

FINAL REPORT

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Evaluation (Years 1 & 2 - 2014/15 - 2015-16)

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Author/s: Michael Luy & Joseph Affum

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Project Title: Bruce Highway Wide Centreline Effectiveness Evaluation
Project Number: 010582

TMR Project Leader

Name: Simon Harrison

Position/Title: Director, Safer Roads

Date: / /

ARRB Project Leader

Name: Joseph Affum

Position/Title: Team Leader, Safe Systems

Date: / /

TMR Quality Manager

Name: N/A

Position/Title:

Date: / /

ARRB Quality Manager

Name: Chris Jurewicz

Position/Title: Principal research engineer

Date: 13 / 09 / 2017

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Signature:


(TMR Project Leader)

Date: 6 / 10 / 17

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Position/Title: TMR Agreement Manager

Date: 20 / 10 / 2017

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Position/Title: ARRB Agreement Manager

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SUMMARY

Queensland Department of Transport and Main Roads (TMR) has progressively introduced improvements on the Bruce Highway over the past 10 years to improve its overall safety performance. A wide range of treatments have been installed, including wide centreline treatments (WCLT). The objective of this project was to investigate the effectiveness of WCLT for reducing crashes on the Bruce Highway, especially head-on crashes.

WCLT was installed in 2011 between Cooroy and Curra on the Bruce Highway (roads 10A and 10B). The section suffered from poor vertical and horizontal alignment and high traffic volumes. The risk of head-on crashes was high, especially with the high posted speed limit (100 km/h).

The effectiveness evaluation involved before-and-after studies of fatal and serious injury (FSI) and all injury crashes, occurring between 2007 and 2015 at 15 treatment sites. Property damage-only crashes were excluded from the analysis.

Descriptive statistics and the Empirical Bayes method were used to evaluate the effectiveness of the treatment on straight road sections. Total injury crashes (all crash types), head-on plus cross-centreline crashes (HOCL), and run-off-road-left crashes (RORL) were investigated as likely crash types to be impacted by WCLT.

A number of Safety Performance Functions (SPFs) were generated for Total, HOCL and RORL FSI and injury crashes.

The key findings of the evaluation for straight rural highway sections were reductions of 33% in HOCL injury crashes and 21% for all injury crashes, and positive economic returns with a BCR of 6.4. Effectiveness by crash types are as follows:

Crash type	FSI crash reduction	All injury crash reduction
HOCL	30%	33%
RORL	24%	21%
Total crashes	8%	21%

These findings were in broad agreement with international research. Further investigation with more sites may refine the estimates or provide additional information about the performance of the treatment (e.g. the effects on heavy vehicles).

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CONTENTS

1	INTRODUCTION	1
1.1	Background	1
1.2	Wide Centreline Treatment	1
1.3	Study Objectives	2
2	METHOD	3
2.1	Target Crash Types Considered for the Safety Benefit of WCLT	3
2.2	Assessment of Treatment Effectiveness	3
2.2.1	<i>Descriptive Statistics</i>	4
2.2.2	<i>Empirical Bayes Method</i>	4
2.3	Limitations of Analysis	8
3	SAFETY BENEFIT OF WIDE CENTRELINES	9
3.1	Descriptive Statistics	9
3.2	Empirical Bayes	9
3.2.1	<i>SPF Models</i>	9
3.2.2	<i>AMF Adjusted Models</i>	10
3.2.3	<i>Model Parameters and Effectiveness of WCLT</i>	11
3.3	Cost-benefit Analysis	12
4	DISCUSSION	15
5	SUMMARY AND CONCLUSIONS	16
	REFERENCES	17
APPENDIX A	TREATMENT SITES LIST	18
APPENDIX B	REFERENCE SITES LIST	19
APPENDIX C	FSI CRASHES BY SITE	21
APPENDIX D	ALL INJURY CRASHES BY SITE	23
APPENDIX E	SPF MODELS	25
APPENDIX F	SPF GRAPHS	28

TABLES

Table 2.1:	Data periods for reference and treatment site data	5
Table 3.1:	FSI and all injury crashes and percentage changes for treatment sections (10A and 10B).....	9
Table 3.2:	SPFs selected for HOCL, RORL and Total FSI crashes.....	10
Table 3.3:	SPFs selected for HOCL, RORL and Total all injury crashes	10
Table 3.4:	AMF-adjusted SPF models for HOCL, RORL and Total FSI crashes	11
Table 3.5:	AMF-adjusted SPF models for HOCL, RORL and Total injury crashes	11
Table 3.6:	Calculated parameters for HOCL, RORL, and Total FSI crashes.....	11
Table 3.7:	Treatment effectiveness and percentage reduction of HOCL, RORL and Total FSI crashes.....	12
Table 3.8:	Calculated parameters for HOCL, RORL and Total injury crashes.....	12
Table 3.9:	Treatment effectiveness and percentage reduction of HOCL, RORL and Total injury crashes.....	12
Table 3.10:	Willingness to pay crash costs – 2015 dollar value	13
Table 3.11:	Fatality and Hospitalisation proportions in the before period for HOCL, RORL and Total FSI crashes.....	13
Table 3.12:	Crash severity proportions in the before period for HOCL, RORL and Total injury crashes.....	13
Table 3.13:	BCR calculations for HOCL, RORL and Total FSI crashes	13
Table 3.14:	BCR calculations for HOCL, RORL and Total injury crashes	14

FIGURES

Figure 1.1:	General layout of WCLT.....	2
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1 INTRODUCTION

1.1 Background

Queensland Department of Transport and Main Roads (TMR) has progressively introduced improvements on the Bruce Highway over the past 10 years to improve its overall safety performance.

