feature and for usage patterns to stabilise (Kitali & Sando 2017). Therefore, data during this period is atypical and should be excluded from the study as any data may be unforeseeably influenced. While the SPF models were developed using crash data from control sites, the treatment site crashes during the construction period may influence the resulting Empirical Bayes estimates. Therefore, to allow time for construction and then for the treatment and traffic around the treatment to stabilise a buffer period was created, as recommended by AASHTO (2010). This was done by excluding data from the year that the treatment was applied/completed. While this exclusion time frame may be excessive to construction and stabilisation needs, it was done to provide greater confidence in the traffic patterns being typical during the ‘before’ and ‘after’ periods and subsequently provide greater confidence in the validity of the results.

Chapter 4 Analysis

4.1 Introduction

This chapter provides detail on the analysis performed as set out in the Methodology, including the organisation of data, the statistical analysis undertaken and the models and results of the analysis process.

As with previous studies into the effectiveness of WCLT this research grouped crashes into three different crash types and analysed the effect on each.

- The first group was the Head-on/Cross centreline (HOCL) crash which includes DCA codes 201, 702 and 704, as per Table 2.6. These crash types are the target of the WCLT as discussed in the Literacy Review Section 2.6.
- The second crash type group was the focus of this research, the Run-off-road-left (RORL) crash, which included DCA codes 701 and 703. The crash type was expected to be negatively affected due to the reduced shoulder width required under the WCLT application guideline. However, previous studies on data from the Bruce Highway had indicated a positive effect.
- The final group included was total crashes. This was included to analyse the effect of WCLT on all crash types on a range of Queensland highways and add to the work of previous studies from the Bruce Highway.

The analysis process was broken down into five main stages:

1. Crash data collection
2. Treatment group segment selection
3. Control group segment selection
4. Development of SPF functions
5. Empirical Bayes analysis

4.2 Crash data collection

As noted in Section 3.3.1, TMR's road crash database for all reported Queensland crashes from 1 January 2001 through to 30 June 2018 was available for download from the Queensland Government Data Portal. It includes all fatal, hospitalisation, medical treatment, minor injury and property damage crashes for all crash types and is updated annually. With over 321,000 crashes on file for the entire state, this dataset had to be refined to include only the events applicable to this research. However, even filtering by variables such as highway, speed limit, and year to refine the database still resulted in a file containing thousands of records. As such, Appendix C shows just an extract of the initially refined dataset.

As shown in Appendix C, the road crash dataset included numbers of casualties. For this research it was assumed that crash type was independent of casualty or vehicle numbers - that the likelihood of a crash incident where a vehicle crosses the centreline or runs off the road is not influenced by the number of vehicle occupants or vehicles. Therefore, each recorded event was treated as a single crash irrespective of these numbers.

The dataset also provided crash locations. Locations were identified as a latitude and longitude value based on the GDA94 coordinate system rather than a chainage along a section of highway or road. Geocentric Datum of Australia (GDA94) is a geocentric coordinate system, adopted nationally in Australia in 2000 and referenced to the centre of the Earth's mass, thereby enabling compatibility of coordinates with global GPS coordinates (Intergovernmental Committee on Surveying and Mapping 2019). Due to crash locations being recorded in this way, the database .csv file was imported into Google Earth and crashes were displayed as an overlay of point locations on the base map as depicted in Figure 4.1. This would enable visual identification of crash events and subsequent filtering later in the analysis process.

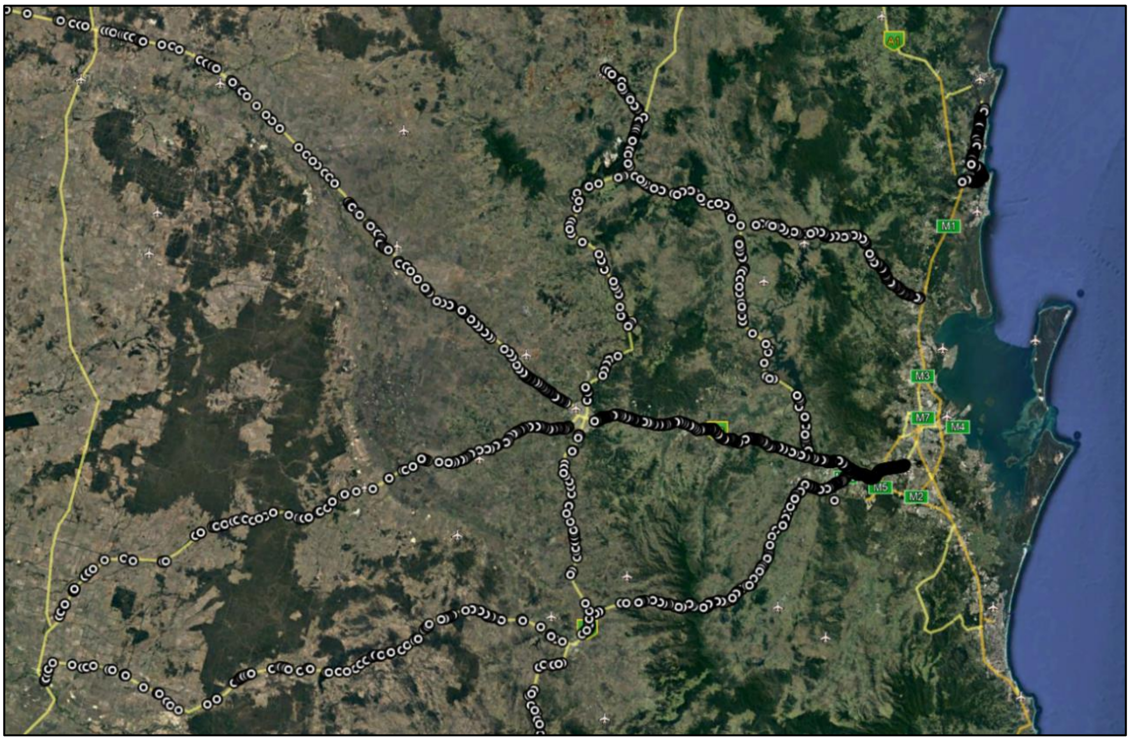


Figure 4.1 – Screenshot of highway crash location overlay in Google Earth

4.3 Treatment group segment selection

The first task involved identifying highways in the Darling Downs and south east Queensland region that have the WCLT and then determining the start and end chainages of segments suitable for inclusion in this study. As noted in Section 2.13, the focus of WCLT studies carried out by Whittaker (2012), Harrison et al. (2015), Cuckson (2016) and Luy et al. (2018) focused on treated sections of the Bruce Highway where the lowest traffic volume along the treated segments exceeded 12,000. As AADT is a proven factor influencing crash rate and the objective of this study was to determine if the degree of success of WCLT on RORL events can be confirmed on lower volume rural highways, highways were identified where the minimum AADT was greater than the 2000 specified by TMR's RPDM guideline, shown in Table 2.2 but no greater than 10,000.

TMR provided a data file of all two-lane highways with WCLT applied in the Darling Downs and south east Queensland region, as listed in Table 3.1. Using traffic census data, freely available from the Queensland Government Data Portal, the list of treated highways applicable to this study was refined. The Sunshine Motorway was excluded from this study as its minimum AADT has over 20,000 since 2011 (Department of Transport and Main Roads 2019d).

The next step was to review each of the potential subject highway's characteristics to determine those suitable for inclusion in the analysis. TMR's Digital Video Road (DVR) program provides a recorded view of a road with road properties such as gradient, pavement width and chainage presented on screen as the user's position moves along the road. As this was not accessible, in lieu of access to DVR, a combination of NearMap and Google Street View was employed. A methodical process of simultaneously comparing the high resolution NearMap satellite imagery with the Street View 'driver point of view' imagery was used. This enabled the measurement of pavement widths and verification of road cross-sections, street furniture and any other features along each potential highway that would affect the highway's suitability for inclusion in this project. The additional benefit of NearMap was its historical satellite imagery which enabled a review of each highway over the past ten years.

The Brisbane Valley Highway (42A) was not included in this study for selection of treatment segments. The initial review using Street View identified that while the Brisbane Valley Highway contains three short WCLT segments (with the total treatment length being approximately 1 km), each of these segments contains an overtaking lane, as shown in Figure 4.2. The treated New England Highway segments (22C) were also excluded. While the highway contained numerous treatment segments, the original width of the pavement of less than 10 m excluded the highway for comparison purposes. Additionally, significant lengths of the highway that include treated segments have been realigned thereby making the 'before' period crash data invalid. The Mt

Lindesay Highway (25B) and the Gore Highway (28B) were also excluded from the study due to the insufficient width of their original pavements. Section 17C of the Cunningham Highway was excluded from the treatment group as it was only completed in June 2018, so no post treatment data was available. Finally, the Warrego Highway (18B & 18C) was excluded as it had less than 12 months post-treatment data available and no events recorded in that period.

Figure 4.2 – Brisbane Valley Highway (42A) with WCLT and overtaking lane
Source: Street View (2017a)

Therefore, it was determined that treated segments from the Cunningham Highway (17B & 17C) and the D'Aguilar Highway (40A) would be used. These highways have segments of two-lane WCLT and are not limited to running in a North-South direction. Additionally, they provide a broad range of traffic volumes and a mixture of overtaking permitted/not-permitted segments.

Next the simultaneous use of Street View and the Route Planner application from Ride with GPS was employed to verify the treatment segment start and end chainages and determine any control segment chainages. The Route Planner enabled the highway road section start and finish points to be determined. First the route along the identified highway was set out by dropping pins along the route. Multiple pins would be used, and the route would be visually reviewed to ensure no deviations off the highway of interest occurred. Verification of the route chainages was then undertaken by confirming the start and end chainages of WCLT locations corresponded with the respective WCLT chainages provided by TMR. Once the highway start and end points were established, all segment start and end chainages of the WCLT were confirmed. Additionally, the segment start and end of any suitable control segments were recorded.

The screenshot shown in Figure 4.3 depicts the methodical simultaneous review process for each highway. It also exemplifies a potential control section that was excluded due to the guard rails in the Street View image. This screenshot also shows how the gradient of the road at the point of interest was also reviewed. The longitudinal profile provided in the Route Planner (lower left section of screenshot) identifies the chainage (20.4 km), elevation (27 m AHD) and gradient (-0.9% in the direction of travel) at the location of the blue dot in the satellite image. In this way, to ensure reasonably consistent gradients of segments, segments where the average gradient was greater than 3% were excluded. Short segments less than 200m total were also excluded.

Figure 4.3 – Screenshot showing of simultaneous review of the Cunningham Highway

Treated segments to be removed from the analysis were also identified by this process due to speed limits below the 90-100km range accepted for this study. Figure 4.4 depicts an example of this on the D'Aguilar Highway where the start of the WCLT can be seen in centre of image while the posted speed is 80 km/h. Other issues identified were the incorporation of overtaking lanes with the WCLT resulting in the exclusion of some treated segments, as shown in Figure 4.5.

Figure 4.4 – WCLT in 80km/h speed zone, D'Aguilar Highway (40A)
Source: Street View (2017b)

Figure 4.5 – WCLT with overtaking lane, D'Aguilar Highway (40A)
Source: Street View (2017c)

Given the completion dates of the WCLT and time period of post-treatment crash data available the treatments sites for analysis in this study were finalised and are shown in Table 4.1. A locality map of each highway showing sections from which treatment segments were selected is provided in this report as Appendix E, while a more general locality map is shown in Figure 4.7.

Table 4.1 – WCLT highways included in this analysis

Road ID	Treated Highway	Completion Date	Total number of segments	Total length of segments (km)	Pre-WCLT data	Post-WCLT data
17B	Cunningham Highway	June 2015	7	19.90	2012, 2013, 2014	2 years - 2016, 2017
40A	D'Aguilar Highway	July 2015	11	16.91	2012, 2013, 2014	2 years – 2016, 2017
Total			18	36.81		

The final step for the treated segments was to match them with the crash data. The crash data layer in Google Earth enabled visual identification of any recorded crash events that had occurred within the identified treatment segments by decreasing the view altitude, as shown in Figure 4.6. This manual process, while time consuming, enabled each crash point to be analysed for suitability. The DCA codes indicating HOCL and RORL events could be quickly verified against the accident description and the crash recoded against the appropriate segment. For OTHER crash types, as this would affect TOTAL crash numbers, not all other DCA codes were included. 'Hit animal' events were not included as, while seasonal variation was expected to be cyclic and repeat each year, this crash type also had potential to be influenced by factors such as crash reporting, drought (affecting availability and locations of food and water), proximal human population density, verge maintenance and driver sight lines. These latter two reasons were also considered to influence incidents with vehicles leaving driveways, so these crash types were also excluded.

This data was transferred into a new .csv file and assembled in a way that would be suitable for analysis. An example extract of one of these assembled files is shown below in Table 4.2, while the complete arrangement of all WCLT segment datasets for the empirical Bayes analysis is included as Appendix F.

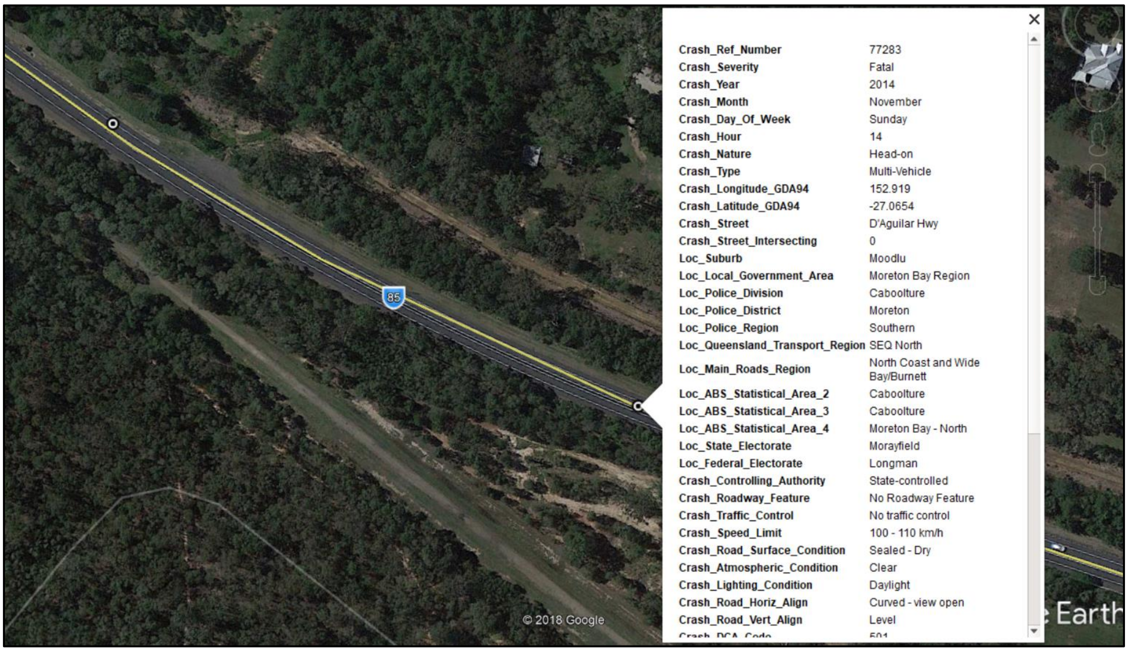


Figure 4.6 – Screenshot of D'Aguilar Hwy (40A) crash location data layer in Google Earth

Table 4.2 – Extract from WCLT segments dataset for analysis (before period)

Year	Road ID	Section Number	Start Chainage (km)	End Chainage (km)	Length (km)	AADT	HOCL	RORL	OTHER	TOTAL
2012	17B	1	24.5	27.64	3.14	5493	0	1	0	1
	17B	17	91.48	93.24	1.76	4284	0	0	0	0
	17B	18	97.87	101.45	3.58	4284	0	0	0	0
	17B	19	101.93	105.96	4.03	4284	0	0	0	0
	17B	20	106.21	107.55	1.34	4064	0	0	0	0
	17B	21	108.01	110.6	2.59	4064	0	0	0	0
	17B	22	110.73	114.19	3.46	4064	0	0	0	0

4.4 Control group segment selection

Determining the control group segments involved the identification of road segments with similar characteristics to the treatment group but without the WCLT, as described in Section 3.3.3. First, roads had to have a similar function and environment to the treatment sites. This identified highways which provided links between rural centres. Next, each highway's AADT data was reviewed. As noted previously, with an objective of this study to determine if the degree of success of WCLT on RORL events can be confirmed on lower volume rural highways, highways were identified where the typical minimum AADT was greater than the 2000 specified by TMR's RPDM guideline, shown in Table 2.2. From these highways, segments with a similar total pavement width of 10 - 11m and having a two-lane, two-way cross section were identified. Many lengths of highway, particularly along the Bruce Highway, were excluded during this process as they have undergone major cross-sectional change or had received WCLT in recent years.

As had been carried out for the selection of treated segments, a methodical process of simultaneously comparing the high resolution NearMap satellite imagery with the Street View 'driver point of view' imagery was used. This process enabled a review of each segment's pavement width, cross-sections, street furniture and any other feature that may affect the segment's suitability for inclusion in the control group.

Next, as with the treatment group, the simultaneous use of Street View and the Route Planner application from Ride with GPS was employed to determine the control segment start and end chainages. In this way, the vertical geometry of the potential segments could also be checked to ensure the average segment gradient was less than 3%. Also, as for the treatment group, short segments less than 200m total were also excluded.

Finally, the crash data layer in Google Earth was used to identify any recorded crash events that had occurred within the identified control segments. This data was transferred into a new .csv file and assembled in a way that would be suitable for analysis. An example extract from the assembled 'control group' file is shown below in Table 4.4, with the complete assembled 'control group' file included as Appendix G. Highways from which control sites were selected with a summary of their data are tabulated below in Table 4.3.

Table 4.3 – Summary of control segment data

Road ID	Highway Name	Towns	Total number of segments	Total length of segments (km)	Average AADT* (2013-2018)	Total crash events (2010-2018)			
						HOCL	RORL	Other	Total
10B & 10C	Bruce Highway	Gympie-Gin-Gin	10	17.70	4990	9	4	6	19
42A	Brisbane Valley Highway	Ipswich-Harlin	26	60.78	4057	15	4	42	61
17B	Cunningham Highway	Brisbane-Warwick	13	17.60	5435	0	0	1	1
28A	Gore Highway	Toowoomba-Millmerran	18	48.80	3177	11	5	18	34
22B	New England Highway	Toowoomba-Warwick	21	46.20	4119	12	6	15	33
18C	Warrego Highway	Dalby-Miles	7	31.98	3512	2	2	2	6
TOTAL			95	223.06		49	21	84	154

* Average AADT = (segment length x AADT)/total length

Table 4.4 – Extract from Control segments dataset for analysis

Year	Road ID	Section Number	Start Chainage (km)	End Chainage (km)	Length (km)	AADT	HOCL	RORL	OTHER	TOTAL
2012	42A	1	3.9	5.7	1.8	9097	0	0	0	0
	42A	2	6.0	7.4	1.4	8410	0	0	0	0
	42A	3	8.3	8.8	0.5	8410	0	0	0	0
	42A	4	9.0	11.1	2.1	8410	0	0	3	3
	42A	5	11.3	11.7	0.4	8410	0	0	0	0
	42A	6	12.0	13.6	1.6	8410	1	0	1	2
	42A	7	16.5	17.0	0.5	3409	0	0	0	0
	42A	8	18.2	18.7	0.5	3409	0	0	0	0
	42A	9	19.1	19.8	0.7	3409	0	0	0	0
	42A	10	20.1	21.4	1.3	3409	0	0	0	0

In summary, 18 treatment segments with a total length of 36.81 km and 95 control segments with a total length of 223.06 km were selected for this project. Referring to Linden and Samuels (2013) optimal treatment to control ratio of 1:4 for matched studies, the selected segments provided an overall ratio of approximately 1:5 as shown in Table 4.5. However, as segments varied in length from 300 m up to 10 km, the ratio for total length of segments was also compared and found to be similar providing confidence in the ability of the control data to protect against statistical bias. A review of the descriptive statistics summary for the control and treatment segments, provided in Table 4.6, indicated the respective means and medians were not statistically different, providing a further element of confidence in the suitability of the control data. For comparison of the treated segments statistics, those of the Bruce Highway (10A & 10B) WCLT segments was also included in the table. In calculating these statistics it was noted that some of the treatment segments used in the original Bruce Highway study by Whittaker (2012) were upgraded to divided carriageways in 2012 and the segments were adjusted in later studies to account for this (Cuckson 2016; Luy et al. 2018). A general locality map showing stretches of highway from which treatment and control group segments were selected is shown in Figure 4.7.