The treatments installed include, but are not limited to the following:

- wide centreline treatment (WCLT) with or without audio tactile line marking (ATLM)
- painted median (with or without ATLM)
- ATLM only (edge line / centreline)
- wire rope barrier
- turning lanes at intersections
- removal of roadside hazards
- barrier protection
- overtaking lanes
- shoulder widening
- road duplication
- rest areas
- vertical/horizontal realignment
- sideslope improvement.

The collection of data for monitoring and evaluation purposes of these treatments is ongoing.

WCLT was installed over a 35.2 km long section of the Bruce Highway from Cooroy to Curra in June 2011 (TMR roads with ID 10A and 10B). Sites which had no additional safety treatments after WCLT were selected for analysis, leaving a remaining total of 25.3 km. Before-and-after analysis was conducted with data collected from:

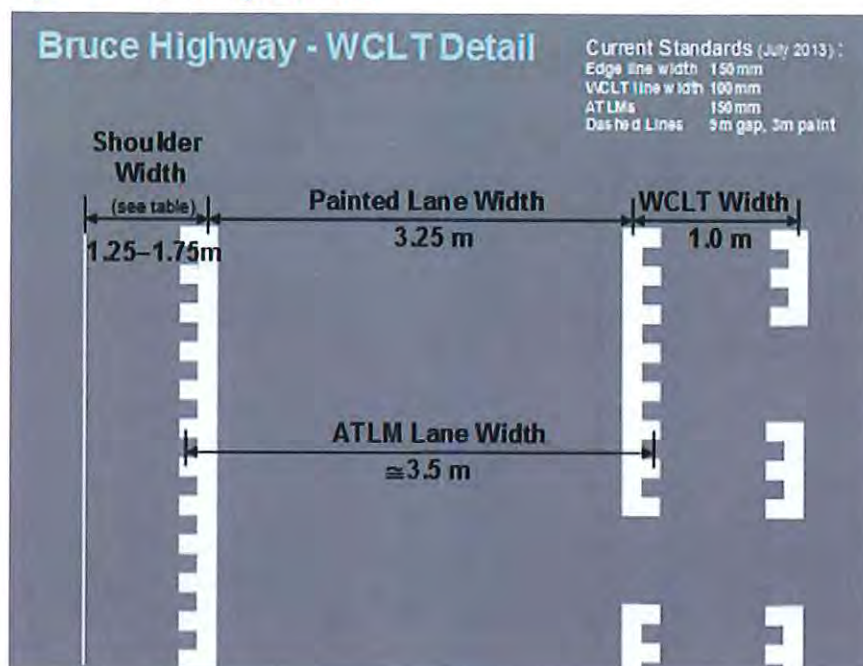
- January 2007 to January 2011 (four years) as the 'before' period
- July 2011 to June 2015 (four years) as the 'after' period.

1.2 Wide Centreline Treatment

WCLT refers to the installation of line markings to increase the separation between opposing traffic by two lines up to 1 metre apart. The general layout is shown in Figure 1.1. Most installations aim to maintain lane widths of at least 3.25 metres; in most cases this involves a reduction in shoulder width. However, the lane widths in the sites analysed were narrower, approximately 3 metres.

This report focusses on the effect of WCLT on fatal and serious (FSI) and all injury crashes (including fatal injuries).

Figure 1.1: General layout of WCLT



Source: Queensland Department of Transport and Main Roads, 2013.

1.3 Study Objectives

The main objective of the study was to determine the effectiveness of WCLT for reducing fatal and serious injury crashes, all injury crashes, targeted crash types, and the resulting financial savings from its implementation. Specific objectives included the following:

- Gauge the magnitude of the impact of WCLT by first using descriptive statistics.
- Use the Empirical Bayes (EB) method to:
 - develop Safety Performance Functions (SPF) for each crash type
 - assess the effectiveness of WCLT for reducing FSIs and all injury crashes for each target crash type.
- Determine the benefit-cost ratio (BCR) of implementing WCLT based on the reduction in FSIs and all injury crashes against the cost of implementing these measures.

This report presents the results of this investigation.

2 METHOD

2.1 Target Crash Types Considered for the Safety Benefit of WCLT

The crash data supplied by TMR included FSI and all injury crashes from 1 January 2007 to 31 August 2016. The full dataset was filtered according to crash severity, year, road ID and Definitions for Coding Accidents (DCA) codes to obtain the relevant crashes for the analysis. Average Annual Daily Traffic (AADT) data for the selected sites for each year was also supplied by the Department.

The main crash types that may be impacted by WCLT are head-on and cross-centreline crashes (HOCL), and run-off-road-left crashes (RORL). The effectiveness of WCLT was assessed for these crash types along with all injury crash types (Total). The DCA codes were:

- 201, 702, and 704 for HOCL
- 701 and 703 for RORL
- All codes for Total injury crashes.

The main reason for investigating crashes coded as 'off carriageway to right' (DCA code 702) and 'right off carriageway into object' (DCA code 704) is that movements on a two-lane highway that resulted in those types of crashes are similar to movements that could result in a head-on crash.

Crashes on curves were not included because the coding for run-off-road crashes on curves does not differentiate between running off the road to the left or right. There were some crashes on curves within the selected sites, but these could not be categorically deemed to be either HOCL or RORL crashes, so they were excluded from the analysis to avoid having to make assumptions. Therefore, the findings of this study can be only directly applied to straight road sections.

2.2 Assessment of Treatment Effectiveness

Treatment effectiveness for any road section can be expressed as:

$$B - A$$

where B is the number of crashes that would have occurred without treatment, and A is the actual number of crashes with treatment.

The evaluation consisted of two approaches:

- descriptive statistics
- the EB method.

The EB method is an established and recommended method for determining the safety effect of road treatments (Elvik 2008). It controls for regression-to-the-mean bias in before-and-after studies, which must be done to maintain the validity of developed models (Persaud & Lyon 2007). The analysis presented in this report followed the method used by Persaud, Retting & Lyon (2004) to investigate the crash reduction effect of centreline rumble strips on two-lane roads. The method properly accounts for regression-to-the-mean bias and 'normalises differences in traffic volume and other factors between the before and after periods' (Persaud et al. 2004).

The key steps were:

- develop SPFs by using the crash data at selected reference sites
- combine the crash estimates derived from these SPFs with before period crash data at the treatment sites to obtain B

- factor and compare the value of B with crash counts in the after period, A , to determine treatment effectiveness.

A more detailed discussion of the EB method is presented in Section 2.2.2.

2.2.1 Descriptive Statistics

The percentage changes in FSI and all injury crashes before and after treatment were determined for both roads 10A and 10B, as well as each treatment site within.

The following were investigated:

- FSI and injury crashes on roads 10A and 10B (crash counts and percentage changes)
- FSI and injury crashes at each treatment site for HOCL, RORL, and all crashes.

2.2.2 Empirical Bayes Method

The EB method increases the precision of crash estimates when the available accident history is short by controlling for regression-to-the-mean bias (Hauer et al. 2002). Sections of road that have a history of high accident counts become prone to this bias. As a result, accident counts on those roads alone will not give a complete picture of the road's safety. The safety of similar roads on the network (in terms of volume, horizontal and vertical geometry, cross-section, etc.) must be used in conjunction with the high-accident-count roads as a control, to yield more precise crash estimates.

The perceived reduction in crashes after a treatment has been installed may not be solely attributable to the treatment itself. Other factors such as changes in posted speed limit and traffic volumes will have an impact on the resulting crash counts after treatment. These are taken into account with the EB method.

The EB method involved:

- site selection and data collection
- development of SPFs
- determination of the accident modification factors
- determination of the estimated expected number of crashes and combining them with actual crash data
- determination of the treatment's effectiveness.

Site selection and data collection

Two types of sites were used in the EB analysis – treatment and reference sites. Treatment sites were sections of the Bruce Highway treated with WCLT. Reference sites were road sections with similar horizontal and vertical geometry, geographical location and cross-section to the treatment sites, but without WCLT.

The treatment sites included 15 sections, ranging in length from 0.31 to 6.03 km, with AADT between 9 000 and 17 300. FSI and injury crashes were filtered for those occurring between 1 January 2007 to 31 December 2010 (before period), and 1 July 2011 to 30 June 2015 (after period). A list of the treatment sites is provided in Appendix A.

The reference sites included 60 road sections on 10A and 10B as well as on other highways (17B, 18B, 22B, 40A, 42A), ranging in length from 0.13 to 19.25 km, with AADT between 3 200 and 17 300. FSI and injury crashes were filtered for those occurring between 2007 and 2013. A brief review of video data of the reference sites confirmed there was no installation of safety improvements at the sites during the analysis period. A full list of the reference sites selected is provided in Appendix B.

Certain sites in the initial study by Whittaker (2012) were upgraded from WCLT to divided carriageways in 2012. These were excluded from the treatment sites in the EB analysis following a check of the video data (sites C to H omitted in Appendix A, which are segments 3 to 8 in Appendix B). Their crash data from 2007–2010 which predated the upgrade was included in the reference site data.

Safety performance functions (SPFs)

A SPF is a mathematical model that relates the expected crash frequency to specific road characteristics, based on collected data. It averages the safety of similar road entities, and when combined with the accident counts from the treatment sites removes regression-to-the-mean bias (Hauer et al. 2002).

Details of the data periods for the reference and treatment sites used are shown in Table 2.1. The crash data collected at the treatment sites during the before period was also used in the reference crash data for SPF development, because no WCLT had yet been applied.