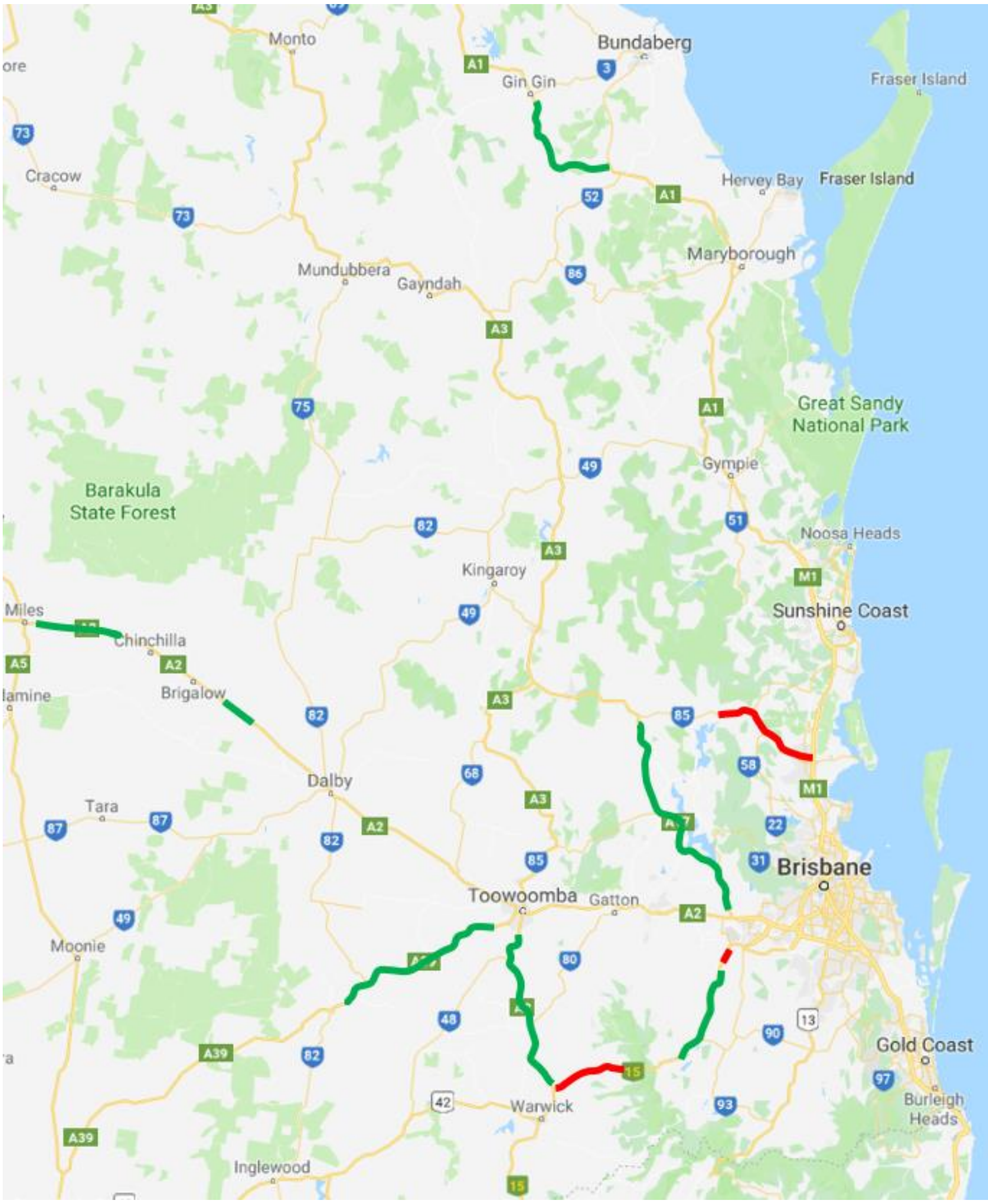
Table 4.5 – Ratio of Treatment to Control data for analysis

Road ID	Treated Highway	Total number of segments	Total length of segments (km)	Segment Ratio (approx)	Length Ratio (approx.)
17B	Cunningham Highway	7	19.90	1:14	1:11
40A	D’Aguilar Highway	11	16.91	1:9	1:13
	Total	18	36.81	1:5	1:6

Table 4.6 – Comparison of descriptive statistics for highway segments

Statistic	Treated Bruce Highway (10A & 10B)*	Treated Cunningham & D’Aguilar Highway (17B & 40A)	Control segments used in this study
Mean	1.293	2.046	2.348
Standard Error	0.313	0.312	0.205
Median	0.860	1.730	1.900
Mode	0.360	3.580	0.400
Standard Deviation	1.327	1.325	1.995
Sample Variance	1.762	1.755	3.979
Kurtosis	9.689	-1.623	3.857
Skewness	2.811	0.140	1.737
Range	5.735	3.790	10.500
Minimum	0.255	0.240	0.300
Maximum	5.990	4.030	10.800
Sum	23.270	36.815	223.06
Count	18	18	95

* Descriptive statistics for treated Bruce Highway segments were calculate from segment details set out in Cuckson (2016).



Approximate highway locality of TREATMENT segments*

Approximate highway locality of CONTROL segments*

* see Appendix E for more detailed maps of selected segment locations

Figure 4.7 - Locality map of treatment & control segments

4.5 Development of SPF functions

With the required data compiled into a suitable format the next stage could begin. This involved using a statistical software package to develop the SPF models for each crash type by running a regression analysis on the control group data. The SPF models would enable the expected crash numbers for each treatment segment to be estimated. The standard method of modelling yearly crash frequencies involves applying a negative binomial distribution with a log link to a generalised linear model (AASHTO 2010), as described in Section 3.2.1.

The statistical software SPSS was selected for the regression analysis. A freeware software package, PSPP was initially considered. However, while it had a user-friendly interface and was capable of many statistical procedures it did not appear to have the functionality to run a negative binomial distribution nor determine the overdispersion parameter required by the EB methodology. SPSS had the required functionality and the user interface enabled analysis programming by selection of the necessary combinations of distribution, link, response, and covariates rather than by coding.

The control group data was imported into SPSS and the Generalised Linear Model regression analysis function was set up. Setting up involved selecting a negative binomial distribution with logarithmic link function and requiring the program to estimate the parameter value of the distribution using a maximum likelihood error (MLE) structure. This was to maximise the probability of the observed data in the statistical model. The response (or dependent) variable was adjusted each time the analysis was run changing to match the crash type model being developed i.e. HOCL, RORL or TOTAL crash events. The predictors (independent) variables of traffic volume (AADT) and segment length were selected as covariates and specified as having the main effects on the model. For parameter estimation when optimising the model, the Fisher method was selected to estimate the variance of the values from the observed information and Pearson's chi-squared test was employed to estimate how likely any observed difference was due to chance. Any remaining default settings such as number of iterations and convergence criteria were left unchanged. The selection of these settings enabled the regression analysis to be run and the model parameters for each crash type to be determined.

SPSS analysis Case Processing Summaries for all crash type models being developed indicated 100% of site data was included in the model calibration process. The Continuous Variable Information output table provided descriptive statistics on the dependent variable and covariates. Notably in this table the suitability of applying a negative binomial distribution as explained in AASHTO (2010) was confirmed as the standard deviation of the dependent variable was much greater than the mean, as shown for the RORL crashes example in Table 4.7. This relationship was the same for all crash types processed. Also, for each crash type the Goodness of Fit output table, which returns values indicating how well the model fits the data, returned a Pearson chi-square value divided by degrees of freedom of very close to 1, where 1 is a perfect fit.

Table 4.7 – SPSS output – Continuous Variable Information for RORL data analysis

Continuous Variable Information						
		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	RORL	570	0	2	.04	.206
Covariate	Length(km)	570	.30	10.80	2.3480	1.98589
	AADT	570	2387	10530	4262.16	1667.627

The next output tables produced reflected the effects of variables on the calibrated model. From these it was conspicuous that, while the Omnibus Test results confirmed the significance of the effect of the independent variables on the model, the Tests of Model Effects output indicated that for these low volume highways segment length had a much more significant effect on the model than traffic volume. The low significance of AADT on the model was subsequently reflected in the Parameter Estimates output table. For each crash type this table provides the parameter estimates for incorporation into the applicable SPF model and the over-dispersion parameter, *k*, that will be required during the EB analysis. Screenshots showing SPSS setup process and a full set of SPSS outputs for each crash type is provided in Appendix H and Appendix I respectively.

Using the RORL events Parameter Estimates table shown in Table 4.8 as an example, parameter values could be substituted into Equation 4-1 to begin developing the SPF model for the RORL events.

$$N_{spf\ rs} = CMF' \times e^{[\alpha+(\beta_1 \times L)+(\beta_2 \times AADT)]} \qquad \text{Eqn. 4-1}$$

Where from Table 4.8: α = -3.804 β_1 = 0.245 β_2 = 0.00005596 k = 1.000

Table 4.8 – SPSS output – Parameter estimates for RORL data analysis

Parameter Estimates							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-3.804	.7922	-5.357	-2.2525	23.059	1	.000
Length(km)	.245	.0789	.090	.399	9.618	1	.002
AADT	-5.596E-5	.0002	.000	.000	.121	1	.728
(Scale)	.993[a]						
(Negative binomial)	1.000[b]	.	.	.			

To determine the CMF' the characteristics of the control group needed to be considered. As all the control group segments were selected from major rural highways between regional towns in the Darling Downs and eastern Queensland regions, they had the same purpose and geographic location as the treatment group segments. Additionally, for all bar three treatment segments, no adjustment was required to allow for the effect of a change in the posted speed limit. The speed limit on each control highway of 100 km/h was consistent with most treatment segments selected. For these treatment segments the CMF' was determined to be 1.00, as this value makes no adjustment to the SPF estimate.

Three treated segments along the D'Aguilar Highway (40A), Segments 1, 5 & 6, had a posted speed limit of 90 km/h. To account for the difference in speed limit along these segments Gross et al. (2010) recommended the use of surrogate measure studies for speed reduction treatments, noting the tables from Harkey et al. (2008), shown below as Figure 4.8. The tables from Harkey et al. (2008) were converted to km/h then extrapolated to include a reduction in speed of 10 kmph (approximately 6.21 mph). Using linear interpolation for non-fatal injury crashes the CMF is 0.727655, while the CMF for fatal injury crashes is 0.507325. As this project included all crash types and there was not a significant difference between fatal and non-fatal crashes on the treated sections, an average *CMF'* of 0.61749 was applied for the three segments to calibrate the SPF models. The finalised SPF models for the years after 2012 for each crash type are shown in Table 4.9.

Non-fatal Injury Crashes						
$\Delta\bar{v}$ (mph)	$\bar{v}_0$ (mph)					
	30	40	50	60	70	80
−5	0.57	0.66	0.71	0.75	0.78	0.81
−4	0.64	0.72	0.77	0.80	0.83	0.85
−3	0.73	0.79	0.83	0.85	0.87	0.88
−2	0.81	0.86	0.88	0.90	0.91	0.92
−1	0.90	0.93	0.94	0.95	0.96	0.96
0	1.00	1.00	1.00	1.00	1.00	1.00
1	1.10	1.07	1.06	1.05	1.04	1.04
2	1.20	1.15	1.12	1.10	1.09	1.08
3	1.31	1.22	1.18	1.15	1.13	1.12
4	1.43	1.30	1.24	1.20	1.18	1.16
5	1.54	1.38	1.30	1.26	1.22	1.20

$\bar{v}_0$ = initial mean travel speed
$\Delta\bar{v}$ = change in mean travel speed

Fatal Injury Crashes						
$\Delta\bar{v}$ (mph)	$\bar{v}_0$ (mph)					
	30	40	50	60	70	80
−5	0.22	0.36	0.48	0.58	0.67	0.75
−4	0.36	0.48	0.58	0.66	0.73	0.80
−3	0.51	0.61	0.68	0.74	0.80	0.85
−2	0.66	0.73	0.79	0.83	0.86	0.90
−1	0.83	0.86	0.89	0.91	0.93	0.95
0	1.00	1.00	1.00	1.00	1.00	1.00
1	1.18	1.14	1.11	1.09	1.07	1.05
2	1.38	1.28	1.22	1.18	1.14	1.10
3	1.59	1.43	1.34	1.27	1.21	1.16
4	1.81	1.59	1.46	1.36	1.28	1.21
5	2.04	1.75	1.58	1.46	1.36	1.27

$\bar{v}_0$ = initial mean travel speed
$\Delta\bar{v}$ = change in mean travel speed

Figure 4.8 – Speed reduction CMF tables for non-fatal and fatal injury events
Source: Harkey et al. (2008)

Table 4.9 – SPF models

Crash type	SPF model	Significant variables
For D'Aguilar Highway (40A), segments 1, 5 & 6 (90km/h posted speed)		
HOCL	$P_{HOCL} = 0.61749 \text{ x } e^{[-3.992 + (AADT \text{ x } 0.000) + (Segment\ length \text{ x } 0.279)]}$	All
RORL	$P_{RORL} = 0.61749 \text{ x } e^{[-3.804 + (AADT \text{ x } -0.00005596) + (Segment\ length \text{ x } 0.245)]}$	Segment length & intercept
TOTAL	$P_{TOTAL} = 0.61749 \text{ x } e^{[-2.685 + (AADT \text{ x } 0.000) + (Segment\ length \text{ x } 0.301)]}$	All
For all other treated highway segments (100km/h posted speed)		
HOCL	$P_{HOCL} = e^{[-3.992 + (AADT \text{ x } 0.000) + (Segment\ length \text{ x } 0.279)]}$	All
RORL	$P_{RORL} = e^{[-3.804 + (AADT \text{ x } -0.00005596) + (Segment\ length \text{ x } 0.245)]}$	Segment length & intercept
TOTAL	$P_{TOTAL} = e^{[-2.685 + (AADT \text{ x } 0.000) + (Segment\ length \text{ x } 0.301)]}$	All

4.6 Empirical Bayes analysis

This stage of the process determined the safety effect of the WCLT by finding the difference between the expected/predicted number of crashes had no treatment been applied, $N_{expected,T,A}$ (or for simplicity, E_A), and the sum of the observed/actual crashes in post-treatment period, $N_{observed,T,A}$ (or O_A). First, in order to estimate the number of crashes expected had no treatment been applied, the empirical Bayes approach utilised two information sources for the treated segments:

1. the observed number of crashes during the before period, and
2. the predicted number of crashes during the before period for a comparable segment based on the SPF model for the crash type of interest.

With data for the observed number of crashes during the before period already compiled a new spreadsheet for running all the empirical Bayes calculations was developed. The observed crash data, including segment lengths and AADT for both 'before' and 'after' periods, was transferred into the EB spreadsheet. New columns for the SPF formulas were created and used to estimate the predicted number of crashes during the before period for each segment. An example set of derived SPF crash estimates for the before period shown in the three right hand side columns of Table 4.10, below, alongside the observed crash data totals. Also shown below, the total of the derived predicted crash data, P_B, was determined for each crash type.

Table 4.10 – Treatment sites crash data and unweighted SPF estimates

Road ID	Site no.	Start Chainage	End Chainage	Site length, L (km)	AADT Before			Observed crash freq. in *before* period				$N_{spf\ rs}$ SPF estimates for predicted average crash freq. in *before* period		
					2012	2013	2014	HOCL	RORL	Other	Total	HOCL	RORL	TOTAL
40A	1	0.91	2.14	1.23	10329	10389	10907	0	0	1	1	0.046	0.032	0.152
	2	4.31	7.18	2.87	10329	10389	10907	2	0	2	4	0.118	0.082	0.417
	3	7.50	7.90	0.40	11931	11931	11931	0	0	0	0	0.059	0.040	0.189
	4	8.10	8.50	0.40	11931	11931	11931	0	0	0	0	0.059	0.040	0.189
	5	16.69	17.49	0.80	9065	9640	9640	0	0	1	1	0.041	0.030	0.133
	6	17.72	18.70	0.98	6593	9640	9640	0	0	2	2	0.043	0.032	0.140
	7	30.61	34.19	3.58	6593	6754	6988	1	0	1	2	0.144	0.114	0.523
	8	34.35	38.14	3.79	6593	6754	6988	0	0	3	3	0.152	0.121	0.560
	9	39.42	39.66	0.23	6593	6754	6988	0	0	0	0	0.056	0.046	0.179
	10	39.81	41.50	1.69	6593	6754	6988	1	0	1	2	0.085	0.068	0.286
	11	41.65	42.58	0.93	6593	6754	6988	0	0	0	0	0.069	0.055	0.224
Total 40A				16.91				4	0	11	15	0.872	0.661	2.993
17B	1	24.50	27.64	3.14	5493	6306	5675	0	2	0	2	0.127	0.105	0.454
	17	91.48	93.16	1.76	4284	4311	4382	0	0	0	0	0.086	0.076	0.292
	18	97.87	101.45	3.58	4284	4311	4382	0	0	0	0	0.144	0.125	0.523
	19	101.93	105.96	4.03	4284	4311	4382	0	0	0	0	0.163	0.141	0.604
	20	106.21	107.55	1.34	4064	4265	4382	0	0	0	0	0.077	0.068	0.255
	21	108.01	110.6	2.59	4064	4265	4382	0	0	0	0	0.109	0.095	0.381
	22	110.73	114.19	3.46	4064	4265	4382	0	1	0	0	0.139	0.121	0.503
Total 17B				19.90				0	3	0	3	0.845	0.730	3.014
				Total length				$N_{observed,T,B}$				P_B (or $N_{predicted,T,B}$)		
Overall Total				36.81				4	3	11	18	1.716	1.391	6.008

As set out in Section 3.2, for the next stage of the EB approach the values for P_B were used to determine the weighted expected number of crashes at the treatment site in the before period, E_B. This is a weighted average calculated by weighing the observed number of crashes at the treatment site, O_B, and P_B by the complimentary weighting factors, w_1 and w_2, both of which consider the overdispersion factor of the data distribution. The results of these calculations are shown below as Table 4.11.

$$E_B = w_1 \times O_B + w_2 \times P_B \qquad \text{Eqn. 4-2}$$

Where,

$$w_1 = \frac{P_B}{P_B + 1/k} \qquad \text{Eqn. 4-3}$$

$$w_2 = \frac{1}{k(P_B + 1/k)} \qquad \text{Eqn. 4-4}$$

k = the overdispersion parameter of the negative binomial distribution created earlier in the regression model during the SPF calibration process.

With the expected number of crashes at the treatment site in the before period, E_B, now determined the process for estimating the expected number of crashes at the treatment site in the after period had no treatment been applied could begin. First an adjustment factor, R, the ratio of the predicted SPF estimates P_A and P_B was calculated to account for the effect of any differences in the length of the before and after periods on non-time related variables. Then the expected number of crashes expected in the after period had no treatment been applied, E_A, was calculated.

$$R = P_A / P_B \qquad \text{Eqn. 4-5}$$

$$E_A = E_B \times R \qquad \text{Eqn. 4-6}$$

With E_A and E_A now established, a basic odds ratio to describe the overall treatment effectiveness was calculated, as shown as Equation 4-7.

$$OR' = O_A / E_A \qquad \text{Eqn. 4-7}$$

No safety improvement was noted at this stage for any crash type as all ratios were values greater than 1. Hauer, cited in AASHTO (2010), describes this basic odds ratio estimate of effectiveness as potentially biased. Therefore, the adjusted method that considers the variance of the expected number of crashes expected in the after period had no treatment been applied, shown as Equation 4-8 and 4-9, was used to obtain a more reliable, unbiased estimate of treatment effectiveness, θ. From this the overall unbiased safety effectiveness, *CMF*, was calculated as a percentage change in the frequency of crashes.

$$\theta = \frac{OR\prime}{1+\left[\frac{Var(E_A)}{{E_A}^2}\right]} \qquad \text{Eqn. 4-8}$$

Where, $Var(E_A) = R^2 \times E_B \times w_1$ Eqn. 4-9

$$CMF = 100 \times (1 - \theta) \qquad \text{Eqn. 4-10}$$

The final steps determined the statistical significance of the *CMF* values. This was determined by first estimating the variance of the unbiased estimate of treatment effectiveness, θ, using Equation. 4-11.

$$Var(\theta) = \frac{\theta^2\left[\frac{1}{O_A}+\frac{Var(E_A)}{{E_A}^2}\right]}{1+\left[1++\frac{Var(E_A)}{{E_A}^2}\right]} \qquad \text{Eqn. 4-11}$$

This variance was then employed to calculate the standard error (the precision of the unbiased estimate of treatment effectiveness, θ) using Equation 4-12.

$$SE(\theta) = \sqrt{Var(\theta)} \qquad \text{Eqn. 4-12}$$

Finally, the *CMF*'s standard error was calculated with Equation 4-13.

$$SE(CMF) = 100 * SE(\theta) \qquad \text{Eqn. 4-13}$$

Finally, comparing the absolute value of the quotient of the *CMF* over its standard error enables the statistical significance of the estimated safety effectiveness to be revealed and criteria-based conclusions to be drawn. The observed and calculated values for each of the factors described are shown in Table 4.11.

Table 4.11 – Observed and calculated factor values for HOCL, RORL & TOTAL crash types

Factor	HOCL	RORL	TOTAL
Observed crashes during 3 year before period, O_B	4	3	18
Crash modification factor for 90km/h segments, *CMF'*	0.61749	0.61749	0.61749
Base SPF calibration factor, α	-3.992	-3.804	-2.685
SPF calibration factor for segment length, β_1	0.279	0.245	0.301
SPF calibration factor for segment traffic volume, β_2	0.000	-5.596E-05	0.000
SPF predicted crashes during before period, P_B	1.797	1.392	7.030
Overdispersion, k	0.189	1.000	0.660
Weighted adjustment factor for observed crashes, w_1	0.254	0.582	0.823
Weighted adjustment factor for predicted crashes, w_2	0.746	0.418	0.177
Unfactored estimated crashes during before period, E_B	2.356	2.328	16.055
SPF predicted crashes during after period, P_A	1.198	0.892	4.687
Adjustment factor, R	0.667	0.641	0.667
Factored crash estimate during after period, B	1.571	1.492	10.703
Observed crashes during 2 year after period, O_A	2	4	13
Unadjusted odds ratio of safety effectiveness, *OR'*	1.273	2.680	1.215
Unadjusted safety effectiveness (%)	-27.347	-168.034	-21.457
Variance for all sites, $Var(E_A)$	0.265	0.557	5.870
Adjusted odds ratio of safety effectiveness, *OR*	1.150	2.144	1.155
Unbiased safety effectiveness as %, *CMF*	-14.973	-114.427	-15.537
WCLT Crash Modification Factors for low volume hwys	1.15	2.14*	1.15*
Variance of the adjusted odds ratio, *Var(OR)*	0.890	2.874	0.180
Standard error of the adjusted odds ratio, *SE(OR)*	0.943	1.695	0.424
Standard error of the unbiased safety effectiveness, *SE(CMF)*	94.322	169.520	42.409
Statistical significance of the estimated safety effectiveness	0.159	0.675	0.366

* Crash Modification Factor is indicative only as crash type is not the target crash type

Chapter 5 Evaluation of the results

5.1 Introductory summary

This study found no support to accept that WCLT reduce the rate of RORL events on low volume rural Queensland highways. Additionally, as the findings were not statistically significant, this study did not provide support for a review of road shoulder widths associated with WCLT or trials into the use of narrower sealed shoulders.

5.2 Evaluation of the results

The empirical Bayes analysis of wide centreline treated sites along the Cunningham Highway (17B) and D'Aguilar Highway (40A) determined that in the two years post-treatment the TOTAL number of all crash types has increased by 15.5%. HOCL crash types were also determined to have increased by a similar amount, 15.0%. However, the most notable result was in the crash type that was the subject of particular interest in this study, the RORL. This crash type was determined to have more than doubled in the post-treatment period, with an increase of 114%. While the analysis results were not identified as statistically significant, the trend was consistent across each crash type. The increase in crash rates contrasted with the trends of previous studies for higher volume Queensland highways into the effects of WCLT carried out on Sections 10A and 10B of the Bruce Highway. While the WCLT on the Bruce Highway did not permit overtaking, as compared with this study which included all overtaking types, the most recent study results, from Luy et al. (2018) are provided below for trend comparison purposes. Luy et al. (2018) established reductions of over 20% for each crash type investigated, as shown in Table 5.1 and for visual comparison in Figure 5.1, with a 21% all injury crash rate reduction for RORL events. Overall, a clear difference in the determined effect trend of WCLT on each crash type can be seen between the Luy et al. (2018) Bruce Highway results and those from the combined lower volume highways analysed in this study. Not only were the various crash rates found to increase on the lower volume rural highways but a dramatic increase in RORL events was determined.

Table 5.1 – Comparison of WCLT effectiveness by crash type

Crash Type	Cunningham & D'Aguilar Hwy – All injury crash effect	Bruce Hwy – All injury crash effect*
HOCL	- 14.97%	33%
RORL	- 114.43%	21%
Total crashes	- 15.54%	21%

*Source: Luy et al. (2018)

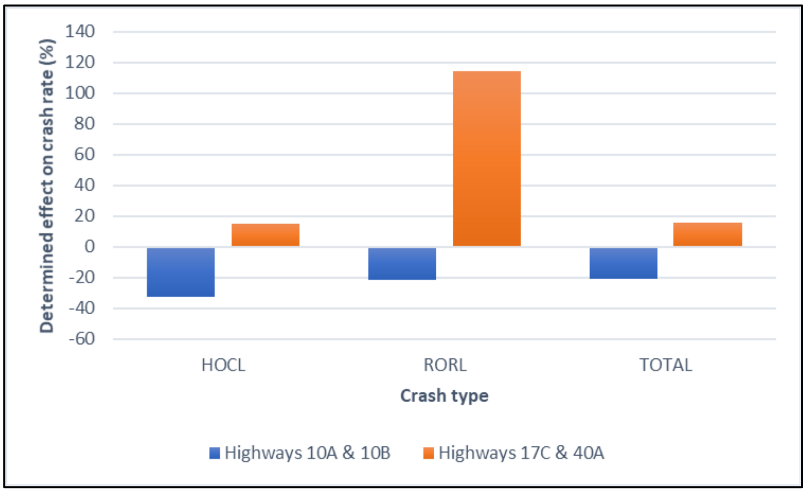


Figure 5.1 – Comparison of Cunningham/D'Aguilar Hwy results with Bruce Hwy study

A critical element of this study on the Cunningham and D’Aguilar highways was the selection of appropriate reference sites. In this respect, sites with similar physical and functional characteristics and similar range of AADT were identified. A total of 95 control segments with a total length of 223.06 km were selected. This provided an overall ratio of approximately 1:5, as shown in Table 4.5, similar to the optimal treatment to control ratio of 1:4 for matched studies identified by Linden and Samuels (2013), thereby providing confidence in the ability of the control data to protect against statistical bias.

The calibrated SPF models provided an estimate of average crash frequency based on the sites selected in the control group. Crash data was collected from the control sites for all years across the pre- and post-treatment periods to ensure extrapolation of the derived SPF models would not be required. Additionally, the control segments included lengths ranging from 0.3 km to 10 km which was beyond the length of the longest treatment segments of 4.03 km. Again, this ensured no need for extrapolation and provided further confidence that the control data could account for any trends in the post-treatment period and in the treated segment lengths. While the derived SPF models may be useful for investigations into safety on low volume rural highways in the future, this study notes that they are most appropriate for studies using treatment data up to the end of 2017 and road segments up to 10 km long. Beyond these limits additional data to improve the scope and robustness of the models is recommended rather than extrapolating from these models to make assumptions regarding road safety.

The SPSS regression analysis of the control data returned statistically significant estimates at the 95% confidence interval for all parameters in the HOCL and TOTAL calibrated SPF models. However, the AADT parameter for the RORL SPF model was not significant and must be considered with any interpretation of the RORL results despite the AADT parameter estimate of -5.596×10^{-5} being small.

With respect to the aim of this investigation, the empirical Bayes analysis of WCLT on low volume rural highways determined no crash reduction effect in the two-year post-treatment period and the low statistical significance of the results provided no support for reviewing road shoulder width guidelines. The two crash types with statistically significant models, HOCL and TOTAL crashes both increased by 15% in the post-treatment years. While these two results show a common trend the variance in the data lead to the statistical significance of these results being very low, as shown in Table 5.2 and any interpretation of the results must consider this. Of the crash types studied, most notably, RORL crash types were found to have doubled in the post-treatment years with an increase in incidents by 114%. In terms of new crash modification factors, these resulted in values of 1.15 (HOCL), 2.14 (RORL), and 1.15 (TOTAL) on low volume highways. However, due to the low statistical significance of the results use of these factors would be restricted to stimulus for a further study when more post-treatment data is available.

Table 5.2 – Calculated treatment effectiveness for HOCL, RORL and TOTAL crash events

Factor	HOCL	RORL	TOTAL
Ratio of safety effectiveness	1.150	2.144	1.155
Safety effectiveness as a crash modification factor, CMF	-14.973	-114.427	-15.537
Crash Modification Factors for low volume highways	1.15	2.14	1.15
Standard error of the CMF	94.322	169.520	42.409
Statistical significance of the estimated safety effectiveness (where 95%CI = 2, 65%CI = 1)	0.159	0.675	0.366

Further review of the estimated crashes derived from the SPF models, shown in Table 5.3, indicated that the observed pre-WCLT crash rate at the treatment sites was much higher than expected based on the control group data. This is reiterated visually in Figure 5.2. This graph shows a significant difference between the basic SPF prediction and the observed recordings. For TOTAL crashes the recorded crashes were 10% higher than the weighted crash estimate. Additionally, the recorded crashes for RORL and HOCL events were significantly higher than their estimated crashes, at 22% and 41% respectively. AASHTO (2010) states that when using the empirical Bayes approach an excess from the expected average crash frequency, particularly as seen for the HOCL and RORL events, would suggest there may have been a crash problem at the treatment sites prior to WCLT implementation and supports the need for identifying a suitable road safety treatment on these highways.

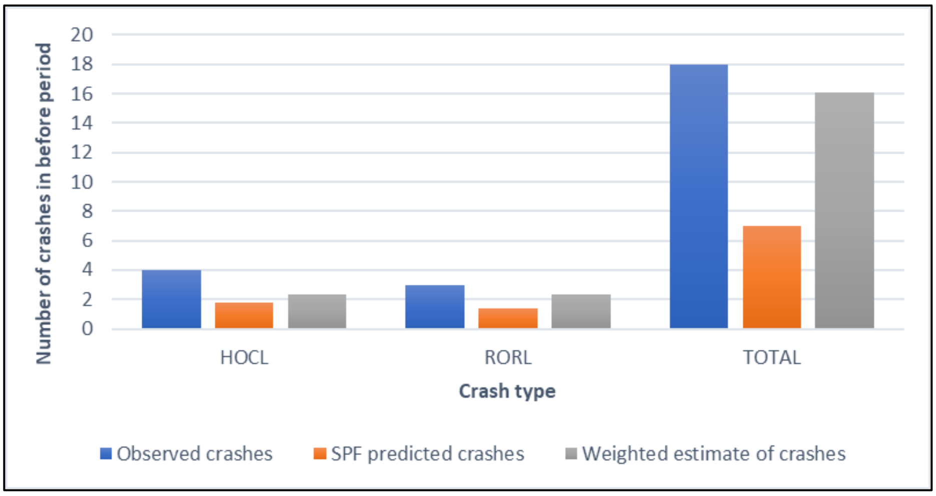


Figure 5.2 – Comparison of observed and estimated crashes during the 3 year before period

Table 5.3 – Comparison of observed and estimated crashed during before and after periods

Factor	HOCL	RORL	TOTAL
Observed crashes during 3 year before period, O_B	4	3	18
SPF predicted crashes during before period, P_B	1.797	1.392	7.030
Weighted estimate of crashes during before period, E_B	2.356	2.328	16.055
Change from observed crashes in before period (%)	41.106	22.404	10.805
Observed crashes during 2 year after period, O_A	2	4	13
SPF predicted crashes during after period, P_A	1.198	0.892	4.687
Factored crash estimate during after period, B	1.571	1.492	10.703
Change from observed crashes in after period (%)	21.474	62.691	17.666

A similar comparison for the post-treatment period indicated that the treated sites may still have a crash problem. All crash types show significant differences between both the SPF and factored crash estimates compared to the observed data. Table 5.3 shows that the smallest change from observed crashes to the weighted crash estimate was about 21.5% for HOCL events. This change in the weighted crash estimates from the observed crashes is reflected in the comparison graph for the post-WCLT treatment period, shown below as Figure 5.3. As Table 5.3 shows the change from observed crashes in the after period for HOCL has decreased it suggests that some safety benefit may be occurring on this target crash type of the WCLT. However, for the non-target crash type groups the change has generally got larger, which suggests that the RORL and TOTAL crash problem on the Cunningham and D'Aguilar highways has got worse for these crash types.

This trend also suggests that the data period is not influenced by regression to the mean. If the before period was during an unusually high crash period, it would be expected that any regression to the mean would be reflected here by the observed number of crashes being lower than the empirical Bayes estimates. That the observed crashes remained higher after treatment further suggests the low volume rural highways studied may have a crash problem.

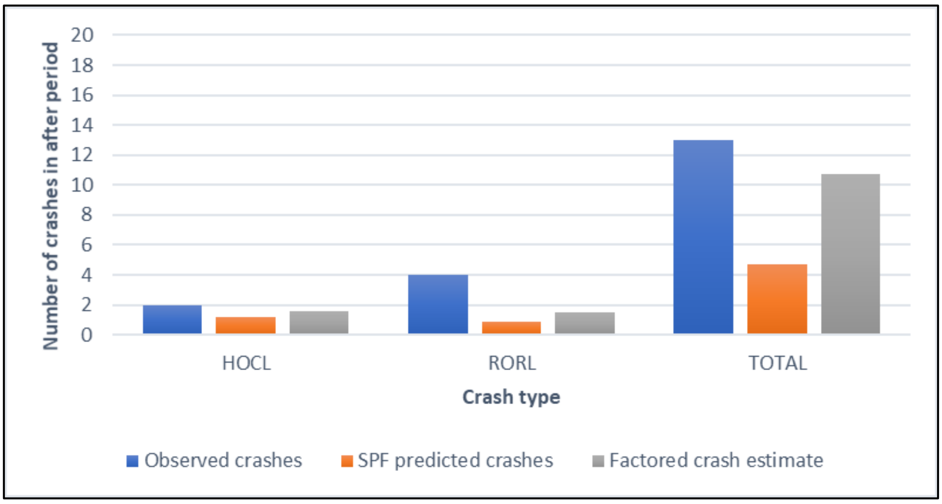


Figure 5.3 – Comparison of observed and estimated crashes during the 2 year after period

The benefit of WCLT in reducing the rate of the HOCL target crash type is well published and the effectiveness has been refined since the first study of the Bruce Highway treated segments in 2012. Whittaker (2012); Cuckson (2016); Luy et al. (2018) all reported significant reductions in this most severe crash type but also determined significant reductions in total crash events and, unexpectedly, in RORL events. However, the same effect was not reflected in this study of the combined Cunningham and D'Aguilar Highway treatment sites (17B & 40A). The contrast of this study's results suggests that, while the benefits of WCLT are well documented for those segments of the Bruce Highway, WCLT may not be the most beneficial safety treatment option for low volume Queensland highways.

5.3 Recommendations for further research

The results of this study, while not statistically significant, determined an increase in crash rates on the low volume highways for all crash types post-WCLT. Confirming these findings when more post-treatment data is available and identifying the factors influencing the crashes on these highways will provide industry stakeholders with a more complete understanding of the use of WCLT as a safety feature.

There may be scope for simulator research to investigate whether there is an optimum level or frequency of changes to the road environment to counter fatigue and influence the effectiveness of any safety treatment. It is known that many factors influence crash rate. On the low volume highways factors such as perception of risk, fatigue, and speed may be magnified and influence the effectiveness of WCLT on these highways. Considering fatigue, WCLT provide a lateral buffer between oncoming traffic flows and, combined with ATLM, provide a reasonably alert driver with sufficient warning and room to correct should they be deviating from their lane. However, it is possible that the location and design of some highways may put greater demand on a driver, thereby influencing their degree of alertness, potentially enabling the ATLM to elicit a faster response and the WCLT to have greater crash reduction effect. In Queensland, the long stretches of reasonably repetitive, low volume rural highways enable efficient high-speed travel between rural centres. However, this driving environment may reduce demand on driver action when Ahlström et al. (2018) found demand on driver action had a positive benefit - countering fatigue. Additionally these highways may provide the monotonous driving environment that Farahmand and Boroujerdian (2018) report can lead to loss of concentration and have detrimental effects on driver performance. It is possible that there is an optimum level or frequency of changes to the road environment, such as road geometry, frequency of towns, large intersections or traffic volume, which periodically increase demand on the driver. This demand on driver action may positively influence the driver's degree of alertness, and thereby influence the potential effectiveness of the WCLT and ATLM combination at a given location.

Further to this, further research could investigate whether shorter segments influence the effectiveness of WCLT. Reviewing the descriptive statistics shown in Table 4.6, the mean (1.293 km) and median (0.860 km) of the Bruce Highway study treatment segments were typically shorter by almost half than the combined Cunningham and D'Aguilar Highway treatment (mean = 2.046 km and median = 1.730 km) and control (mean = 2.348 km and median = 1.900 km) segments used in this study. Shorter segments indicate an increased frequency of interruption or change in the driving environment of what would otherwise be a longer segment. These interruptions or changes increase the likelihood of stimulating a driver response and countering fatigue. A less fatigued driver is less likely to crash as Farahmand and Boroujerdian (2018) found they have better time on task and higher lane positioning ability and will respond to stimuli from the driving environment earlier.

There may be scope for simulator research to investigate whether perception of risk influences the effectiveness of WCLT. Considering traffic volume and perception of risk, comparing the combined Bruce Highway treatment sites (10A & 10B) and the combined Cunningham and D'Aguilar Highway treatment sites (17B & 40A) there were notable driving environment differences. In terms of traffic volume, the 2011-2015 (post-treatment) median AADT for the Bruce Highway was in excess of 15500 vehicles per day, whereas the combined post-treatment traffic volume for the Cunningham and D'Aguilar highways for 2016-2017 was less than half that, at 7548 vehicles per day. While WCLT and lower traffic volume reduce the HOCL risk, it is proposed the combined effect of fewer vehicles and separation from on-coming vehicles may significantly decrease drivers' perception of risk. Lower perception of risk can lead to negative effects on speed and lateral position (Ben-Bassat & Shinar 2011; Bella 2013) which may be reflected on these low volume highways and, thereby, be influencing crash rates and the effectiveness or suitability of WCLT.

There is opportunity for this dissertation's study to be repeated in two years' time when crash data for a 4-year post-WCLT period is available to enable statistically significant results to be determined. This study found no support to accept that WCLT reduce the rate of RORL events on low volume rural highways and no support for a review of associated road shoulder width guidelines. However, while the results of this study were not statistically significant, the trend of increased crash rates determined for all crash types post-WCLT suggests a stand-alone WCLT with ADLM may not be the best cost-benefit treatment for this highway type. This study utilised 3 years of pre- and 2 years of post-treatment crash data. While post-treatment data for the first six months of 2018 was available it was excluded to avoid having to extrapolate or make assumptions. However, the empirical Bayes method optimally requires 3 to 5 years of crash data (AASHTO 2010), thereby supporting the replication of this study in two years' time when crash data for a 4-year post-WCLT period is available. Undertaking a similar study when more post-treatment data is available could be further justified to increase the power of the SPF models. Inclusion of four years of pre- and post-treatment data may reduce the variance and improve the statistical significance of the results.

There is opportunity for a further study to determine the effect of WCLT on crash injury severity on low volume highways. While this study considered all injury events, the benefit of a safety treatment is not always limited to just reducing crashes but may come in the form of decreasing severity of crashes. Therefore, there would be benefits in determining the effect of WCLT on crash injury severity data on low volume highways. Should crash and FSI results increase then it may be that alternative treatments should be considered for low volume rural highways, such as Narrow Median Wire Rope Safety Barriers (NMWRSB) or Flexible Centreline Safety Barriers. Such treatments come with greater capital cost. However, studies reported in the Austroads compendium *Towards Safe System Infrastructure* suggest that while these barriers are still struck by vehicles, fatalities have been reduced by over 85%. One New Zealand study, by Marsh & Pilgram (2010) cited in Austroads (2018a), recorded twelve fatal crashes in the eight years prior to NMWRSB treatment and zero fatalities in the five years after. The results of this study on the Cunningham and D'Aguilar highways indicate that while WCLT have a previously proven crash reduction potential in Queensland on the Bruce Highway, they may not be the most effective treatment on the long, generally straight stretches of low volume highways that are typical of rural Queensland.

Finally, with regards to undertaking further studies into the effect of WCLT on low volume rural Queensland highways the use of the full Bayes method may be required. WCLT is now applied to over 700 km of Queensland highways (Department of Transport and Main Roads 2018e). While the empirical Bayes method is less complex and produces comparable results to the full Bayes approach (Persaud et al. 2010, p. 38), the empirical Bayes method requires numerous control sites with very similar physical and functional characteristics to the treatment sites for referencing over the study time period. This identification of control sites for the required time period is critical for development of SPF models that accurately reflect crash patterns throughout the pre- and post-treatment periods and account for hidden influences that may have changed with time. However, as the number of kilometres of WCLT highway increases, the quantity of potential control sites will have decreased further by the time another study is undertaken. As discussed in Section 2.11.4, instead of using crash trend information from similar sites, the full Bayes approach generates a distribution of likely values that is combined with the treatment site specific crash trend data to create an estimate of the expected treatment site crashes had treatment not been applied (Khan et al. 2015). Therefore, as the number of suitable control segments reduces, with utilisation of the full Bayes method, there will still be suitable methodology and potential scope for further research into the effect of WCLT on low volume highways when more post-treatment data is available.

Chapter 6 Conclusion & further work

6.1 Conclusion

This study found no support to accept that WCLT reduce the rate of RORL events on low volume rural Queensland highways when all overtaking types are considered. Additionally, as the findings were not statistically significant, this study did not provide support for a review of associated road shoulder width guidelines. An increase in crash rates for all crash types post-WCLT was determined. This included an increase in the target HOCL and TOTAL crashes of 15%. However, the most notable result was the 114% increase reported for RORL events.

The WCLT applied for the previous Bruce Highway studies was constrained to the 'no overtaking permitted' type applied to segments studied. As this study included all overtaking types of WCLT it is proposed that the WCLT with no overtaking permitted may be more effective than other overtaking types and further investigation of this proposal is recommended.