Table 2.1: Data periods for reference and treatment site data

Site	Site type	Reference data set period (with no WCLT)	Treatment data set periods (before, after)
10A	Reference/treatment	2007 – 2010	2007 – 2010, mid 2011 – mid 2015
10B	Reference/treatment	2007 – 2010	2007 – 2010, mid 2011 – mid 2015
17B	Reference	2007 - 2013	-
18B	Reference	2007 - 2013	-
22B	Reference	2007 - 2013	-
40A	Reference	2007 - 2013	-
42A	Reference	2007 - 2013	-

A number of different models were generated and compared. The main regressors were AADT and length of the road section, with crash frequency used as the dependent variable. The explored model types included:

- negative binomial distributions with estimated and fixed over-dispersion parameters
- non-linear models with exponential terms
- multivariate linear models.

Negative binomial distributions are a type of Generalised Linear Model (GLM). It consists of three components: a random component, a linear function of regressors, and a linearizing link function (Fox 2008). The link function used in this project was a log link, which inverts to become an exponential function with the exponent being a linear function of the regressors. This takes the form:

$$\text{Crashes per year} = e^{(\alpha + \beta_1 x_1 + \beta_2 x_2 + \dots)}$$

where α is a constant and β_1 to β_n are the coefficients of the regressors x_1 to x_n . These coefficients were estimated by using the reference site data only.

The model should return 0 expected crashes when there is no traffic, and so AADT must sit outside the exponential function. By regressing the crashes per year with the natural logarithm of the AADT data, the SPF model can be manipulated as follows:

$$\begin{aligned}
\text{Crashes per year} &= e^{(\alpha + \beta_1 \times \ln(AADT) + \beta_2 \times \text{Length})} \\
&= e^\alpha \times e^{\beta_1 \times \ln(AADT)} \times e^{\beta_2 \times \text{Length}} \\
&= e^\alpha \times e^{\ln(AADT^{\beta_1})} \times e^{\beta_2 \times \text{Length}} \\
&= e^\alpha \times AADT^{\beta_1} \times e^{\beta_2 \times \text{Length}} \\
&= AADT^{\beta_1} \times e^{(\alpha + \beta_2 \times \text{Length})}
\end{aligned}$$

SPF models of similar form with AADT raised to an estimated power, with the other explanatory variables in the linear function have been used in EB evaluations by Patel, Council & Griffith (2007).

The negative binomial distribution of the data was fitted using the Maximum Likelihood Estimation (MLE) method in SPSS Statistics version 22. It has been shown to fit accident counts more accurately than Poisson distributions (Hauer et al. 2002). The Poisson distribution relies on the assumption that the data variance equals the mean. When this is not the case the data is said to be 'over-dispersed', and an over-dispersion parameter, k , is estimated. The over-dispersion parameter was estimated for several of the models. This parameter was fixed to 1 in others, so that the fit could be compared.

Non-linear models reported in Patel et al. (2007) and Elvik (2008), as well as multivariate models, were also fitted to the data for comparison.

Accident modification factors

The posted speed limit on sections 10A and 10B of the Bruce Highway was reduced from 100 km/h to 90 km/h in December 2008. The data for the reference SPFs came mostly from highways with a 100 km/h speed limit. Thus, the SPF estimates for the years after 2008 were adjusted with accident modifications factors (AMFs) to allow for the expected effect. Lower posted speed limits have been shown to reduce the number of crashes on a road, and this should be accounted for in the SPF estimates.

Nilsson (1981) suggested power relationships between traffic speed and road trauma. The powers proposed by Nilsson were refined by Elvik et al. (2004) through meta-analysis of 98 evaluation studies relating road trauma to speed changes.

The power model relating FSI and injury crashes to changes in mean speed is:

$$Y_1 = \left(\frac{V_1}{V_0} \right)^{\text{Exponent}} Y_0$$

where Y_0 and Y_1 are the number of crashes before and after the change in mean speed respectively. The exponent in the model is dependent on the severity of the crashes considered. V_0 and V_1 are the mean speeds before and after the change (Cameron & Elvik 2008). The resulting coefficient in front of Y_0 is taken as the AMF.

Elvik et al. (2004) developed the following relationship between changes in posted speed limit and vehicle mean speed:

$$y = 0.2525x - 1.2204$$

where x is the change in posted speed limit, and y is the change in mean speed. The values from this equation are used to calculate V_0 and V_1 in the power model.

Estimating crash numbers at treatment sites

Solely using treatment site crash counts may give higher than average estimates of reduction (Hauer et al. 2002). This is due to the regression to mean effect, where treatment sites show increased crash counts due to chance, not the actual high risk. This problem is particularly evident when dealing with small crash numbers. The before period treatment crash counts were combined with the SPF estimates of crashes at those sites using weighting factors.

The overall unfactored estimate, m , which uses both crash counts and SPF estimates is given by:

$$m = w_1 x + w_2 P_B$$

where P_B is the sum of the SPF estimated crashes at all the treatment sites in the before period, and x is the sum of the actual crashes at those sites in the before period. Weights w_1 and w_2 are given by:

$$w_1 = \frac{P_B}{P_B + \frac{1}{k}}$$

and

$$w_2 = \frac{1}{k(P_B + \frac{1}{k})}$$

where k is the over-dispersion factor from the SPF.

B , the expected after period crashes at treatment sites had no treatment been applied, is given by:

$$B = m \times \text{reduction factor}$$

The reduction factor accounts for the changes in AADT between before and after periods, as well as any difference in duration of the data analysed. Only small changes in AADT were observed between the periods. The reduction factor is given by:

$$\text{Reduction factor} = \frac{P_A}{P_B}$$

where P_A is the sum of SPF estimates at the treatment sites in the after period.