The findings of this study were based on 3 years pre- and 2 years post-WCLT data. Data from the year of application was excluded to provide a time buffer to remove the potential influence of construction or other changes in traffic conditions on the study. All possible measures were considered in the identification of treatment and control segments to remove any influence of other safety, road or environmental features that might influence crash results and development of the safety performance functions. The control data referenced was suitably compatible with the treatment highways, a negative binomial regression with log link was used to account for overdispersion in the data, and the significance of the subsequent parameter estimates for the SPF models was generally very high.

The higher than predicted observed crash numbers, both pre- and post-WCLT, suggest the low volume highways in the study may have a crash problem in comparison to the reference highways. It is suggested that a combination of a low level of demand on the driver and a lower perception of risk may be influencing this trend. When combined with the mixed use of WCLT overtaking types the effectiveness of WCLT may be reduced and the suitability of this safety treatment for these highways may need to be reconsidered. Further investigation of this proposal is recommended when more post-treatment data becomes available.

6.2 Further work

It is recommended that further investigations into the effectiveness of WCLT are undertaken when more post-treatment data becomes available. While this study achieved its objectives, the results were not expected given the success seen in previous Queensland wide-centreline studies. This research built on previous research by indicating an increase in all crash type rates at WCLT sites on low volume two lane, two-way rural Queensland highways, particularly a high increase in RORL crash events, when all overtaking types were considered. A follow-up study with more post-treatment data would increase the robustness and significance of these results. A refinement to consider the effect on FSI crash types could also be included as crash severity was outside the scope of this study.

The other main areas for further investigation should include, but not be limited to:

- Determining and comparing the effectiveness of overtaking vs non-overtaking WCLT.
    - This study combined all overtaking types for both control and treated segment data and this may have influenced the results. The ability to overtake may influence drivers' perception of risk and subsequently influence the treatment effectiveness.
- Investigating the potential relationship of highway traffic volume with the effectiveness of various overtaking types of WCLT segments.
    - The results of this study could not directly be compared with previous Bruce Highway studies as it included all overtaking types of WCLT. Lower traffic volumes may influence drivers' perception of risk and level of fatigue, subsequently influencing the suitability of WCLT for safety.
- Investigating the potential relationship of segment length with the effectiveness of various overtaking types of WCLT segments.
    - The treated segments investigated in this study were almost twice the length of those in previous Bruce Highway studies and could not directly be compared. Longer segments increase the likelihood of fatigue. Subsequently, as post-treatment data for longer treated segments, such as from the Warrego Highway, become available, the effect of segment length and its influence on the suitability of WCLT for safety may be determined.
- Investigating the effectiveness of WCLT using the full Bayes (FB) approach.
    - As identified in Section 2.11.4, the FB approach enables more detailed inference, better integrates tasks and better accounts for uncertainty in the data used and the methodology is more attractive for situations where sufficient comparison site data is difficult to acquire, when sample sizes are small or the target crash type is rare (Gross et al. 2010). While the empirical Bayes approach provides comparable results, as WCLT continues to be applied to more rural Queensland highways the availability of suitable control sites will reduce and the FB

approach may become the necessary method of analysis. Additionally, it has not been used by previous Queensland studies to evaluate WCLT.

- Additionally, as discussed in Section 5.3, there may be scope for simulator research on two fronts:
    - to investigate whether perception of risk influences the effectiveness of WCLT.
    - to investigate whether there is an optimum level (or frequency) of changes to the road environment to counter fatigue and influence the effectiveness of any safety treatment.

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Appendix A. – Project Specification

ENG4111/ENG4112 Research Project

Project Specification

For: Peter McNamara

Title: The effect of wide centreline treatments on reducing run-off-road-left incidents on rural Queensland highways and support for a review of road shoulder width guidelines.

Major: Civil Engineering

Supervisor: Soma Somasundaraswaran

Enrolment: ENG4111 – EXT S1, 2019
ENG4112 – EXT S2, 2019

Project Aim: To quantify the effect of wide centreline treatments on run-off-road-left incidents on rural Queensland highways to inform guidelines regarding road shoulder width on treated roads.

Programme: Version 1, 13th March 2016

1. Research the background information relating to centreline treatments (particularly the Wide Centreline Treatment, WCLT), road shoulders, target crash types and any published data on the crash reduction effect of WCLT to date.
2. Review statistical analysis methods for evaluating road crash data that would enable the quantitative effect of WCLT on run-off-the-road-left (RORL) incidents to be determined. Identify most appropriate analysis method for this project.
3. Submit applicable applications to TMR to obtain approval for access to the road and crash databases. Request road data such as road characteristics and traffic volume data.
4. Design/program suitable software (such as Excel and/or Matlab) in preparation for statistical analysis. Test and verify software setup on mock data and, if applicable, liaise with USQ Professional Staff regarding any programming issues.
5. Identify comparable treatment and non-treatment road segments by analysing road characteristics and traffic volume data. Collate road and traffic data on suitable treated and non-treated segments and request crash data for the identified segments from TMR's Road Crash database.
6. Collect and prepare crash data for the identified segments to ensure its form is compatible with the statistical analysis software.
7. Complete statistical analysis of the effect of wide centreline treatments on reducing run-off-road-left incidents.
8. Evaluate the analysis results with respect to the project aim and the potential implications for road shoulder widths. Develop crash modification factors (CMF) and make recommendations.

If time and resources permit:

9. Analyse effect of WCLT on head-on/run-off-the-road-right crash events and develop up-to-date CMF for this event type. It is noted that current project research shows this has already been the focus of several studies so would provide a most recent review of the general effect of WCLT.

Appendix B. – TMR Data Request Form Example

Queensland Government

Road Crash, Registration, Licensing and Infringement Data Request Form

Please send this form to:
Data Analysis, Department of Transport and Main Roads
Email: DataAnalysis@tmr.qld.gov.au
Fax: 07 3066 2410

Contact Details

Name:	Peter McNamara
Organisation	University of Southern Queensland
Phone:	0403 689 376
Email:	U1064631@umail.usq.edu.au

Request Type

Data type required: ☒ Road crash data ☐ Registration/licensing/infringement data

Request Details

When is the data required? *Normal turnaround is at least 5 working days; complex requests will take longer. If data is required earlier, please state the required date (and time if applicable).*

12/06/2019

Is this updating previous data supplied? *Please provide the request number (rqRxxxxx / rqCxxxxx) and if available, please attach the data.*

No

How do you plan to use this data?

For my engineering degree honours project I want to do a before-&-after study on the effectiveness of wide centreline treatments on rural two lane, two way roads in south east Queensland. Data will be used to see if there is any difference in CMF from that determined for the Bruce Highway.

Data request details:

May I be sent a .CSV file with crash and road data for south east Queensland and Darling Downs highways/motorways that have had wide centreline treatment (WCLT) applied, please?

Please include the road ID (and the segment/section ID if available), start chainage, end chainage, AADT and pavement/carriageway width. If roads are split into segments please include this for each segment.

Department of Transport and Main Roads

Form version date: March 2016 Page 1 of 8

Time Period

☐ Calendar year	☐ Financial year

☒ Previous 5 full years	☐ Previous 12 full months	☐ Year to date

Time period details: Do you require the data broken down? For example: by year, month

Break down by calendar year please.
I would like data for the 4 calendar years prior to application of WCLT on each road and for the available whole calendar years after treatment was been applied to the road please.

Geographical Area

☒ All of Queensland	☐ Police region	☐ TMR Customer Services Branch region	☐ Road section
☐ Local Government Area	☐ Police district	☐ TMR Program Delivery and Operations region	☐ Intersection

Geographic details: *Registration, licensing and infringement data is not available for a road section or intersection*

Is it possible to just include South East Queensland and the Darling Downs, please?

Road Crash Data Characteristics

Crashes	Casualties	Units	Unit Controllers	Contributing Circumstances
☒ Severity ☒ Crash nature ☒ Roadway feature ☒ Traffic control ☒ Speed limit ☒ Roadway surface ☐ Atmospheric condition ☒ Lighting ☒ Road alignment ☒ DCA code/group ☐ Time of day ☐ Day of week	☒ Severity ☐ Road user type ☐ Road user type – unit group ☐ Age group ☐ Gender ☐ Helmet use ☐ Restraint use	☐ Unit type ☐ Intended action ☐ Overall damage ☐ Towing ☐ Number of occupants ☐ Dangerous goods ☐ Defective	☐ Road user type ☐ Age group ☐ Gender ☐ Licence type ☐ State licensed in	☐ Contributing circumstances ☐ Contributing factors (circumstance groupings)

Registration, Licensing and Infringement Data Characteristics

Registration	Licensing	Infringement	Recreational Vessels
☐ Body type ☐ Registration category ☐ Make ☐ Model ☐ Gross vehicle mass ☐ Purpose of use	☐ Age ☐ Gender ☐ Class ☐ Level	☐ Category ☐ Description ☐ Code	☐ Length ☐ Draft ☐ Body type ☐ Registration category ☐ Powered by

The Department of Transport and Main Roads is collecting the information on this form for the purposes of providing you with road crash, registration, licensing and infringement data. Your personal details will not be disclosed to any other third party without your consent unless required or authorised to do so by law.

Appendix C. – Extract of Queensland Crash Data

Extract source file: Department of Transport and Main Roads (2019b)

Crash Ref Number	Crash Severity	Crash Year	Crash Month	Crash DCA Code	Crash DCA Group Description	Count Casualty Fatality	Count Casualty Hospitalised	Count Casualty Medically Treated	Count Casualty Minor Injury	Count Casualty Total	Crash Longitude GDA94	Crash Latitude GDA94	Crash Street
75934	Hospitalisation	2010	January	201	Head-on	0	1	0	0	1	152.8748	-27.0455	D'Aguilar Hwy
76114	Property damage only	2010	July	705	Out of control on straight	0	0	0	0	0	152.8504	-27.025	D'Aguilar Hwy
76199	Hospitalisation	2010	August	803	Off carriageway on curve hit object	0	1	0	0	1	152.9053	-27.0592	D'Aguilar Hwy
76224	Property damage only	2010	September	301	Rear-end	0	0	0	0	0	152.8585	-27.038	D'Aguilar Hwy
76267	Property damage only	2010	October	301	Rear-end	0	0	0	0	0	152.9059	-27.06	D'Aguilar Hwy
76273	Property damage only	2010	October	303	Rear-end	0	0	0	0	0	152.9024	-27.0575	D'Aguilar Hwy
76274	Property damage only	2010	October	804	Off carriageway on curve hit object	0	0	0	0	0	152.8413	-27.0117	D'Aguilar Hwy
76299	Property damage only	2010	October	201	Head-on	0	0	0	0	0	152.8681	-27.0405	D'Aguilar Hwy
76305	Hospitalisation	2010	November	202	Opposing vehicles turning	0	2	0	0	2	152.8576	-27.0371	D'Aguilar Hwy
76311	Medical treatment	2010	November	301	Rear-end	0	0	1	0	1	152.9451	-27.0694	D'Aguilar Hwy
76356	Hospitalisation	2010	December	303	Rear-end	0	2	2	0	4	152.873	-27.0453	D'Aguilar Hwy
76363	Property damage only	2010	December	700	Other	0	0	0	0	0	152.8501	-27.0249	D'Aguilar Hwy
76380	Fatal	2011	January	201	Head-on	1	0	1	0	2	152.8498	-27.0243	D'Aguilar Hwy
76400	Hospitalisation	2011	February	303	Rear-end	0	1	0	0	1	152.8766	-27.0457	D'Aguilar Hwy
76407	Medical treatment	2011	March	303	Rear-end	0	0	1	0	1	152.8415	-27.0124	D'Aguilar Hwy
76409	Medical treatment	2011	March	301	Rear-end	0	0	1	0	1	152.8571	-27.0365	D'Aguilar Hwy
76415	Minor injury	2011	March	609	Hit animal	0	0	0	1	1	152.853	-27.0277	D'Aguilar Hwy
76425	Hospitalisation	2011	April	301	Rear-end	0	1	0	1	2	152.9301	-27.0671	D'Aguilar Hwy
76469	Hospitalisation	2011	May	301	Rear-end	0	2	1	1	4	152.9165	-27.0648	D'Aguilar Hwy
76504	Fatal	2011	July	804	Off carriageway on curve hit object	1	1	0	0	2	152.8527	-27.0273	D'Aguilar Hwy

Appendix D. – Extract of WCLT Segments Data

Extract source file: Department of Transport and Main Roads (2019c)

ROAD_ SECTION_ID	TDIST_ START	TDIST _END	LANE_FUNCTION LABEL	COMPLETION DATE
150B	13.4	20.9	Wide Centre Line	27-Mar-13
17B	24.05	27.64	Wide Centre Line	31-Jul-15
17B	91.48	93.16	Wide Centre Line	25-Jun-15
17B	93.16	93.24	Wide Centre Line	25-Jun-15
17B	93.98	95.62	Wide Centre Line	25-Jun-15
17B	96.76	97.21	Wide Centre Line	25-Jun-15
17B	97.87	101.45	Wide Centre Line	25-Jun-15
17B	101.93	105.96	Wide Centre Line	25-Jun-15
17B	106.21	107.55	Wide Centre Line	11-Mar-15
17B	108.01	110.6	Wide Centre Line	25-Jun-15
17B	110.73	114.19	Wide Centre Line	25-Jun-15
17C	6.7	7.1	Wide Centre Line	15-Jun-18
17C	7.49	8.55	Wide Centre Line	15-Jun-18
17C	8.84	9.15	Wide Centre Line	15-Jun-18
17C	9.28	10.63	Wide Centre Line	15-Jun-18
17C	11.38	13.88	Wide Centre Line	15-Jun-18
17C	14.16	14.42	Wide Centre Line	15-Jun-18
17C	15.39	20.1	Wide Centre Line	15-Jun-18
17C	20.38	20.95	Wide Centre Line	15-Jun-18
18B	36.34	41.6	Wide Centre Line	15-Nov-17
18B	44.7	47.88	Wide Centre Line	15-Nov-17
18B	48.08	49.03	Wide Centre Line	15-Nov-17
18B	51.03	53.6	Wide Centre Line	15-Nov-17
18B	55.27	56.21	Wide Centre Line	15-Nov-17
18B	56.46	56.71	Wide Centre Line	15-Nov-17
18B	57.05	59.97	Wide Centre Line	15-Nov-17
18B	60.27	60.29	Wide Centre Line	15-Nov-17
18B	60.29	61.25	Wide Centre Line	15-Nov-17
18B	62.89	63.47	Wide Centre Line	15-Nov-17
18B	63.47	63.5	Wide Centre Line	15-Nov-17
18B	65.11	70.48	Wide Centre Line	15-Nov-17
18B	72.2	72.5	Wide Centre Line	15-Nov-17
18B	72.84	75.69	Wide Centre Line	15-Nov-17

ROAD_ SECTION_ID	TDIST_ START	TDIST _END	LANE_FUNCTION LABEL	COMPLETION DATE
18B	77.71	80.32	Wide Centre Line	15-Nov-17
18C	2.15	2.91	Wide Centre Line	15-Nov-17
18C	4.1	5.32	Wide Centre Line	15-Nov-17
18C	5.73	7.02	Wide Centre Line	15-Nov-17
18C	7.33	8.06	Wide Centre Line	15-Nov-17
18C	8.17	20.6	Wide Centre Line	15-Nov-17
18C	20.96	23.7	Wide Centre Line	15-Nov-17
18C	25.96	33.35	Wide Centre Line	15-Nov-17
18C	33.62	41.12	Wide Centre Line	15-Nov-17
18C	43.35	44.49	Wide Centre Line	15-Nov-17
18C	52.39	53.84	Wide Centre Line	15-Nov-17
18C	66.03	68.89	Wide Centre Line	19-May-17
18C	69.16	69.79	Wide Centre Line	19-May-17
18C	70.75	71.93	Wide Centre Line	19-May-17
18C	72.41	74.31	Wide Centre Line	19-May-17
18C	74.65	75	Wide Centre Line	19-May-17
18C	75.44	76.9	Wide Centre Line	19-May-17
18C	84.68	88.79	Wide Centre Line	15-Nov-17
18C	97.73	101.44	Wide Centre Line	15-Nov-17
18C	103.69	104.13	Wide Centre Line	15-Nov-17
18C	104.53	106.2	Wide Centre Line	15-Nov-17
22C	26.34	26.9	Wide Centre Line	25-Jul-18
22C	27.05	29.26	Wide Centre Line	25-Jul-18
22C	31.3	31.99	Wide Centre Line	25-Jul-18
22C	32.41	33.13	Wide Centre Line	25-Jul-18
22C	34.28	36.25	Wide Centre Line	25-Jul-18
22C	39.83	49.43	Wide Centre Line	25-Jul-18
22C	39.83	49.43	Wide Centre Line	8-Jan-16
22C	50.27	52.35	Wide Centre Line	8-Jan-16
22C	54.47	54.68	Wide Centre Line	8-Jan-16
22C	54.68	54.74	Wide Centre Line	8-Jan-16
22C	62.57	62.78	Wide Centre Line	25-Jul-18
22C	63.16	65.24	Wide Centre Line	25-Jul-18
22C	63.16	65.24	Wide Centre Line	8-Jan-16
22C	65.49	67.74	Wide Centre Line	8-Jan-16
22C	73.56	75.64	Wide Centre Line	8-Jan-16
22C	87.01	91.6	Wide Centre Line	8-Jan-16
25B	4.05	4.77	Wide Centre Line	31-Jan-17

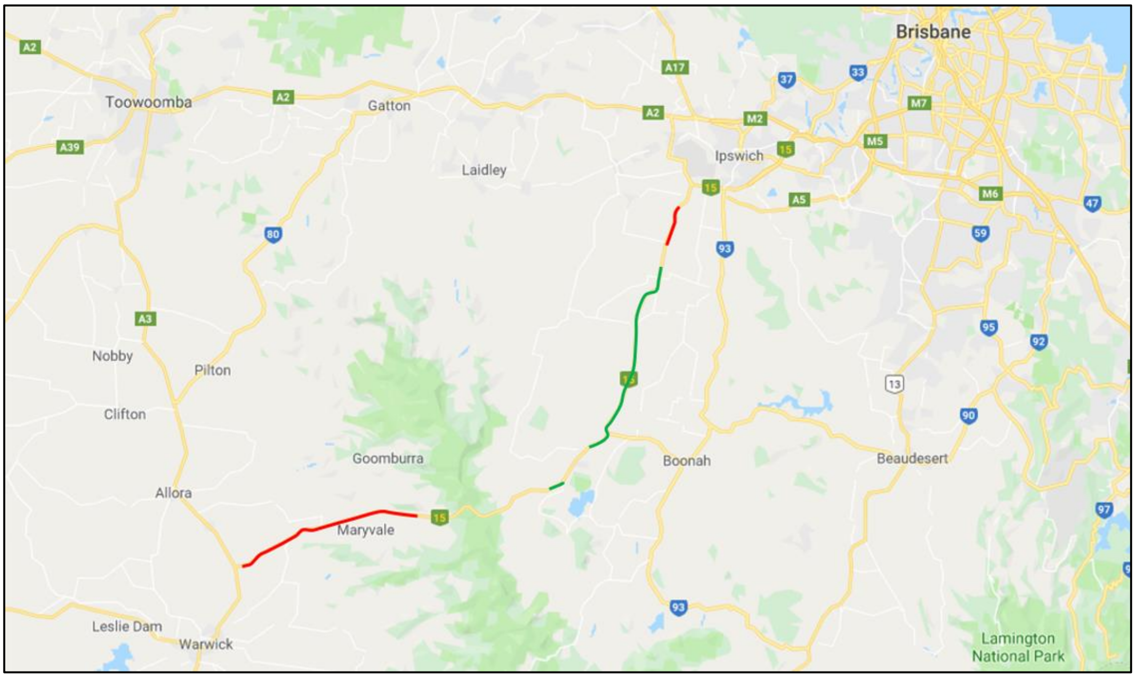
ROAD_ SECTION_ID	TDIST_ START	TDIST _END	LANE_FUNCTION LABEL	COMPLETION DATE
28B	105.61	106.7	Wide Centre Line	2-Feb-15
28B	107.06	107.93	Wide Centre Line	2-Feb-15
40A	0.909	2.14	Wide Centre Line	30-Jul-15
40A	4.309	7.18	Wide Centre Line	30-Jul-15
40A	7.5	7.95	Wide Centre Line	30-Jul-15
40A	7.97	8.5	Wide Centre Line	30-Jul-15
40A	14.53	15.91	Wide Centre Line	30-Jul-15
40A	16.69	17.493	Wide Centre Line	30-Jul-15
40A	17.723	19.17	Wide Centre Line	30-Jul-15
40A	19.24	19.62	Wide Centre Line	30-Jul-15
40A	19.72	21.555	Wide Centre Line	30-Jul-15
40A	21.63	21.68	Wide Centre Line	30-Jul-15
40A	21.745	21.8	Wide Centre Line	30-Jul-15
40A	23.13	23.801	Wide Centre Line	30-Jul-15
40A	30.61	34.19	Wide Centre Line	30-Jul-15
40A	34.345	38.135	Wide Centre Line	30-Jul-15
40A	39.42	39.655	Wide Centre Line	30-Jul-15
40A	39.805	41.5	Wide Centre Line	30-Jul-15
40A	41.65	42.58	Wide Centre Line	30-Jul-15
42A	75.66	76.088	Wide Centre Line	30-Jun-15
42A	76.105	76.295	Wide Centre Line	30-Jun-15
42A	76.53	76.91	Wide Centre Line	30-Jun-15

Appendix E. – Highway segment locality maps

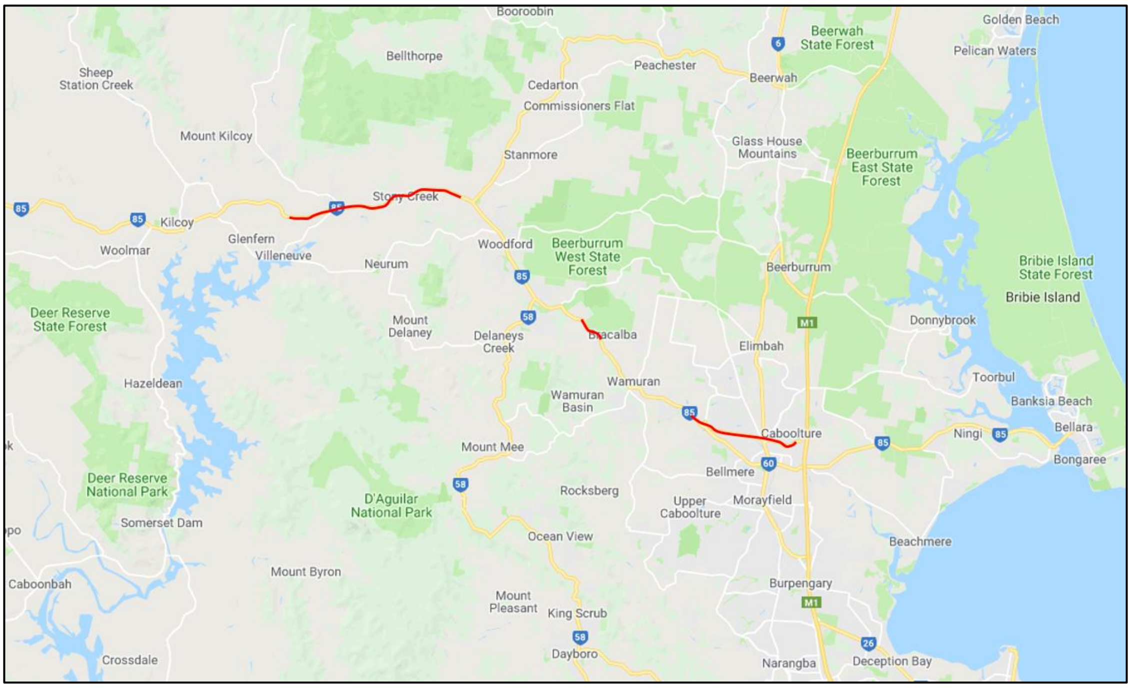
Approximate highway locality of TREATMENT segments

Approximate highway locality of CONTROL segments

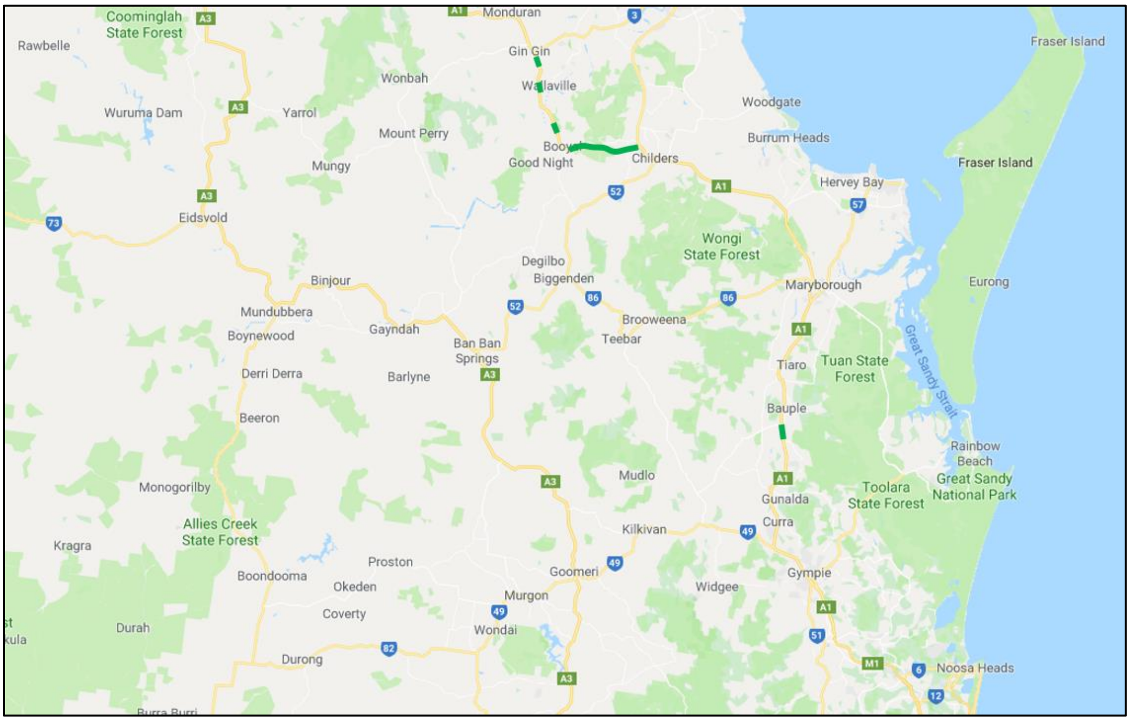
E.1 Cunningham Highway (17B) – Treatment & control segments



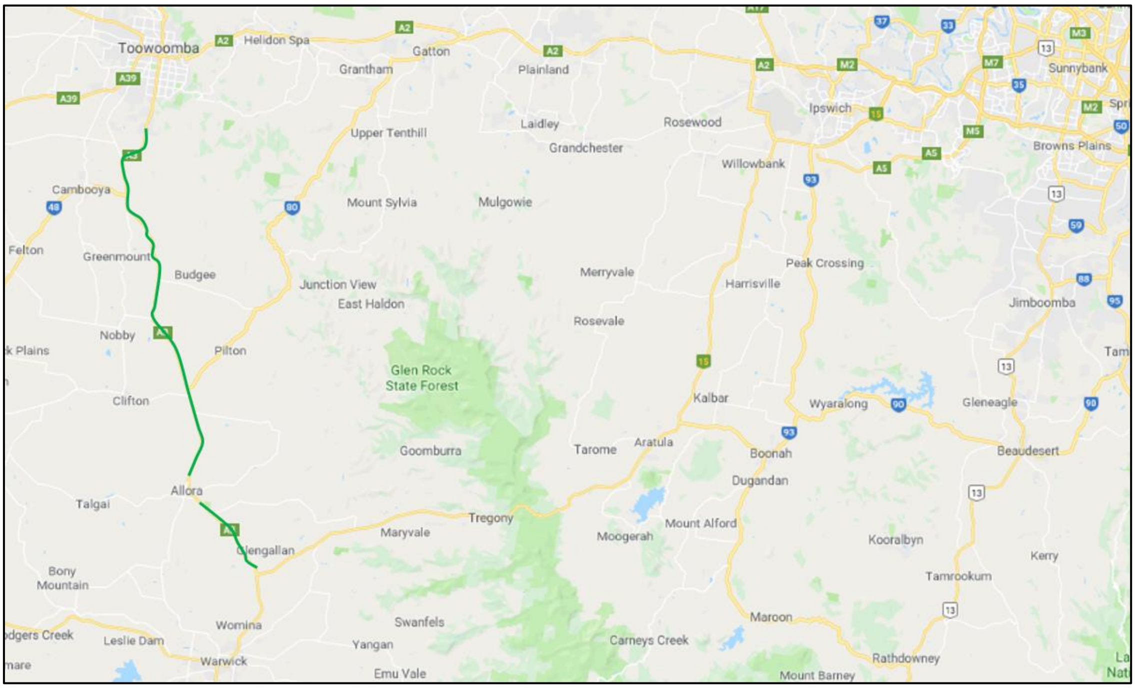
E.2 D’Aguilar Highway (40A) – Treatment segments, no control segments



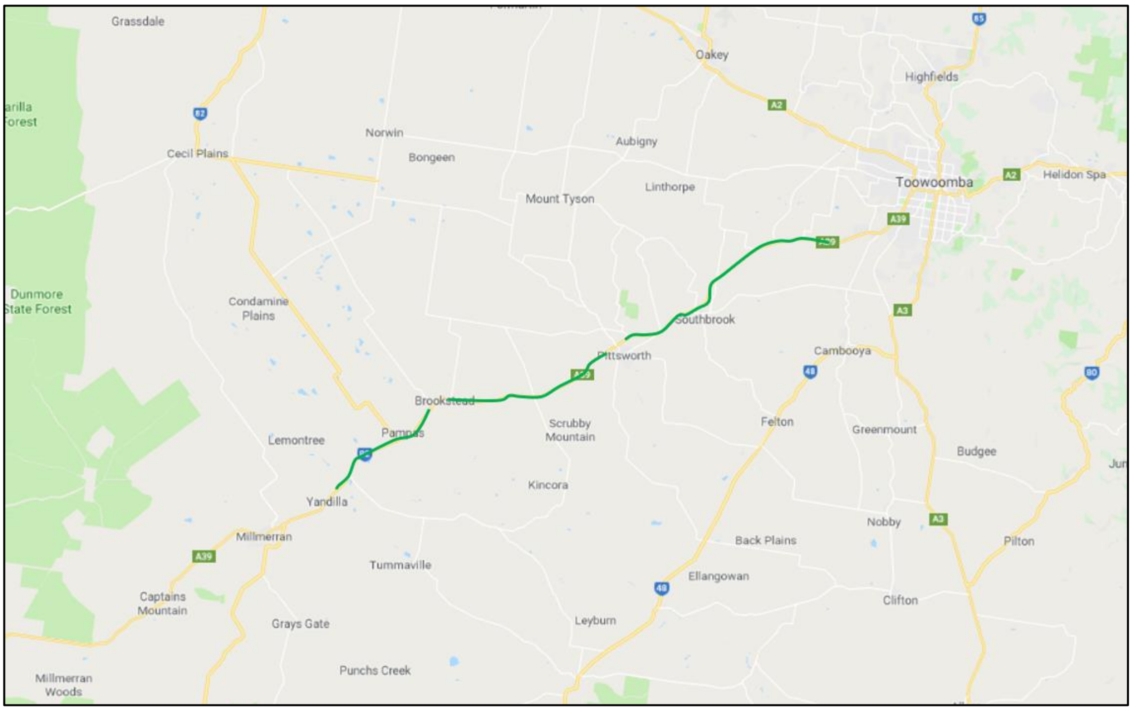
E.3 Bruce Highway (10B & 10C) – Control segments, no treatment segments



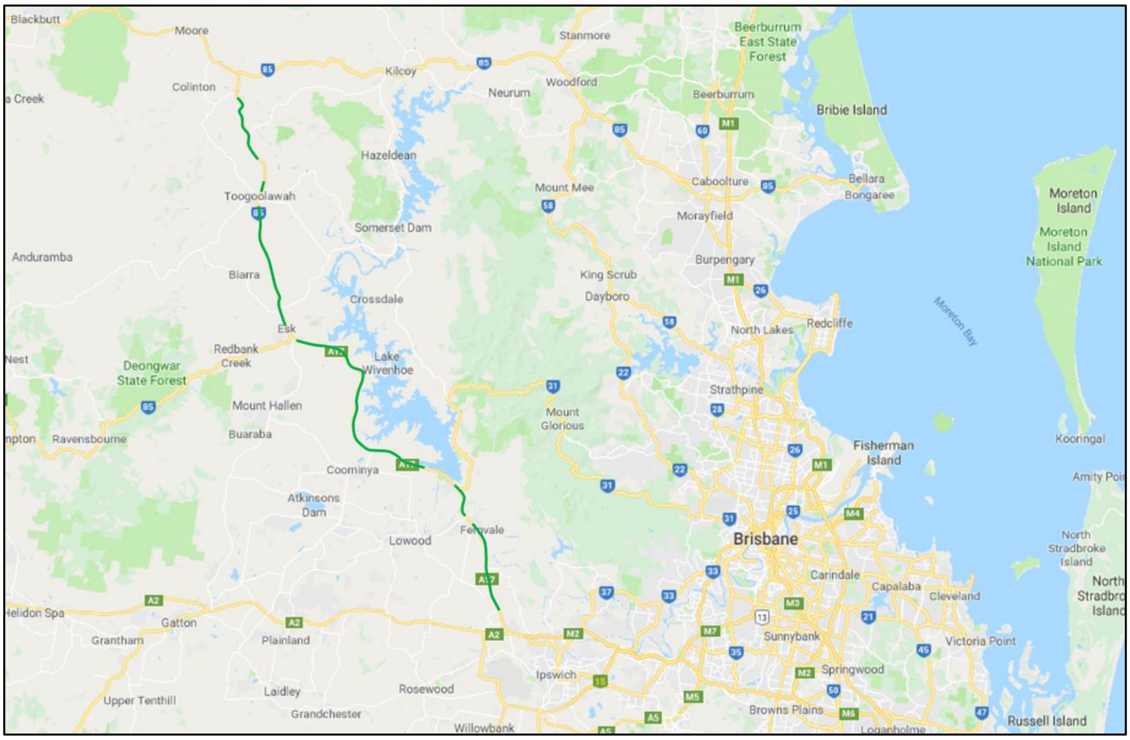
E.4 New England Highway (22B) – Control segments, no treatment segments



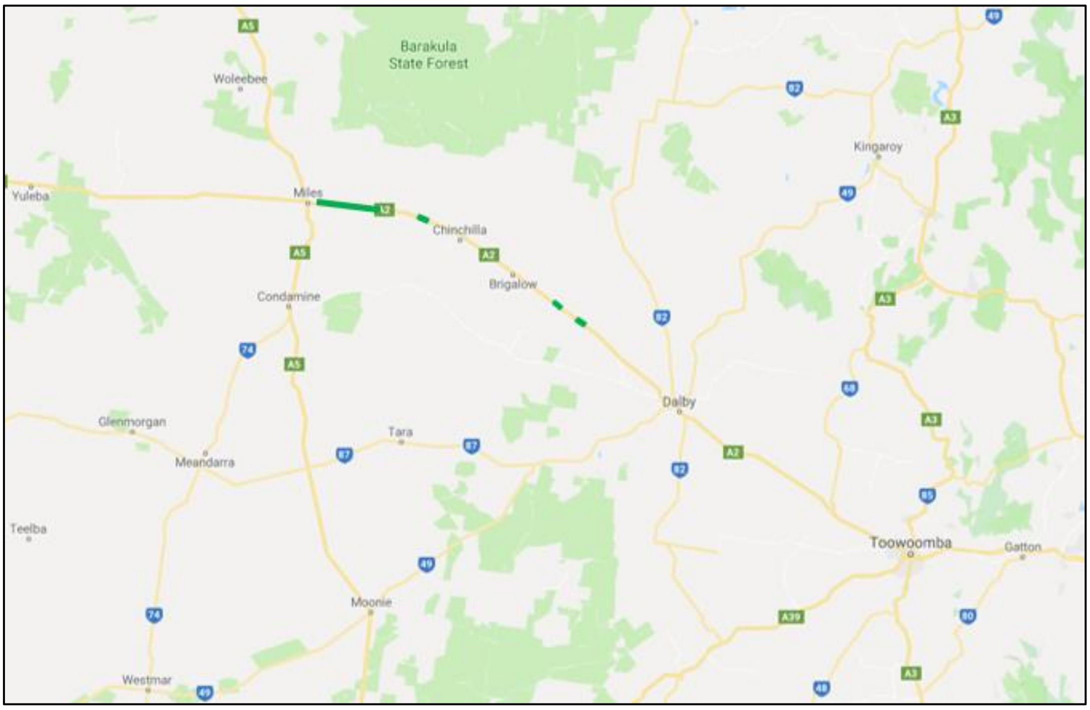
E.5 Gore Highway (28A) – Control segments, no treatment segments



E.6 Brisbane Valley Highway (42A) – Control segments, no treatment segments



E.7 Warrego Highway (18C) – Control segments, no treatment segments



Appendix F. – Treatment segment datasets for analysis

F.1 Cunningham Highway (17B) – Treated segments (BEFORE)

Year	Road ID	Section Number	Start Chainage (km)	End Chainage (km)	Length (km)	AADT	HOCL	RORL	OTHER	TOTAL
2012	17B	1	24.50	27.64	3.14	5493	0	1	0	1
	17B	17	91.48	93.24	1.76	4284	0	0	0	0
	17B	18	97.87	101.45	3.58	4284	0	0	0	0
	17B	19	101.93	105.96	4.03	4284	0	0	0	0
	17B	20	106.21	107.55	1.34	4064	0	0	0	0
	17B	21	108.01	110.60	2.59	4064	0	0	0	0
	17B	22	110.73	114.19	3.46	4064	0	0	0	0
2013	17B	1	24.50	27.64	3.14	6306	0	0	0	0
	17B	17	91.48	93.24	1.76	4311	0	0	0	0
	17B	18	97.87	101.45	3.58	4311	0	0	0	0
	17B	19	101.93	105.96	4.03	4311	0	0	0	0
	17B	20	106.21	107.55	1.34	4265	0	0	0	0
	17B	21	108.01	110.60	2.59	4265	0	0	0	0
	17B	22	110.73	114.19	3.46	4265	0	0	0	0
2014	17B	1	24.50	27.64	3.14	5675	0	1	0	1
	17B	17	91.48	93.24	1.76	4382	0	0	0	0
	17B	18	97.87	101.45	3.58	4382	0	0	0	0
	17B	19	101.93	105.96	4.03	4382	0	0	0	0
	17B	20	106.21	107.55	1.34	4382	0	0	0	0
	17B	21	108.01	110.60	2.59	4382	0	0	0	0
	17B	22	110.73	114.19	3.46	4382	0	1	0	1

F.2 Cunningham Highway (17B) – Treated segments (AFTER)

Year	Road ID	Section Number	Start Chainage (km)	End Chainage (km)	Length (km)	AADT	HOCL	RORL	OTHER	TOTAL
2016	17B	1	24.50	27.64	3.14	5675	1	2	0	3
	17B	17	91.48	93.24	1.76	4241	0	0	0	0
	17B	18	97.87	101.45	3.58	4241	0	0	1	1
	17B	19	101.93	105.96	4.03	4241	0	0	0	0
	17B	20	106.21	107.55	1.34	4241	0	0	0	0
	17B	21	108.01	110.60	2.59	4241	0	0	0	0
	17B	22	110.73	114.19	3.46	4241	0	0	0	0
2017	17B	1	24.50	27.64	3.14	6829	0	0	1	1
	17B	17	91.48	93.24	1.76	4208	0	0	0	0
	17B	18	97.87	101.45	3.58	4208	0	0	0	0
	17B	19	101.93	105.96	4.03	4208	0	0	1	1
	17B	20	106.21	107.55	1.34	4208	0	0	0	0
	17B	21	108.01	110.60	2.59	4208	0	0	0	0
	17B	22	110.73	114.19	3.46	4208	0	1	0	1

F.3 D'Aguilar Highway (40A) – Treated segments (BEFORE)

Year	Road ID	Section Number	Start Chainage (km)	End Chainage (km)	Length (km)	AADT	HOCL	RORL	OTHER	TOTAL
2012	40A	1	0.91	2.14	1.23	10329	0	0	0	0
	40A	2	4.31	7.18	2.87	10329	1	0	0	1
	40A	3	7.50	7.90	0.40	11931	0	0	0	0
	40A	4	8.10	8.50	0.40	11931	0	0	0	0
	40A	5	16.69	17.49	0.80	9065	0	0	0	0
	40A	6	17.72	18.70	0.98	6593	0	0	1	1
	40A	7	30.61	34.19	3.58	6593	0	0	0	0
	40A	8	34.35	38.14	3.79	6593	0	0	1	1
	40A	9	39.42	39.66	0.24	6593	0	0	0	0
	40A	10	39.81	41.50	1.70	6593	0	0	0	0
	40A	11	41.65	42.58	0.93	6593	0	0	0	0
2013	40A	1	0.91	2.14	1.23	10389	0	0	0	0
	40A	2	4.31	7.18	2.87	10389	0	0	1	1
	40A	3	7.50	7.90	0.40	11931	0	0	0	0
	40A	4	8.10	8.50	0.40	11931	0	0	0	0
	40A	5	16.69	17.49	0.80	9640	0	0	0	0
	40A	6	17.72	18.70	0.98	9640	0	0	0	0
	40A	7	30.61	34.19	3.58	6754	1	0	1	2
	40A	8	34.35	38.14	3.79	6754	0	0	1	1
	40A	9	39.42	39.66	0.24	6754	0	0	0	0
	40A	10	39.81	41.50	1.70	6754	1	0	1	2
	40A	11	41.65	42.58	0.93	6754	0	0	0	0
2014	40A	1	0.91	2.14	1.23	10907	0	0	1	1
	40A	2	4.31	7.18	2.87	10907	1	0	1	2
	40A	3	7.50	7.90	0.40	11931	0	0	0	0
	40A	4	8.10	8.50	0.40	11931	0	0	0	0
	40A	5	16.69	17.49	0.80	9640	0	0	1	1
	40A	6	17.72	18.70	0.98	9640	0	0	1	1
	40A	7	30.61	34.19	3.58	6988	0	0	0	0
	40A	8	34.35	38.14	3.79	6988	0	0	1	1
	40A	9	39.42	39.66	0.24	6988	0	0	0	0
	40A	10	39.81	41.50	1.70	6988	0	0	0	0
	40A	11	41.65	42.58	0.93	6988	0	0	0	0