Effectiveness of treatment

An estimate of the safety effectiveness, λ , could be obtained by:

$$\lambda = \frac{A}{B}$$

which is simply a ratio of the actual number of crashes at a site (A) to the estimated crashes had no treatment been applied, B (Patel et al. 2007).

This ratio, even with unbiased estimators A and B , is biased as discussed by Hauer in 1997 (Patel et al. 2007). In contrast, an unbiased measure is the index of effectiveness, θ , given by:

$$\theta = \frac{\frac{A}{B}}{1 + \left[\frac{\text{Var}(\tau)}{B^2} \right]}$$

where $\text{Var}(\tau)$ is the sum of variances of after period estimates at all treatment sites (Patel et al. 2007). The sites considered for $\text{Var}(\tau)$ were the individual sites (classified by Crash list ID) listed in Appendix A.

The standard deviation of θ is given by:

$$SD.\theta = \left[\frac{\theta^2 \left\{ \left[\frac{Var(A)}{A^2} \right] + \left[\frac{Var(B)}{B^2} \right] \right\}}{\left[1 + \left[\frac{Var(B)}{B^2} \right] \right]^2} \right]^{0.5}$$

The variances of A and B are given by the square of their standard deviations.

The percentage reduction in crashes is related to θ , and is given by:

$$\text{Percentage reduction (\%)} = 100 \times (1 - \theta)$$

2.3 Limitations of Analysis

The number of reference sites with similar characteristics to the treatment sites was limited. AADT was a major attribute that restricted the number of available sites, along with location, sufficient data, and having no safety treatments installed. The selection of the reference sites has a significant impact on the treatment effectiveness determined by the EB method. It was important therefore to select appropriate reference sites and not relax the criteria to include sites which were too dissimilar. Future research should aim to find even more reference sites to give added robustness to the information regarding similar entities.

The coding for crashes on curves does not differentiate between those running off the road to the left, or to the right. These were therefore excluded from the analysis, as they could have been HOCL or RORL crashes. Only crashes on straight highway sections were included in the analysis.

The earliest data used in the analysis dated back to 2007. Many changes may have been made to the roadside condition at the reference and treatment sites. Roadside condition and hazards would be a large determining factor in the severity of run-off-road crashes. The findings determined for the reduction in RORL crashes in this analysis should be interpreted with this in mind.

3 SAFETY BENEFIT OF WIDE CENTRELINES

3.1 Descriptive Statistics

The numbers and percentage changes in FSI and all injury crashes at the treatment sites are shown in Table 3.1. The Table shows the results not adjusted for the effect of the speed limit reduction, changes in AADT, and may be a subject to regression to the mean. After the implementation of WCLT there were reductions in FSI and all injury crashes of 9% and 24% respectively.

Table 3.1: FSI and all injury crashes and percentage changes for treatment sections (10A and 10B)

Crash type	Fatal			Hospitalisation			FSI crashes			All injury crashes		
	Before	After	Per cent change	Before	After	Per cent change	Before	After	Per cent change	Before	After	Per cent change
HOCL	1	2	100%	8	5	-37.5%	9	7	-22.2%	15	10	-33.3%
RORL	0	0	N/A	7	4	-42.9%	7	4	-42.9%	14	7	-50.0%
Total	5	3	-40%	28	27	-3.6%	33	30	-9.1%	72	55	-23.6%

There were overall reductions in FSI crashes for HOCL (22.2%), RORL (42.9%) and total crashes (9.1%) between the before and after period. Changes in FSI crashes at the treatment sites between the before and after periods vary. The number of HOCL, RORL and total FSI crashes by site, as well as percentage changes, are presented in Appendix C.

Between the before and after period there were overall reductions in all injury crashes for HOCL (33.3%), RORL (50%), and total crashes (23.6%). The changes were not consistent between sites or in severity. All injury crashes by site, as well as percentage changes for the three crash types, are shown in Appendix D.

Three sites – K, L, and P – recorded significantly higher FSI and all injury crashes in the after period. The small crash numbers observed at these sites were prone to natural statistical variation; however, potential contributing factors were investigated. The percentage increase in AADT at these sites between the before and after periods was not greater than their respective roads. Further analysis of the crash data found that there was far more driver distraction/inattention, controller condition/impairment, and young adult drivers (aged 16 – 24) as crash factors at these locations compared to all sites during the after period.

3.2 Empirical Bayes

3.2.1 SPF Models

A number of SPF models were generated for HOCL, RORL, and Total FSI and all injury crashes to assist in estimation of expected crashes if no treatment was undertaken. The full list is shown in Appendix E. The SPFs were compared and selected based on the following criteria:

- The SPF should return 0 expected crashes when there is no traffic ($AADT = 0$), so that necessitates that the $AADT$ regressor lies outside the exponential
- The over-dispersion parameter, k , should be estimated by the MLE method in the negative binomial distributions
- Both $AADT$ and $Length$ were regressors in the model, and ideally both should be statistically significant.