F.4 D'Aguilar Highway (40A) – Treated segments (AFTER)

Year	Road ID	Section Number	Start Chainage (km)	End Chainage (km)	Length (km)	AADT	HOCL	RORL	OTHER	TOTAL
2016	40A	1	0.91	2.14	1.23	17715	0	0	0	0
	40A	2	4.31	7.18	2.87	12160	0	1	0	1
	40A	3	7.50	7.90	0.40	13524	0	0	0	0
	40A	4	8.10	8.50	0.40	13524	0	0	0	0
	40A	5	16.69	17.49	0.80	11508	0	0	0	0
	40A	6	17.72	18.70	0.98	11508	0	0	0	0
	40A	7	30.61	34.19	3.58	7548	1	0	0	1
	40A	8	34.35	38.14	3.79	7548	0	0	0	0
	40A	9	39.42	39.66	0.24	7548	0	0	0	0
	40A	10	39.81	41.50	1.70	7548	0	0	0	0
	40A	11	41.65	42.58	0.93	7548	0	0	0	0
2017	40A	1	0.91	2.14	1.23	18613	0	0	0	0
	40A	2	4.31	7.18	2.87	12733	0	0	0	0
	40A	3	7.50	7.90	0.40	14119	0	0	0	0
	40A	4	8.10	8.50	0.40	14119	0	0	0	0
	40A	5	16.69	17.49	0.80	11553	0	0	1	1
	40A	6	17.72	18.70	0.98	11553	0	0	1	1
	40A	7	30.61	34.19	3.58	7750	0	0	1	1
	40A	8	34.35	38.14	3.79	7750	0	0	1	1
	40A	9	39.42	39.66	0.24	7750	0	0	0	0
	40A	10	39.81	41.50	1.70	7750	0	0	0	0
	40A	11	41.65	42.58	0.93	7750	0	0	0	0

Appendix G. – Control segment datasets for analysis

Year	Road ID	Section Number	Start Chainage (km)	End Chainage (km)	Length (km)	AADT	HOCL	RORL	OTHER	TOTAL
2012	10B	1	42.2	44.3	2.1	8870	0	0	0	0
	10C	2	63.6	67	3.4	7147	0	0	0	0
	10C	3	72.2	75.6	3.4	3446	0	0	0	0
	10C	4	76	78.5	2.5	3446	0	0	0	0
	10C	5	79.5	82	2.5	3446	0	0	0	0
	10C	6	90.3	92	1.7	3831	0	0	0	0
	10C	7	92.4	92.7	0.3	3831	0	0	0	0
	10C	8	101.8	102.2	0.4	3831	0	0	0	0
	10C	9	102.4	102.7	0.3	4721	0	0	0	0
	10C	10	108.8	109.9	1.1	4721	0	0	0	0
2013	10B	1	42.2	44.3	2.1	9151	0	0	0	0
	10C	2	63.6	67	3.4	7094	1	1	0	2
	10C	3	72.2	75.6	3.4	3557	0	1	0	1
	10C	4	76	78.5	2.5	3557	0	0	0	0
	10C	5	79.5	82	2.5	3557	1	0	1	2
	10C	6	90.3	92	1.7	3995	0	0	0	0
	10C	7	92.4	92.7	0.3	3995	0	0	0	0
	10C	8	101.8	102.2	0.4	3995	0	0	0	0
	10C	9	102.4	102.7	0.3	4926	0	0	0	0
	10C	10	108.8	109.9	1.1	4926	1	0	0	1
2014	10B	1	42.2	44.3	2.1	8729	0	0	0	0
	10C	2	63.6	67	3.4	6549	0	0	1	1
	10C	3	72.2	75.6	3.4	3444	1	0	1	2
	10C	4	76	78.5	2.5	3444	0	0	0	0
	10C	5	79.5	82	2.5	3444	0	0	0	0
	10C	6	90.3	92	1.7	3742	0	0	0	0
	10C	7	92.4	92.7	0.3	3742	0	0	0	0
	10C	8	101.8	102.2	0.4	3742	0	0	0	0
	10C	9	102.4	102.7	0.3	4398	0	0	0	0
	10C	10	108.8	109.9	1.1	4398	0	0	0	0
2015	10B	1	42.2	44.3	2.1	8789	0	0	0	0
	10C	2	63.6	67	3.4	6614	0	0	0	0
	10C	3	72.2	75.6	3.4	3670	0	0	0	0
	10C	4	76	78.5	2.5	3670	0	0	0	0
	10C	5	79.5	82	2.5	3670	0	0	0	0
	10C	6	90.3	92	1.7	3793	0	1	1	2
	10C	7	92.4	92.7	0.3	3793	0	0	0	0
	10C	8	101.8	102.2	0.4	3793	0	0	0	0
	10C	9	102.4	102.7	0.3	4452	0	0	0	0
	10C	10	108.8	109.9	1.1	4452	2	0	0	2
2016	10B	1	42.2	44.3	2.1	9369	2	0	0	2
	10C	2	63.6	67	3.4	6731	0	0	0	0
	10C	3	72.2	75.6	3.4	3718	0	0	0	0
	10C	4	76	78.5	2.5	3718	0	0	1	1
	10C	5	79.5	82	2.5	3718	0	0	0	0
	10C	6	90.3	92	1.7	3807	0	0	0	0
	10C	7	92.4	92.7	0.3	3807	0	0	0	0
	10C	8	101.8	102.2	0.4	3807	0	0	0	0
	10C	9	102.4	102.7	0.3	4581	0	0	0	0
	10C	10	108.8	109.9	1.1	4581	0	1	0	1
2017	10B	1	42.2	44.3	2.1	9255	0	0	0	0
	10C	2	63.6	67	3.4	6621	0	0	1	1

	10C	3	72.2	75.6	3.4	3968	0	0	0	0
	10C	4	76	78.5	2.5	3968	0	0	0	0
	10C	5	79.5	82	2.5	3968	0	0	0	0
	10C	6	90.3	92	1.7	3850	0	0	0	0
	10C	7	92.4	92.7	0.3	3850	0	0	0	0
	10C	8	101.8	102.2	0.4	3850	0	0	0	0
	10C	9	102.4	102.7	0.3	4936	0	0	0	0
	10C	10	108.8	109.9	1.1	4936	1	0	0	1
2012	17B	2	31.3	32.1	0.8	5493	0	0	0	0
	17B	3	32.3	33.3	1	5493	0	0	0	0
	17B	4	33.8	35.4	1.6	4884	0	0	0	0
	17B	5	36	37	1	4884	0	0	0	0
	17B	6	37.4	38.6	1.2	4884	0	0	0	0
	17B	7	42.1	43.1	1	4695	0	0	1	1
	17B	8	43.5	45.6	2.1	4695	0	0	0	0
	17B	9	46	48.6	2.6	4695	0	0	0	0
	17B	10	52.3	52.8	0.5	4695	0	0	0	0
	17B	11	53.1	54.4	1.3	4695	0	0	0	0
	17B	12	55.7	58.6	2.9	4598	0	0	0	0
	17B	13	65.3	66.4	1.1	4598	0	0	0	0
	17B	14	66.8	67.3	0.5	4598	0	0	0	0
2013	17B	2	31.3	32.1	0.8	6306	0	0	0	0
	17B	3	32.3	33.3	1	6306	0	0	0	0
	17B	4	33.8	35.4	1.6	5512	0	0	0	0
	17B	5	36	37	1	5512	0	0	0	0
	17B	6	37.4	38.6	1.2	5512	0	0	0	0
	17B	7	42.1	43.1	1	4786	0	0	0	0
	17B	8	43.5	45.6	2.1	4786	0	0	0	0
	17B	9	46	48.6	2.6	4786	0	0	0	0
	17B	10	52.3	52.8	0.5	4786	0	0	0	0
	17B	11	53.1	54.4	1.3	4786	0	0	0	0
	17B	12	55.7	58.6	2.9	6406	0	0	0	0
	17B	13	65.3	66.4	1.1	6406	0	0	0	0
	17B	14	66.8	67.3	0.5	6406	0	0	0	0
2014	17B	2	31.3	32.1	0.8	5675	0	0	0	0
	17B	3	32.3	33.3	1	5675	0	0	0	0
	17B	4	33.8	35.4	1.6	5023	0	0	0	0
	17B	5	36	37	1	5023	0	0	0	0
	17B	6	37.4	38.6	1.2	5023	0	0	0	0
	17B	7	42.1	43.1	1	4930	0	0	0	0
	17B	8	43.5	45.6	2.1	4930	0	0	0	0
	17B	9	46	48.6	2.6	4930	0	0	0	0
	17B	10	52.3	52.8	0.5	4930	0	0	0	0
	17B	11	53.1	54.4	1.3	4930	0	0	0	0
	17B	12	55.7	58.6	2.9	6203	0	0	0	0
	17B	13	65.3	66.4	1.1	6203	0	0	0	0
	17B	14	66.8	67.3	0.5	6203	0	0	0	0
2015	17B	2	31.3	32.1	0.8	5675	0	0	0	0
	17B	3	32.3	33.3	1	5675	0	0	0	0
	17B	4	33.8	35.4	1.6	5023	0	0	0	0
	17B	5	36	37	1	5023	0	0	0	0
	17B	6	37.4	38.6	1.2	5023	0	0	0	0
	17B	7	42.1	43.1	1	5097	0	0	0	0
	17B	8	43.5	45.6	2.1	5097	0	0	0	0
	17B	9	46	48.6	2.6	5097	0	0	0	0
	17B	10	52.3	52.8	0.5	5097	0	0	0	0
	17B	11	53.1	54.4	1.3	5097	0	0	0	0
	17B	12	55.7	58.6	2.9	5730	0	0	0	0

	17B	13	65.3	66.4	1.1	5730	0	0	0	0
	17B	14	66.8	67.3	0.5	5730	0	0	0	0
2016	17B	2	31.3	32.1	0.8	5675	0	0	0	0
	17B	3	32.3	33.3	1	5675	0	0	0	0
	17B	4	33.8	35.4	1.6	5466	0	0	0	0
	17B	5	36	37	1	5466	0	0	0	0
	17B	6	37.4	38.6	1.2	5466	0	0	0	0
	17B	7	42.1	43.1	1	5234	0	0	0	0
	17B	8	43.5	45.6	2.1	5234	0	0	0	0
	17B	9	46	48.6	2.6	5234	0	0	0	0
	17B	10	52.3	52.8	0.5	5234	0	0	0	0
	17B	11	53.1	54.4	1.3	5234	0	0	0	0
	17B	12	55.7	58.6	2.9	6654	0	0	0	0
	17B	13	65.3	66.4	1.1	6654	0	0	0	0
	17B	14	66.8	67.3	0.5	6654	0	0	0	0
2017	17B	2	31.3	32.1	0.8	6829	0	0	0	0
	17B	3	32.3	33.3	1	6829	0	0	0	0
	17B	4	33.8	35.4	1.6	5415	0	0	0	0
	17B	5	36	37	1	5415	0	0	0	0
	17B	6	37.4	38.6	1.2	5415	0	0	0	0
	17B	7	42.1	43.1	1	5221	0	0	0	0
	17B	8	43.5	45.6	2.1	5221	0	0	0	0
	17B	9	46	48.6	2.6	5221	0	0	0	0
	17B	10	52.3	52.8	0.5	5221	0	0	0	0
	17B	11	53.1	54.4	1.3	5221	0	0	0	0
	17B	12	55.7	58.6	2.9	7267	0	0	0	0
	17B	13	65.3	66.4	1.1	7267	0	0	0	0
	17B	14	66.8	67.3	0.5	7267	0	0	0	0
2012	18C	10	41.12	43.35	2.23	3370	0	0	0	0
	18C	12	47.7	51.7	4	2895	0	0	0	0
	18C	21	90.2	97	6.8	3608	0	0	0	0
	18C	23	101.44	103.69	2.25	3608	0	0	0	0
	18C	26	106.2	111.2	5	3442	0	0	0	0
	18C	27	112.9	118	5.1	3442	0	0	0	0
	18C	28	118.5	125.1	6.6	3442	1	0	0	1
2013	18C	10	41.12	43.35	2.23	4341	0	0	0	0
	18C	12	47.7	51.7	4	4135	0	0	0	0
	18C	21	90.2	97	6.8	4393	0	0	0	0
	18C	23	101.44	103.69	2.25	4393	0	0	0	0
	18C	26	106.2	111.2	5	4368	0	0	1	1
	18C	27	112.9	118	5.1	4368	0	0	0	0
	18C	28	118.5	125.1	6.6	4368	0	0	0	0
2014	18C	10	41.12	43.35	2.23	3706	0	0	0	0
	18C	12	47.7	51.7	4	3705	0	0	0	0
	18C	21	90.2	97	6.8	4971	1	0	0	1
	18C	23	101.44	103.69	2.25	4971	0	0	0	0
	18C	26	106.2	111.2	5	3873	0	0	0	0
	18C	27	112.9	118	5.1	3873	0	1	0	1
	18C	28	118.5	125.1	6.6	3873	0	0	1	1
2015	18C	10	41.12	43.35	2.23	3144	0	0	0	0
	18C	12	47.7	51.7	4	3060	0	0	0	0
	18C	21	90.2	97	6.8	4718	0	0	0	0
	18C	23	101.44	103.69	2.25	4718	0	0	0	0
	18C	26	106.2	111.2	5	2866	0	0	0	0
	18C	27	112.9	118	5.1	2866	0	0	0	0
	18C	28	118.5	125.1	6.6	2866	0	0	0	0
2016	18C	10	41.12	43.35	2.23	2929	0	0	0	0
	18C	12	47.7	51.7	4	2829	0	0	0	0

	18C	21	90.2	97	6.8	3331	0	0	0	0
	18C	23	101.44	103.69	2.25	3331	0	0	0	0
	18C	26	106.2	111.2	5	2625	0	0	0	0
	18C	27	112.9	118	5.1	2625	0	1	0	1
	18C	28	118.5	125.1	6.6	2625	0	0	0	0
2017	18C	10	41.12	43.35	2.23	2963	0	0	0	0
	18C	12	47.7	51.7	4	2854	0	0	0	0
	18C	21	90.2	97	6.8	3106	0	0	0	0
	18C	23	101.44	103.69	2.25	3106	0	0	0	0
	18C	26	106.2	111.2	5	2704	0	0	0	0
	18C	27	112.9	118	5.1	2704	0	0	0	0
	18C	28	118.5	125.1	6.6	2704	0	0	0	0
2012	22B	1	10.1	11	0.9	3637	0	0	0	0
	22B	2	11.3	14.1	2.8	3637	1	0	0	1
	22B	3	14.7	18	3.3	6540	0	0	1	1
	22B	4	18.8	19.8	1	5119	0	0	0	0
	22B	5	20.4	23.5	3.1	5119	0	0	1	1
	22B	6	24.4	25.6	1.2	5119	0	0	0	0
	22B	7	27.4	34.4	7	3536	0	1	0	1
	22B	8	34.7	36.8	2.1	3064	0	0	0	0
	22B	9	37	42.6	5.6	3064	1	0	1	2
	22B	10	42.9	43.7	0.8	3064	0	0	0	0
	22B	11	45.3	47	1.7	3736	0	0	0	0
	22B	12	47.5	47.9	0.4	3736	0	0	0	0
	22B	13	48.1	50.9	2.8	3736	0	1	0	1
	22B	14	51.2	55.5	4.3	3736	1	1	0	2
	22B	15	57.8	58.1	0.3	3067	0	0	0	0
	22B	16	58.4	60.6	2.2	3067	0	0	0	0
	22B	17	60.9	62.8	1.9	3067	0	0	0	0
	22B	18	63.9	64.3	0.4	3067	0	0	0	0
	22B	19	64.5	66.9	2.4	3067	0	0	0	0
	22B	20	67.1	68.7	1.6	3067	0	0	0	0
	22B	21	69.1	69.5	0.4	3067	0	0	0	0
2013	22B	1	10.1	11	0.9	3861	0	0	0	0
	22B	2	11.3	14.1	2.8	3861	0	0	0	0
	22B	3	14.7	18	3.3	6401	0	0	0	0
	22B	4	18.8	19.8	1	5409	0	0	0	0
	22B	5	20.4	23.5	3.1	5409	0	0	0	0
	22B	6	24.4	25.6	1.2	5409	1	0	0	1
	22B	7	27.4	34.4	7	3633	0	0	0	0
	22B	8	34.7	36.8	2.1	3320	0	0	0	0
	22B	9	37	42.6	5.6	3320	2	0	1	3
	22B	10	42.9	43.7	0.8	3320	0	0	0	0
	22B	11	45.3	47	1.7	4026	1	0	1	2
	22B	12	47.5	47.9	0.4	4026	0	0	0	0
	22B	13	48.1	50.9	2.8	4026	0	0	0	0
	22B	14	51.2	55.5	4.3	4026	0	0	0	0
	22B	15	57.8	58.1	0.3	3405	0	0	0	0
	22B	16	58.4	60.6	2.2	3405	0	0	0	0
	22B	17	60.9	62.8	1.9	3405	0	0	0	0
	22B	18	63.9	64.3	0.4	3405	0	0	0	0
	22B	19	64.5	66.9	2.4	3405	0	0	0	0
	22B	20	67.1	68.7	1.6	3405	0	0	0	0
	22B	21	69.1	69.5	0.4	3405	0	0	0	0
2014	22B	1	10.1	11	0.9	4023	0	0	0	0
	22B	2	11.3	14.1	2.8	4023	0	0	0	0
	22B	3	14.7	18	3.3	6630	0	0	0	0
	22B	4	18.8	19.8	1	5465	0	0	0	0

	22B	5	20.4	23.5	3.1	5465	1	0	0	1
	22B	6	24.4	25.6	1.2	5465	0	0	0	0
	22B	7	27.4	34.4	7	3561	0	0	1	1
	22B	8	34.7	36.8	2.1	3235	0	0	0	0
	22B	9	37	42.6	5.6	3235	0	0	1	1
	22B	10	42.9	43.7	0.8	3235	0	0	0	0
	22B	11	45.3	47	1.7	3938	0	0	0	0
	22B	12	47.5	47.9	0.4	3938	0	0	0	0
	22B	13	48.1	50.9	2.8	3938	0	0	0	0
	22B	14	51.2	55.5	4.3	3938	0	0	0	0
	22B	15	57.8	58.1	0.3	3168	0	0	0	0
	22B	16	58.4	60.6	2.2	3168	0	0	0	0
	22B	17	60.9	62.8	1.9	3168	0	0	0	0
	22B	18	63.9	64.3	0.4	3168	0	0	0	0
	22B	19	64.5	66.9	2.4	3168	0	0	0	0
	22B	20	67.1	68.7	1.6	3168	0	0	0	0
	22B	21	69.1	69.5	0.4	3168	0	0	0	0
2015	22B	1	10.1	11	0.9	4015	0	0	0	0
	22B	2	11.3	14.1	2.8	4015	1	1	0	2
	22B	3	14.7	18	3.3	7000	0	0	0	0
	22B	4	18.8	19.8	1	5809	0	0	0	0
	22B	5	20.4	23.5	3.1	5809	0	0	0	0
	22B	6	24.4	25.6	1.2	5809	0	0	0	0
	22B	7	27.4	34.4	7	3870	0	0	0	0
	22B	8	34.7	36.8	2.1	3084	0	0	0	0
	22B	9	37	42.6	5.6	3084	0	1	1	2
	22B	10	42.9	43.7	0.8	3084	0	0	0	0
	22B	11	45.3	47	1.7	3781	0	0	0	0
	22B	12	47.5	47.9	0.4	3781	0	0	0	0
	22B	13	48.1	50.9	2.8	3781	0	0	0	0
	22B	14	51.2	55.5	4.3	3781	0	0	1	1
	22B	15	57.8	58.1	0.3	3045	0	0	0	0
	22B	16	58.4	60.6	2.2	3045	0	0	0	0
	22B	17	60.9	62.8	1.9	3045	0	0	0	0
	22B	18	63.9	64.3	0.4	3045	0	0	0	0
	22B	19	64.5	66.9	2.4	3045	1	0	0	1
	22B	20	67.1	68.7	1.6	3045	0	0	0	0
	22B	21	69.1	69.5	0.4	3045	0	0	0	0
2016	22B	1	10.1	11	0.9	4412	0	0	0	0
	22B	2	11.3	14.1	2.8	4412	0	0	0	0
	22B	3	14.7	18	3.3	7375	0	0	0	0
	22B	4	18.8	19.8	1	6103	0	0	0	0
	22B	5	20.4	23.5	3.1	6103	0	0	1	1
	22B	6	24.4	25.6	1.2	6103	0	0	0	0
	22B	7	27.4	34.4	7	3965	0	0	1	1
	22B	8	34.7	36.8	2.1	3677	0	0	0	0
	22B	9	37	42.6	5.6	3677	0	0	0	0
	22B	10	42.9	43.7	0.8	3677	0	0	0	0
	22B	11	45.3	47	1.7	4372	0	0	0	0
	22B	12	47.5	47.9	0.4	4372	0	0	0	0
	22B	13	48.1	50.9	2.8	4372	0	0	0	0
	22B	14	51.2	55.5	4.3	4372	0	0	2	2
	22B	15	57.8	58.1	0.3	3450	0	0	0	0
	22B	16	58.4	60.6	2.2	3450	0	0	0	0
	22B	17	60.9	62.8	1.9	3450	0	0	0	0
	22B	18	63.9	64.3	0.4	3450	0	0	0	0
	22B	19	64.5	66.9	2.4	3450	0	0	0	0
	22B	20	67.1	68.7	1.6	3450	0	0	0	0

	22B	21	69.1	69.5	0.4	3450	0	0	0	0
2017	22B	1	10.1	11	0.9	4462	0	0	0	0
	22B	2	11.3	14.1	2.8	4462	0	0	0	0
	22B	3	14.7	18	3.3	7679	1	0	0	1
	22B	4	18.8	19.8	1	6169	0	0	0	0
	22B	5	20.4	23.5	3.1	6169	0	0	0	0
	22B	6	24.4	25.6	1.2	6169	0	0	0	0
	22B	7	27.4	34.4	7	4100	0	0	2	2
	22B	8	34.7	36.8	2.1	3727	0	0	0	0
	22B	9	37	42.6	5.6	3727	0	1	0	1
	22B	10	42.9	43.7	0.8	3727	0	0	0	0
	22B	11	45.3	47	1.7	4470	0	0	0	0
	22B	12	47.5	47.9	0.4	4470	0	0	0	0
	22B	13	48.1	50.9	2.8	4470	1	0	0	1
	22B	14	51.2	55.5	4.3	4470	0	0	0	0
	22B	15	57.8	58.1	0.3	3461	0	0	0	0
	22B	16	58.4	60.6	2.2	3461	0	0	0	0
	22B	17	60.9	62.8	1.9	3461	0	0	0	0
	22B	18	63.9	64.3	0.4	3461	0	0	0	0
	22B	19	64.5	66.9	2.4	3461	0	0	0	0
	22B	20	67.1	68.7	1.6	3461	0	0	0	0
	22B	21	69.1	69.5	0.4	3461	0	0	0	0
2012	28A	1	9.5	14	4.5	4064	1	0	1	2
	28A	2	14.5	16.6	2.1	4064	0	0	1	1
	28A	3	20.5	23.8	3.3	4064	0	0	0	0
	28A	4	24	25.6	1.6	4064	0	0	0	0
	28A	5	26.2	27.8	1.6	4064	0	0	1	1
	28A	6	28.1	28.7	0.6	4064	0	0	0	0
	28A	7	30.2	34.5	4.3	4064	1	0	0	1
	28A	8	34.9	35.4	0.5	4064	0	0	0	0
	28A	9	37.1	37.8	0.7	2573	0	0	0	0
	28A	10	38	39.6	1.6	2573	0	0	0	0
	28A	11	41.5	46.6	5.1	2573	0	0	1	1
	28A	12	47	56.4	9.4	2573	0	0	0	0
	28A	13	56.9	57.7	0.8	2573	0	0	0	0
	28A	14	58	59.7	1.7	2573	1	0	0	1
	28A	15	60.2	62.4	2.2	2573	0	0	0	0
	28A	16	62.7	68.7	6	2573	0	0	0	0
	28A	17	68.9	69.7	0.8	2573	0	0	0	0
	28A	18	70	72	2	2573	0	0	0	0
2013	28A	1	9.5	14	4.5	3358	0	0	1	1
	28A	2	14.5	16.6	2.1	3358	0	0	0	0
	28A	3	20.5	23.8	3.3	3358	0	0	0	0
	28A	4	24	25.6	1.6	3358	0	0	0	0
	28A	5	26.2	27.8	1.6	3358	0	0	0	0
	28A	6	28.1	28.7	0.6	3358	0	0	0	0
	28A	7	30.2	34.5	4.3	3358	0	0	0	0
	28A	8	34.9	35.4	0.5	3358	0	0	0	0
	28A	9	37.1	37.8	0.7	2387	0	0	0	0
	28A	10	38	39.6	1.6	2387	0	0	0	0
	28A	11	41.5	46.6	5.1	2387	0	0	0	0
	28A	12	47	56.4	9.4	2387	0	1	1	2
	28A	13	56.9	57.7	0.8	2387	0	0	0	0
	28A	14	58	59.7	1.7	2387	0	0	0	0
	28A	15	60.2	62.4	2.2	2387	0	0	0	0
	28A	16	62.7	68.7	6	2387	0	0	0	0
	28A	17	68.9	69.7	0.8	2387	0	0	0	0
	28A	18	70	72	2	2387	0	0	0	0

2014	28A	1	9.5	14	4.5	3888	1	0	1	2
	28A	2	14.5	16.6	2.1	3888	0	0	0	0
	28A	3	20.5	23.8	3.3	3888	0	0	0	0
	28A	4	24	25.6	1.6	3888	0	0	0	0
	28A	5	26.2	27.8	1.6	3888	0	0	0	0
	28A	6	28.1	28.7	0.6	3888	0	0	0	0
	28A	7	30.2	34.5	4.3	3888	0	0	1	1
	28A	8	34.9	35.4	0.5	3888	0	0	0	0
	28A	9	37.1	37.8	0.7	2489	0	0	0	0
	28A	10	38	39.6	1.6	2489	0	0	1	1
	28A	11	41.5	46.6	5.1	2489	0	0	0	0
	28A	12	47	56.4	9.4	2489	1	0	2	3
	28A	13	56.9	57.7	0.8	2489	0	0	0	0
	28A	14	58	59.7	1.7	2489	0	0	0	0
	28A	15	60.2	62.4	2.2	2489	0	0	0	0
	28A	16	62.7	68.7	6	2489	0	0	0	0
	28A	17	68.9	69.7	0.8	2489	1	0	0	1
	28A	18	70	72	2	2489	0	0	0	0
2015	28A	1	9.5	14	4.5	4288	0	0	1	1
	28A	2	14.5	16.6	2.1	4288	0	0	1	1
	28A	3	20.5	23.8	3.3	4288	0	2	1	3
	28A	4	24	25.6	1.6	4288	0	0	0	0
	28A	5	26.2	27.8	1.6	4288	0	0	0	0
	28A	6	28.1	28.7	0.6	4288	0	0	0	0
	28A	7	30.2	34.5	4.3	4288	0	0	1	1
	28A	8	34.9	35.4	0.5	4288	0	0	0	0
	28A	9	37.1	37.8	0.7	2540	0	0	0	0
	28A	10	38	39.6	1.6	2540	0	0	0	0
	28A	11	41.5	46.6	5.1	2540	1	2	0	3
	28A	12	47	56.4	9.4	2540	1	0	0	1
	28A	13	56.9	57.7	0.8	2540	0	0	0	0
	28A	14	58	59.7	1.7	2540	0	0	0	0
	28A	15	60.2	62.4	2.2	2540	0	0	0	0
	28A	16	62.7	68.7	6	2540	0	0	0	0
	28A	17	68.9	69.7	0.8	2540	0	0	0	0
	28A	18	70	72	2	2540	0	0	0	0
2016	28A	1	9.5	14	4.5	4503	0	0	0	0
	28A	2	14.5	16.6	2.1	4503	0	0	0	0
	28A	3	20.5	23.8	3.3	4503	0	0	0	0
	28A	4	24	25.6	1.6	4503	0	0	0	0
	28A	5	26.2	27.8	1.6	4503	1	0	0	1
	28A	6	28.1	28.7	0.6	4503	0	0	0	0
	28A	7	30.2	34.5	4.3	4503	0	0	0	0
	28A	8	34.9	35.4	0.5	4503	0	0	0	0
	28A	9	37.1	37.8	0.7	2666	0	0	0	0
	28A	10	38	39.6	1.6	2666	0	0	0	0
	28A	11	41.5	46.6	5.1	2666	1	0	1	2
	28A	12	47	56.4	9.4	2666	0	0	1	1
	28A	13	56.9	57.7	0.8	2666	0	0	0	0
	28A	14	58	59.7	1.7	2666	0	0	0	0
	28A	15	60.2	62.4	2.2	2666	0	0	0	0
	28A	16	62.7	68.7	6	2666	0	0	0	0
	28A	17	68.9	69.7	0.8	2666	0	0	0	0
	28A	18	70	72	2	2666	0	0	0	0
2017	28A	1	9.5	14	4.5	4821	0	0	0	0
	28A	2	14.5	16.6	2.1	4821	0	0	0	0
	28A	3	20.5	23.8	3.3	4821	0	0	0	0
	28A	4	24	25.6	1.6	4821	0	0	0	0

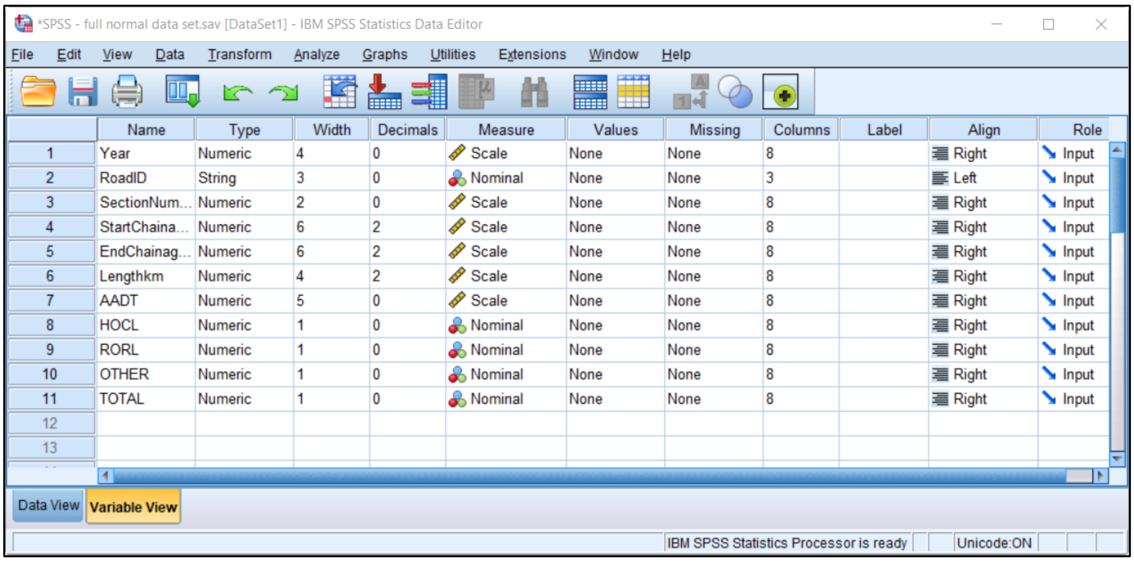
	28A	5	26.2	27.8	1.6	4821	0	0	0	0
	28A	6	28.1	28.7	0.6	4821	0	0	0	0
	28A	7	30.2	34.5	4.3	4821	0	0	0	0
	28A	8	34.9	35.4	0.5	4821	0	0	0	0
	28A	9	37.1	37.8	0.7	2827	0	0	0	0
	28A	10	38	39.6	1.6	2827	0	0	0	0
	28A	11	41.5	46.6	5.1	2827	0	0	0	0
	28A	12	47	56.4	9.4	2827	1	0	1	2
	28A	13	56.9	57.7	0.8	2827	0	0	0	0
	28A	14	58	59.7	1.7	2827	0	0	0	0
	28A	15	60.2	62.4	2.2	2827	0	0	0	0
	28A	16	62.7	68.7	6	2827	0	0	0	0
	28A	17	68.9	69.7	0.8	2827	0	0	0	0
	28A	18	70	72	2	2827	0	0	0	0
2012	42A	1	3.9	5.7	1.8	9097	0	0	0	0
	42A	2	6	7.4	1.4	8410	0	0	0	0
	42A	3	8.3	8.8	0.5	8410	0	0	0	0
	42A	4	9	11.1	2.1	8410	0	0	3	3
	42A	5	11.3	11.7	0.4	8410	0	0	0	0
	42A	6	12	13.6	1.6	8410	1	0	1	2
	42A	7	16.5	17	0.5	3409	0	0	0	0
	42A	8	18.2	18.7	0.5	3409	0	0	0	0
	42A	9	19.1	19.8	0.7	3409	0	0	0	0
	42A	10	20.1	21.4	1.3	3409	0	0	0	0
	42A	11	25.1	29.3	4.2	3409	0	0	0	0
	42A	12	29.5	32.3	2.8	3409	0	0	0	0
	42A	13	32.7	36.9	4.2	2743	0	0	0	0
	42A	14	37.1	38.5	1.4	2743	0	0	0	0
	42A	15	38.7	41.3	2.6	2743	0	0	0	0
	42A	16	41.5	43.6	2.1	2743	0	0	1	1
	42A	17	43.7	46.6	2.9	2743	1	0	0	1
	42A	18	46.8	47.2	0.4	2743	0	0	0	0
	42A	19	47.4	52.7	5.3	2743	0	0	1	1
	42A	20	55.6	57.9	2.3	4183	0	0	0	0
	42A	21	58.1	68.9	10.8	3581	0	0	1	1
	42A	22	69.8	70.4	0.6	3581	0	0	0	0
	42A	23	72.4	74.7	2.3	2755	0	0	1	1
	42A	24	75	75.4	0.4	2755	0	0	0	0
	42A	25	77.2	80.5	3.3	2755	0	0	0	0
	42A	26	80.9	85.3	4.4	2755	0	0	0	0
2013	42A	1	3.9	5.7	1.8	9622	0	0	0	0
	42A	2	6	7.4	1.4	7757	0	0	0	0
	42A	3	8.3	8.8	0.5	7757	0	0	0	0
	42A	4	9	11.1	2.1	7757	0	0	0	0
	42A	5	11.3	11.7	0.4	7757	0	0	0	0
	42A	6	12	13.6	1.6	7757	1	0	1	2
	42A	7	16.5	17	0.5	3458	0	0	0	0
	42A	8	18.2	18.7	0.5	3458	0	0	0	0
	42A	9	19.1	19.8	0.7	3458	0	0	1	1
	42A	10	20.1	21.4	1.3	3458	0	0	0	0
	42A	11	25.1	29.3	4.2	3458	0	0	0	0
	42A	12	29.5	32.3	2.8	3458	0	0	0	0
	42A	13	32.7	36.9	4.2	2786	0	0	0	0
	42A	14	37.1	38.5	1.4	2786	0	0	1	1
	42A	15	38.7	41.3	2.6	2786	0	0	0	0
	42A	16	41.5	43.6	2.1	2786	0	0	0	0
	42A	17	43.7	46.6	2.9	2786	0	0	0	0
	42A	18	46.8	47.2	0.4	2786	0	0	0	0

	42A	19	47.4	52.7	5.3	2786	0	0	1	1
	42A	20	55.6	57.9	2.3	3925	0	0	1	1
	42A	21	58.1	68.9	10.8	3925	2	0	2	4
	42A	22	69.8	70.4	0.6	3527	0	0	0	0
	42A	23	72.4	74.7	2.3	2720	0	0	0	0
	42A	24	75	75.4	0.4	2720	0	0	0	0
	42A	25	77.2	80.5	3.3	2720	0	0	1	1
	42A	26	80.9	85.3	4.4	2720	0	0	1	1
2014	42A	1	3.9	5.7	1.8	9621	0	0	0	0
	42A	2	6	7.4	1.4	7757	1	0	0	1
	42A	3	8.3	8.8	0.5	7757	0	0	0	0
	42A	4	9	11.1	2.1	7757	0	0	1	1
	42A	5	11.3	11.7	0.4	7757	0	0	0	0
	42A	6	12	13.6	1.6	7757	0	0	1	1
	42A	7	16.5	17	0.5	3458	0	0	0	0
	42A	8	18.2	18.7	0.5	3458	0	0	0	0
	42A	9	19.1	19.8	0.7	3458	0	0	1	1
	42A	10	20.1	21.4	1.3	3458	0	0	3	3
	42A	11	25.1	29.3	4.2	3458	0	0	0	0
	42A	12	29.5	32.3	2.8	3458	0	0	1	1
	42A	13	32.7	36.9	4.2	2786	0	0	1	1
	42A	14	37.1	38.5	1.4	2786	0	0	0	0
	42A	15	38.7	41.3	2.6	2786	0	0	0	0
	42A	16	41.5	43.6	2.1	2786	0	0	0	0
	42A	17	43.7	46.6	2.9	2786	0	0	0	0
	42A	18	46.8	47.2	0.4	2786	0	0	0	0
	42A	19	47.4	52.7	5.3	2786	0	0	0	0
	42A	20	55.6	57.9	2.3	3925	0	0	1	1
	42A	21	58.1	68.9	10.8	3925	0	0	1	1
	42A	22	69.8	70.4	0.6	3527	0	0	0	0
	42A	23	72.4	74.7	2.3	3812	0	0	1	1
	42A	24	75	75.4	0.4	3812	0	0	0	0
	42A	25	77.2	80.5	3.3	3812	0	0	0	0
	42A	26	80.9	85.3	4.4	3812	1	0	0	1
2015	42A	1	3.9	5.7	1.8	9713	0	0	1	1
	42A	2	6	7.4	1.4	8596	0	1	0	1
	42A	3	8.3	8.8	0.5	8596	0	0	0	0
	42A	4	9	11.1	2.1	8596	0	0	1	1
	42A	5	11.3	11.7	0.4	8596	0	0	0	0
	42A	6	12	13.6	1.6	8596	0	0	0	0
	42A	7	16.5	17	0.5	3590	0	0	0	0
	42A	8	18.2	18.7	0.5	3590	0	0	0	0
	42A	9	19.1	19.8	0.7	3590	0	0	0	0
	42A	10	20.1	21.4	1.3	3590	0	0	0	0
	42A	11	25.1	29.3	4.2	3590	0	0	0	0
	42A	12	29.5	32.3	2.8	3590	0	0	1	1
	42A	13	32.7	36.9	4.2	2974	0	0	0	0
	42A	14	37.1	38.5	1.4	2974	0	0	0	0
	42A	15	38.7	41.3	2.6	2974	0	0	0	0
	42A	16	41.5	43.6	2.1	2974	1	0	0	1
	42A	17	43.8	46.6	2.8	2974	0	0	1	1
	42A	18	46.8	47.2	0.4	2974	0	0	0	0
	42A	19	47.4	52.7	5.3	2974	0	0	0	0
	42A	20	55.6	57.9	2.3	4456	0	0	0	0
	42A	21	58.1	68.9	10.8	4456	0	0	0	0
	42A	22	69.8	70.4	0.6	3798	0	0	1	1
	42A	23	72.4	74.7	2.3	2835	0	0	0	0
	42A	24	75	75.4	0.4	2835	0	0	0	0

	42A	25	77.2	80.5	3.3	2835	0	0	2	2
	42A	26	80.9	85.3	4.4	2835	1	0	1	2
2016	42A	1	3.9	5.7	1.8	9713	0	0	0	0
	42A	2	6	7.4	1.4	9127	0	0	0	0
	42A	3	8.3	8.8	0.5	9127	0	0	0	0
	42A	4	9	11.1	2.1	9127	0	0	0	0
	42A	5	11.3	11.7	0.4	9127	0	0	0	0
	42A	6	12	13.6	1.6	9127	1	0	1	2
	42A	7	16.5	17	0.5	3590	0	0	0	0
	42A	8	18.2	18.7	0.5	3590	0	0	0	0
	42A	9	19.1	19.8	0.7	3590	0	0	0	0
	42A	10	20.1	21.4	1.3	3590	0	1	0	1
	42A	11	25.1	29.3	4.2	3590	0	0	0	0
	42A	12	29.5	32.3	2.8	3590	0	0	0	0
	42A	13	32.7	36.9	4.2	2974	1	0	0	1
	42A	14	37.1	38.5	1.4	2974	0	0	0	0
	42A	15	38.7	41.3	2.6	2974	0	0	0	0
	42A	16	41.5	43.6	2.1	2974	0	0	0	0
	42A	17	43.7	46.6	2.9	2974	0	0	0	0
	42A	18	46.8	47.2	0.4	2974	0	0	0	0
	42A	19	47.4	52.7	5.3	2974	0	0	0	0
	42A	20	55.6	57.9	2.3	4456	0	0	0	0
	42A	21	58.1	68.9	10.8	4456	1	0	1	2
	42A	22	69.8	70.4	0.6	3798	0	0	0	0
	42A	23	72.4	74.7	2.3	2835	0	1	1	2
	42A	24	75	75.4	0.4	2835	0	0	0	0
	42A	25	77.2	80.5	3.3	2835	0	0	1	1
	42A	26	80.9	85.3	4.4	2835	0	0	0	0
2017	42A	1	3.9	5.7	1.8	10530	0	0	0	0
	42A	2	6	7.4	1.4	9288	0	0	0	0
	42A	3	8.3	8.8	0.5	9288	0	0	0	0
	42A	4	9	11.1	2.1	9288	0	0	0	0
	42A	5	11.3	11.7	0.4	9288	0	0	0	0
	42A	6	12	13.6	1.6	9288	0	0	0	0
	42A	7	16.5	17	0.5	3770	0	0	0	0
	42A	8	18.2	18.7	0.5	3770	0	0	0	0
	42A	9	19.1	19.8	0.7	3770	0	0	0	0
	42A	10	20.1	21.4	1.3	3770	0	1	0	1
	42A	11	25.1	29.3	4.2	3770	0	0	0	0
	42A	12	29.5	32.3	2.8	3770	0	0	0	0
	42A	13	32.7	36.9	4.2	2981	0	0	0	0
	42A	14	37.1	38.5	1.4	2981	0	0	0	0
	42A	15	38.7	41.3	2.6	2981	0	0	0	0
	42A	16	41.5	43.6	2.1	2981	1	0	0	1
	42A	17	43.7	46.6	2.9	2981	0	0	0	0
	42A	18	46.8	47.2	0.4	2981	0	0	0	0
	42A	19	47.4	52.7	5.3	2981	0	0	0	0
	42A	20	55.6	57.9	2.3	4754	1	0	0	1
	42A	21	58.1	68.9	10.8	4754	0	0	0	0
	42A	22	69.8	70.4	0.6	3798	0	0	0	0
	42A	23	72.4	74.7	2.3	3061	0	0	1	1
	42A	24	75	75.4	0.4	3061	0	0	0	0
	42A	25	77.2	80.5	3.3	3061	1	0	0	1
	42A	26	80.9	85.3	4.4	3061	0	0	1	1