- The Bayesian Information Criteria (BIC), a model optimisation tool, was used to compare candidate models fitted to the same set of data. The general formula for BIC contains a term that penalises model complexity and poor fit. A lower BIC score indicates a better fitting model with the lowest number of explanatory independent variables.
- R^2 – for linear models – is a measure of how close the regression approximates the data.

The SPFs selected for HOCL, RORL and Total FSI crashes are shown in Table 3.2.

Table 3.2: SPFs selected for HOCL, RORL and Total FSI crashes

Crash type	Severity	SPF model	Significant variables	Over-dispersion (k)
HOCL	FSI	HOCL FSI crashes = $e^{-12.320+0.153 \times \text{Length}} \times \text{AADT}^{1.080}$	All	1.093E-07
RORL	FSI	RORL FSI crashes = $e^{-12.991+0.145 \times \text{Length}} \times \text{AADT}^{1.051}$	Length	0.234
Total	FSI	Total FSI crashes = $e^{-8.809+0.197 \times \text{Length}} \times \text{AADT}^{0.817}$	All	0.523

Note: The SPF models are valid for road sections 20km or shorter, similar to the reference sites.

where AADT is the average annual daily traffic, and Length is the length of the straight road segment in kilometres.

The very small over-dispersion parameter of the HOCL SPF model indicates that there is very little over-dispersion in the data. In such a case, the variance is very close to the mean, and the negative binomial model is almost identical to the Poisson model estimated from the same set of data.

The SPFs selected for HOCL, RORL and Total all injury crashes are shown in Table 3.3.

Table 3.3: SPFs selected for HOCL, RORL and Total all injury crashes

Crash type	Severity	SPF model	Significant variables	Over-dispersion (k)
HOCL	All injury	HOCL injury crashes = $e^{-11.751+0.157 \times \text{Length}} \times \text{AADT}^{1.057}$	All	0.312
RORL	All injury	RORL injury crashes = $e^{-12.609+0.156 \times \text{Length}} \times \text{AADT}^{1.097}$	All	1.626E-04
Total	All injury	Total injury crashes = $e^{-8.633+0.178 \times \text{Length}} \times \text{AADT}^{0.874}$	All	0.092

Note: The SPF models are valid for road sections 20km or shorter, similar to the reference sites.

The very small over-dispersion parameter for RORL injury crashes again indicates little over-dispersion.

3.2.2 AMF Adjusted Models

AMFs were calculated using the power model suggested by Nilsson (1981) with updated power values from Cameron and Elvik (2008). For FSI crashes, the meta-analysis revised power estimate was 2.592. For all injury crashes, the power estimate was 2.495 (Cameron & Elvik 2008). The power models used were:

$$\text{FSI crashes: } Y_1 = \left(\frac{V_1}{V_0} \right)^{2.592} Y_0$$

$$\text{All injury crashes: } Y_1 = \left(\frac{V_1}{V_0} \right)^{2.495} Y_0$$

The coefficient in front of Y_0 describes the estimated proportion of the original crashes that would be expected to occur after a change in posted speed limit, which is the AMF.

Cameron and Elvik (2008) assumed that the posted speed limit was an appropriate estimator of the mean speed before the change (V_0). To estimate V_1 , the following relationship between change in posted speed limit (x) and change in mean speed (y) was used:

$$y = 0.2525x - 1.2204$$

Given that the change in posted speed limit was -10 km/h on roads 10A and 10B, the change in mean speed was estimated to be -3.75 km/h. The ratio V_1 / V_0 based on an initial posted speed of 100 km/h was 0.96 , giving an AMF of 0.906 for FSI crashes and 0.909 for all injury crashes. These factors were applied to their respective SPF models for the years after 2008, as shown in Table 3.4 and Table 3.5.

Table 3.4: AMF-adjusted SPF models for HOCL, RORL and Total FSI crashes

Crash type	Severity	Adjusted SPF model
HOCL	FSI	HOCL FSI crashes = $0.90579 \times e^{-12.320+0.153 \times \text{Length}} \times \text{AADT}^{1.080}$
RORL	FSI	RORL FSI crashes = $0.90579 \times e^{-12.991+0.145 \times \text{Length}} \times \text{AADT}^{1.051}$
Total	FSI	Total FSI crashes = $0.90579 \times e^{-8.809+0.197 \times \text{Length}} \times \text{AADT}^{0.817}$

Note: The SPF models are valid for road sections 20km or shorter, similar to the reference sites.

Table 3.5: AMF-adjusted SPF models for HOCL, RORL and Total injury crashes

Crash type	Severity	Adjusted SPF model
HOCL	All injury	HOCL injury crashes = $0.90915 \times e^{-11.751+0.157 \times \text{Length}} \times \text{AADT}^{1.057}$
RORL	All injury	RORL injury crashes = $0.90915 \times e^{-12.609+0.156 \times \text{Length}} \times \text{AADT}^{1.097}$
Total	All injury	Total injury crashes = $0.90915 \times e^{-8.633+0.178 \times \text{Length}} \times \text{AADT}^{0.874}$

Note: The SPF models are valid for road sections 20km or shorter, similar to the reference sites.

Comparison of the SPFs with the AMFs applied are presented in Appendix F.