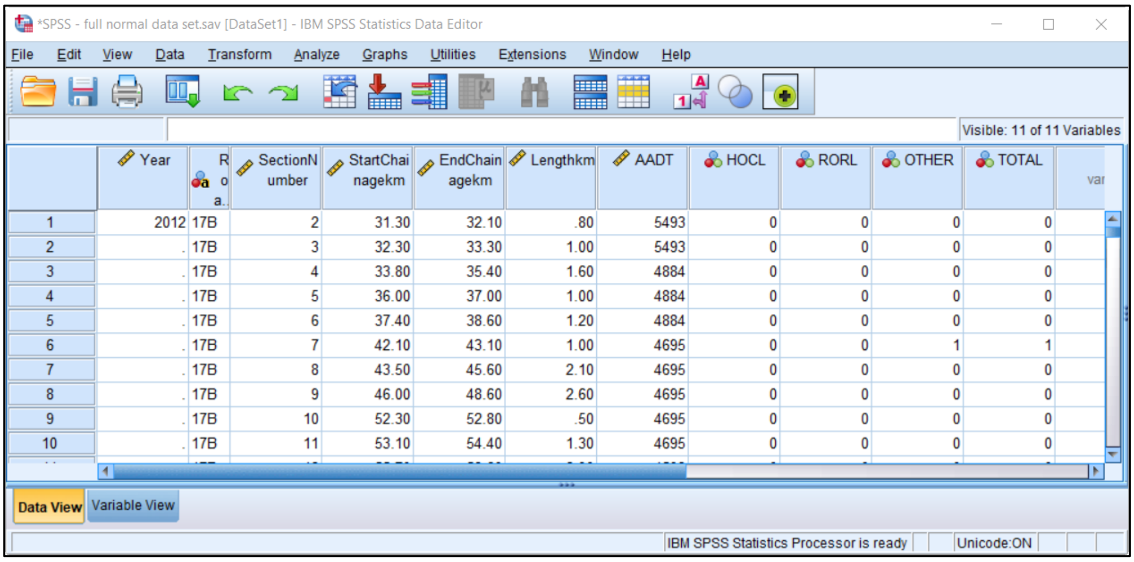
Appendix H. – SPSS Generalised Linear Models Analysis setup

H.1 Data imported – Variable view



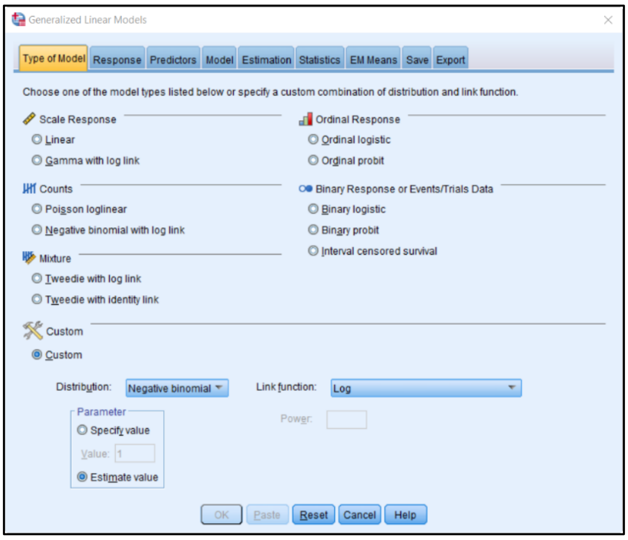
	Name	Type	Width	Decimals	Measure	Values	Missing	Columns	Label	Align	Role
1	Year	Numeric	4	0	Scale	None	None	8		Right	Input
2	RoadID	String	3	0	Nominal	None	None	3		Left	Input
3	SectionNum...	Numeric	2	0	Scale	None	None	8		Right	Input
4	StartChaina...	Numeric	6	2	Scale	None	None	8		Right	Input
5	EndChainag...	Numeric	6	2	Scale	None	None	8		Right	Input
6	Lengthkm	Numeric	4	2	Scale	None	None	8		Right	Input
7	AADT	Numeric	5	0	Scale	None	None	8		Right	Input
8	HOCL	Numeric	1	0	Nominal	None	None	8		Right	Input
9	RORL	Numeric	1	0	Nominal	None	None	8		Right	Input
10	OTHER	Numeric	1	0	Nominal	None	None	8		Right	Input
11	TOTAL	Numeric	1	0	Nominal	None	None	8		Right	Input
12											
13											

H.2 Data imported – Data view

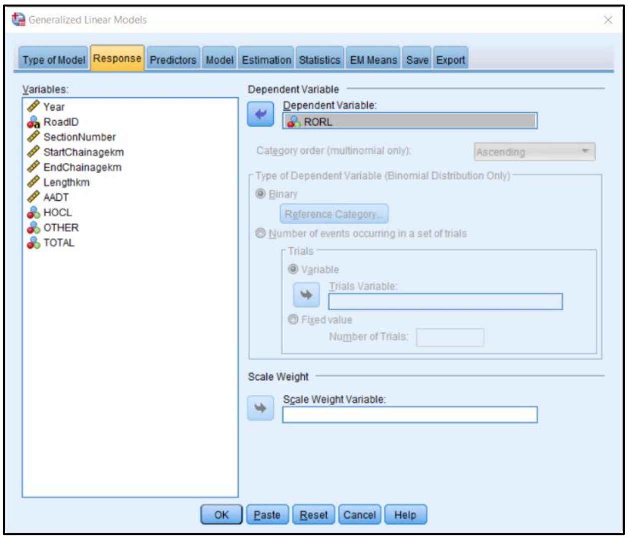


	Year	Roa..	SectionNumber	StartChainagekm	EndChainagekm	Lengthkm	AADT	HOCL	RORL	OTHER	TOTAL
1	2012	17B	2	31.30	32.10	.80	5493	0	0	0	0
2	.	17B	3	32.30	33.30	1.00	5493	0	0	0	0
3	.	17B	4	33.80	35.40	1.60	4884	0	0	0	0
4	.	17B	5	36.00	37.00	1.00	4884	0	0	0	0
5	.	17B	6	37.40	38.60	1.20	4884	0	0	0	0
6	.	17B	7	42.10	43.10	1.00	4695	0	0	1	1
7	.	17B	8	43.50	45.60	2.10	4695	0	0	0	0
8	.	17B	9	46.00	48.60	2.60	4695	0	0	0	0
9	.	17B	10	52.30	52.80	.50	4695	0	0	0	0
10	.	17B	11	53.10	54.40	1.30	4695	0	0	0	0

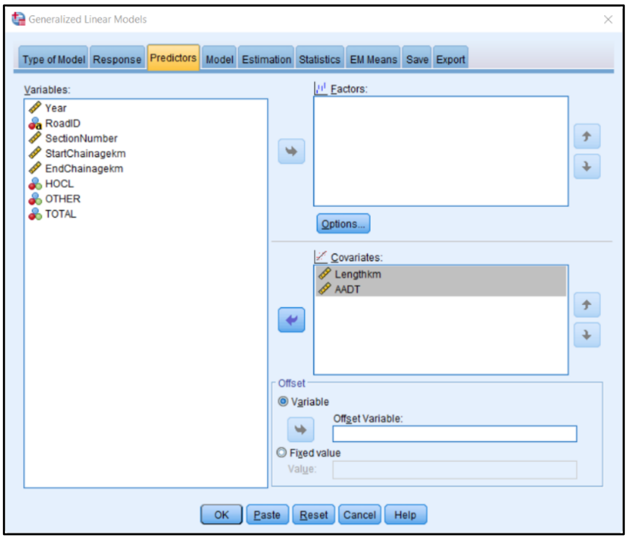
H.3 Generalized Linear Model setup – Type of mode (distribution and link function)



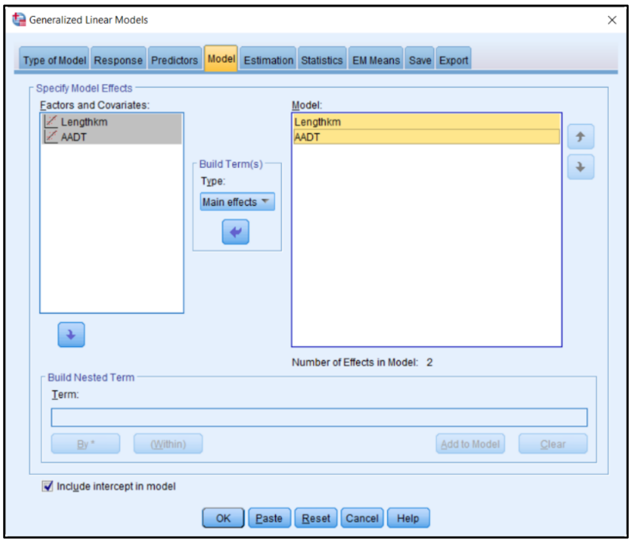
H.4 Generalized Linear Model setup – Dependent variables



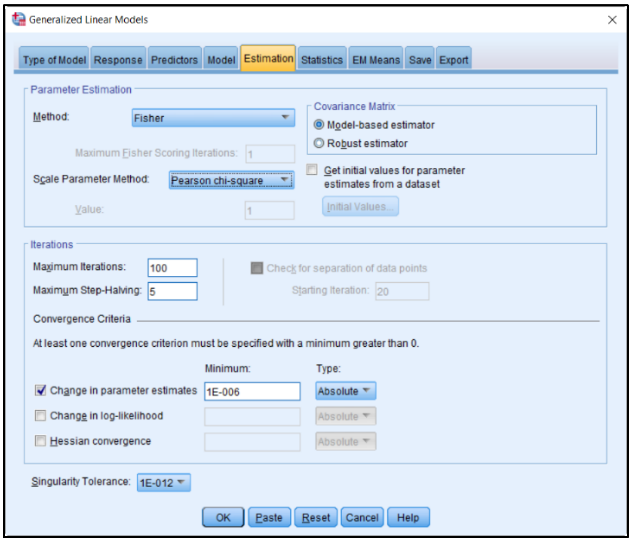
H.5 Generalized Linear Model setup – Independent variables



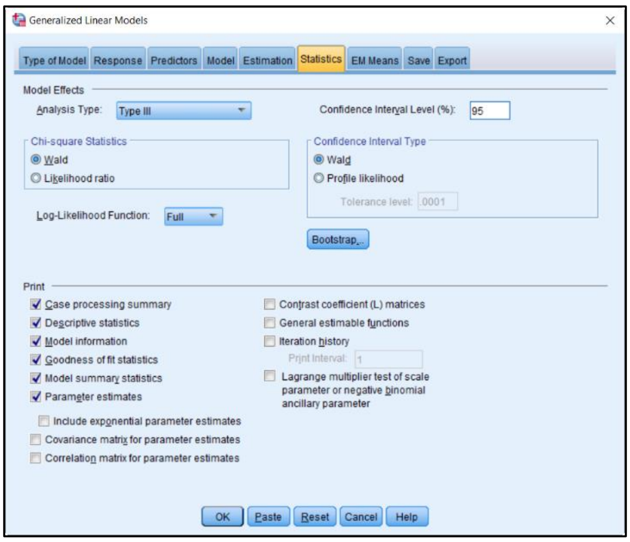
H.6 Generalized Linear Model setup – Model effects



H.7 Generalized Linear Model setup – Parameter estimation



H.8 Generalized Linear Model setup – Model statistics and output



Appendix I. – SPSS analysis output

I.1 HOCL SPSS analysis output

```
* Generalized Linear Models.
GENLIN HOCL WITH Length(km) AADT
  /MODEL Length(km) AADT INTERCEPT=YES
 DISTRIBUTION=NEGBIN(MLE) LINK=LOG
  /CRITERIA METHOD=FISHER SCALE=PEARSON COVB=MODEL MAXITERATIONS=100
MAXSTEPHALVING=5
    PCONVERGE=1E-006(ABSOLUTE) SINGULAR=1E-012 ANALYSISTYPE=3(WALD)
CILEVEL=95 CITYPE=WALD
    LIKELIHOOD=FULL
  /MISSING CLASSMISSING=EXCLUDE
  /PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION.
```

Model Information

Dependent Variable	HOCL
Probability Distribution	Negative binomial (MLE)
Link Function	Log

Case Processing Summary

	N	Percent
Included	570	100.0%
Excluded	0	0.0%
Total	570	100.0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	HOCL	570	0	2	.09	.305
Covariate	Length(km)	570	.30	10.80	2.3480	1.98589
	AADT	570	2387	10530	4262.16	1667.627

Goodness of Fit[a]			
	Value	df	Value/df
Deviance	217.219	566	.384
Scaled Deviance	224.266	566	
Pearson Chi-Square	548.213	566	.969
Scaled Pearson Chi-Square	566.000	566	
Log Likelihood[b,c]	-159.141		
Adjusted Log Likelihood[d]	-164.304		
Akaike's Information Criterion (AIC)	326.282		
Finite Sample Corrected AIC (AICC)	326.352		
Bayesian Information Criterion (BIC)	343.664		
Consistent AIC (CAIC)	347.664		

Dependent Variable: HOCL
Model: (Intercept), Length(km), AADT
a. Information criteria are in smaller-is-better form.
b. The full log likelihood function is displayed and used in computing information criteria.
c. The log likelihood is based on a scale parameter fixed at 1.
d. The adjusted log likelihood is based on an estimated scale parameter and is used in the model fitting omnibus test.

Omnibus Test[a]		
Likelihood Ratio Chi-Square	df	Sig.
25.077	2	.000

Dependent Variable: HOCL
Model: (Intercept), Length(km), AADT
a. Compares the fitted model against the intercept-only model.

Tests of Model Effects			
	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	68.174	1	.000
Length(km)	31.235	1	.000
AADT	3.769	1	.052

Dependent Variable: HOCL
Model: (Intercept), Length(km), AADT

Parameter Estimates							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-3.992	.4835	-4.939	-3.044	68.174	1	.000
Length(km)	.279	.0499	.181	.376	31.235	1	.000
AADT	.000	8.2048E-5	-1.528E-6	.000	3.769	1	.052
(Scale)	.969[a]						
(Negative binomial)	.189	.6281	.000	128.386			

Dependent Variable: HOCL

Model: (Intercept), Length(km), AADT

a. Computed based on the Pearson chi-square.

I.2 RORL SPSS analysis output

```
* Generalized Linear Models.
GENLIN RORL WITH Length(km) AADT
  /MODEL Length(km) AADT INTERCEPT=YES
 DISTRIBUTION=NEGBIN(MLE) LINK=LOG
  /CRITERIA  METHOD=FISHER  SCALE=PEARSON  COVB=MODEL  MAXITERATIONS=100
MAXSTEPHALVING=5
    PCONVERGE=1E-006(ABSOLUTE)   SINGULAR=1E-012   ANALYSISTYPE=3(WALD)
CILEVEL=95 CITYPE=WALD
    LIKELIHOOD=FULL
  /MISSING CLASSMISSING=EXCLUDE
  /PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION.
```

Model Information	
Dependent Variable	RORL
Probability Distribution	Negative binomial (MLE)
Link Function	Log

Case Processing Summary		
	N	Percent
Included	570	100.0%
Excluded	0	0.0%
Total	570	100.0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	RORL	570	0	2	.04	.206
Covariate	Length(km)	570	.30	10.80	2.3480	1.98589
	AADT	570	2387	10530	4262.16	1667.627

Goodness of Fit[a]

	Value	df	Value/df
Deviance	118.121	566	.209
Scaled Deviance	118.922	566	
Pearson Chi-Square	562.186	566	.993
Scaled Pearson Chi-Square	566.000	566	
Log Likelihood[b,c]	-86.447		
Adjusted Log Likelihood[d]	-87.033		
Akaike's Information Criterion (AIC)	180.893		
Finite Sample Corrected AIC (AICC)	180.964		
Bayesian Information Criterion (BIC)	198.276		
Consistent AIC (CAIC)	202.276		

Dependent Variable: RORL

Model: (Intercept), Length(km), AADT

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

c. The log likelihood is based on a scale parameter fixed at 1.

d. The adjusted log likelihood is based on an estimated scale parameter and is used in the model fitting omnibus test.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
8.576	2	.014

Dependent Variable: RORL

Model: (Intercept), Length(km), AADT

a. Compares the fitted model against the intercept-only model.

Tests of Model Effects			
	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	23.059	1	.000
Length(km)	9.618	1	.002
AADT	.121	1	.728

Dependent Variable: RORL

Model: (Intercept), Length(km), AADT

Parameter Estimates							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-3.804	.7922	-5.357	-2.252	23.059	1	.000
Length(km)	.245	.0789	.090	.399	9.618	1	.002
AADT	-5.596E-5	.0002	.000	.000	.121	1	.728
(Scale)	.993[a]						
(Negative binomial)	1.000[b]	.	.	.			

Dependent Variable: RORL

Model: (Intercept), Length(km), AADT

a. Computed based on the Pearson chi-square.

b. Hessian matrix singularity is caused by the scale or negative binomial parameter.

I.3 TOTAL SPSS analysis output

```
* Generalized Linear Models.
GENLIN TOTAL WITH Length(km) AADT
  /MODEL Length(km) AADT INTERCEPT=YES
 DISTRIBUTION=NEGBIN(MLE) LINK=LOG
  /CRITERIA METHOD=FISHER SCALE=PEARSON COVB=MODEL MAXITERATIONS=100
MAXSTEPHALVING=5
    PCONVERGE=1E-006(ABSOLUTE) SINGULAR=1E-012 ANALYSISTYPE=3(WALD)
CILEVEL=95 CITYPE=WALD
    LIKELIHOOD=FULL
  /MISSING CLASSMISSING=EXCLUDE
  /PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION.
```

Model Information	
Dependent Variable	TOTAL
Probability Distribution	Negative binomial (MLE)
Link Function	Log

Case Processing Summary		
	N	Percent
Included	570	100.0%
Excluded	0	0.0%
Total	570	100.0%

Continuous Variable Information						
		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	TOTAL	570	0	4	.27	.608
Covariate	Length(km)	570	.30	10.80	2.3480	1.98589
	AADT	570	2387	10530	4262.16	1667.627

Goodness of Fit[a]			
	Value	df	Value/df
Deviance	359.480	566	.635
Scaled Deviance	364.595	566	
Pearson Chi-Square	558.059	566	.986
Scaled Pearson Chi-Square	566.000	566	
Log Likelihood[b,c]	-343.022		
Adjusted Log Likelihood[d]	-347.904		
Akaike's Information Criterion (AIC)	694.045		
Finite Sample Corrected AIC (AICC)	694.116		
Bayesian Information Criterion (BIC)	711.427		
Consistent AIC (CAIC)	715.427		

Dependent Variable: TOTAL

Model: (Intercept), Length(km), AADT

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

c. The log likelihood is based on a scale parameter fixed at 1.

d. The adjusted log likelihood is based on an estimated scale parameter and is used in the model fitting omnibus test.

Omnibus Test[a]		
Likelihood Ratio Chi-Square	df	Sig.
62.290	2	.000

Dependent Variable: TOTAL
Model: (Intercept), Length(km), AADT
a. Compares the fitted model against the intercept-only model.

Tests of Model Effects			
	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	75.247	1	.000
Length(km)	72.880	1	.000
AADT	3.832	1	.050

Dependent Variable: TOTAL
Model: (Intercept), Length(km), AADT

Parameter Estimates							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-2.685	.3096	-3.292	-2.079	75.247	1	.000
Length(km)	.301	.0353	.232	.371	72.880	1	.000
AADT	.000	5.4617E-5	-1.319E-7	.000	3.832	1	.050
(Scale)	.986[a]						
(Negative binomial)	.660	.2914	.278	1.568			

Dependent Variable: TOTAL
Model: (Intercept), Length(km), AADT
a. Computed based on the Pearson chi-square.