3.2.3 Model Parameters and Effectiveness of WCLT

Table 3.6 shows the calculated parameters for HOCL, RORL, and Total FSI crashes used to estimate the treatment effectiveness.

Table 3.6: Calculated parameters for HOCL, RORL, and Total FSI crashes

Parameter	HOCL FSI crashes	RORL FSI crashes	Total FSI crashes
Overdispersion (k)	1.093E-07	0.234	0.523
SPF estimated crashes (P_B)	9.961	3.792	30.280
Actual crashes during before period (x)	9	7	33
Weight (w_1)	1.089E-06	0.470	0.941
Weight (w_2)	1.000	0.530	0.059
Unfactored crash estimate (m)	9.961	5.300	32.838
Standard deviation ($std\ dev.\ m$)	0.068	0.157	0.862
Reduction factor	1.000	0.998	0.988
Factored crash estimate (B)	9.959	5.290	32.458
Variance ($Var(B)$)	0.005	0.025	0.726
Actual crashes during after period (A)	7	4	30
Variance ($Var(A)$)	0.113	0.051	0.622
Variance ($Var(\tau)$)	0.036	0.005	0.348

The index of effectiveness, percentage reduction in crashes, and their standard deviations, are shown in Table 3.7. The EB analysis indicated that there were reductions of 30%, 24%, and 8% in HOCL, RORL, and Total FSI crashes respectively after WCLT was applied.

Table 3.7: Treatment effectiveness and percentage reduction of HOCL, RORL and Total FSI crashes

Measure	HOCL FSI crashes	RORL FSI crashes	Total FSI crashes
Index of effectiveness (θ)	0.703	0.756	0.924
Standard deviation (θ)	0.034	0.048	0.034
Reduction	30%	24%	8%
Standard error	3%	5%	3%

The calculated parameters for HOCL, RORL and Total injury crashes used to estimate the treatment effectiveness are shown in Table 3.8.

Table 3.8: Calculated parameters for HOCL, RORL and Total injury crashes

Parameter	HOCL injury crashes	RORL injury crashes	Total injury crashes
Over-dispersion (k)	0.312	1.626E-04	0.092
SPF estimated crashes (P_B)	14.292	8.850	59.422
Actual crashes during before period (x)	15	14	72
Weight (w_1)	8.168E-01	0.001	0.845
Weight (w_2)	0.183	0.999	0.155
Unfactored crash estimate (m)	14.870	8.857	70.055
Standard deviation (<i>std dev.</i> m)	0.475	0.062	1.311
Reduction factor	1.001	1.003	0.993
Factored crash estimate (B)	14.881	8.881	69.530
Variance ($Var(B)$)	0.226	0.004	1.694
Actual crashes during after period (A)	10	7	55
Variance ($Var(A)$)	0.171	0.086	1.387
Variance ($Var(\tau)$)	0.075	0.029	1.304

The index of effectiveness, percentage reduction in crashes, and their standard deviations, are shown in Table 3.9. The EB analysis indicated there were reductions of 33%, 21%, and 21% in HOCL, RORL, and Total injury crashes respectively after WCLT was applied.

Table 3.9: Treatment effectiveness and percentage reduction of HOCL, RORL and Total injury crashes

Measure	HOCL injury crashes	RORL injury crashes	Total injury crashes
Index of effectiveness (θ)	0.672	0.788	0.791
Standard deviation (θ)	0.035	0.033	0.022
Reduction	33%	21%	21%
Standard error	4%	3%	2%

3.3 Cost-benefit Analysis

The cost-benefit analysis compared the cost of crashes that were expected to occur without WCLT in the after period (B) to the cost of crashes that actually occurred with WCLT (A). The difference was the cost savings attributable to WCLT.

The proportions used to divide the expected crashes into severity categories were taken from those observed in the before period. There was no reason for the treatment to change the crash

outcome severity, so this approach was considered appropriate. Willingness to pay (WTP) crash cost values determined by TMR in 2015 are shown in Table 3.10.

Table 3.10: Willingness to pay crash costs – 2015 dollar value

Crash severity	Crash cost – \$2015 value
Fatal	8,987,396
Hospitalisation	626,974
Medical treatment	124,154
Minor injury	40,525

The proportions of fatalities and hospitalisations in the before period for each crash type are shown in Table 3.11. These were applied to the SPF estimates and used in calculating the BCR of WCLT for FSI crashes.

Table 3.11: Fatality and Hospitalisation proportions in the before period for HOCL, RORL and Total FSI crashes

Crash type	Fatal	Hospitalisation
HOCL	11%	89%
RORL	0%	100%
Total	15%	85%

The proportion of crashes in each severity category in the before period for each crash type are shown in Table 3.12. These were applied to the SPF estimates and used in calculating the BCR of WCLT for all injury crashes.

Table 3.12: Crash severity proportions in the before period for HOCL, RORL and Total injury crashes

Crash type	Fatal	Hospitalisation	Medical treatment	Minor injury
HOCL	7%	53%	27%	13%
RORL	0%	50%	43%	7%
Total	7%	39%	42%	12%

The SPF estimates of fatalities and hospitalisations compared with the actual counts, used to calculate the BCR of WCLT for FSI crashes are shown in Table 3.13.

Table 3.13: BCR calculations for HOCL, RORL and Total FSI crashes

Crash type	Expected			Actual		Crash cost savings (\$)
	FSIs	Fatal	Hospitalisation	Fatal	Hospitalisation	
HOCL	9.96	1.11	8.85	2	5	-5,614,714.28
RORL	3.78	0.00	3.78	0	4	-134,883.61
Total	29.93	4.53	25.39	3	27	12,786,729.79

The SPF estimates of fatalities and hospitalisations compared with the actual counts, used to calculate the BCR of WCLT for all injury crashes are shown in Table 3.14.

Table 3.14: BCR calculations for HOCL, RORL and Total injury crashes

Crash type	Expected					Actual				Crash cost savings (\$)
	Injury crashes	Fatal	Hospitalisation	Medical treatment	Minor injury	Fatal	Hospitalisation	Medical treatment	Minor injury	
HOCL	14.30	0.95	7.63	3.81	1.91	2	5	3	0	-7,578,852.97
RORL	8.87	0.00	4.44	3.80	0.63	0	4	3	0	399,164.44
Total	58.98	4.10	22.94	24.57	7.37	3	27	24	1	7,627,995.03

The average cost of WCLT was \$33,000 per km. The cost of procurement (low end) provided by TMR was \$27,400 per km of WCLT (only painting and ATLM installation, without road widening). An upper, conservative estimate of the cost provided by TMR was \$40,000 per km for WCLT. Using this upper estimate, the total implementation cost of the WCLT was \$1.1 million in 2011-dollar terms.

A life of five years before replacement/significant maintenance was necessary was considered appropriate for WCLT,. The installation would have cost \$1.2 million in 2015 using a discount rate of 4% typically adopted by TMR.

For all injury crashes, the total cost savings amounted to \$7.6 million. This yielded a BCR of 6.4 for all injury crashes due to installation of the WCLT treatment. The actual project BCR would be higher if the benefits and costs of speed limit reductions were to be included.

4 DISCUSSION

The reduction in crashes associated with wide centreline treatment determined in this study was 21% for total injury crashes. This was comparable to a report by the Land Transport Safety Authority (1995) stating a 19% reduction in crashes after installing flush medians on New Zealand roads. An Austroads research report (Austroads 2010) compiled international research on painted medians and proposed a conservative crash reduction factor for this treatment in the range of 15–20%.

In this study, 60 reference sites and 15 treatment sites were used, giving a control to case ratio of 4:1. This was statistically sufficient to reduce bias. Linden and Samuels (2013) conducted a study on the preferred matching ratio (control:cases) and stated that, generally, a ratio of 4:1 elicits the lowest bias, but control to case ratios of up to 100:1 could be used. A study by Hennessey et al. (1999) showed that little statistical power is gained by using more than four or five controls per case.

There were a few sites with no counts of certain types of crashes, resulting in several zeroes in the analysed data. The use of zero-inflated negative binomial regressions was considered, but they are generally used in over-dispersed count outcome variables (IDRE 2017). As the data in this project was not greatly over-dispersed (k very close to 0 in some instances), the general negative binomial model was elected.

Finding appropriate sites with similar characteristics to allow the safety benefits of WCLT for the wider road network to be estimated was a critical factor. Ensuring that the selected reference sites had an AADT between 3 000 and 17 300 encapsulated roads with AADT volumes as high as the treatment sites. These SPFs may be useful in future investigations of the safety on rural highways in Queensland, using the EB method. Roads with similar AADT's and cross-sections can be used to determine if the safety is worse than expected. Further data could be included to boost the predictive power of the models, including data for crashes on curves.

The SPFs have been developed to fit the reference sites' data and give indication about the safety of road sections typified by the ones selected in this evaluation. The maximum length of reference sites used for SPF development was 19.25 km. The SPFs should therefore not be extrapolated to make assumptions of safety for road sections greater than 20 km. A caveat to be placed on the models is to limit their appropriate use to road sections 20 km or shorter.

The effect of WCLT on reducing all FSIs (8%) was lower than for HOCL (30%) and RORL crashes (24%). The layout of WCLT lends itself to treating certain types of crashes; it could be combined with other road environment treatments to elicit a greater reduction on FSI crashes, to work towards a Safe System environment on rural highways. This could be an avenue of further research in a separate project.

The computed coefficients for the HOCL, RORL and Total crash SPF models were all significant, for all injury crashes. The findings for injury crash reductions and the cost-benefit ratio were therefore supported statistically. The HOCL and Total crash SPF models had significant variables. The AADT variable and the constant in the RORL SPF model for FSI crashes were not significant. The FSI crash reduction of 24% reported for RORL crashes should therefore be considered with this in mind.

The effect of WCLT on heavy vehicles could be examined in future studies when the data becomes available. Possible avenues for research in this area include the effectiveness of the treatment based on heavy vehicle type composition, peak volumes, and comparing routes with higher percentages of heavy vehicles with lower ones.

5 SUMMARY AND CONCLUSIONS

This report has described an investigation into the effect of WCLT on FSI and all injury crashes along straight sections of the Bruce Highway using before and after crash data and reference sites. Property damage-only crashes were excluded from the analysis.

Following comparison with other generated models, a number of SPFs were developed for HOCL, RORL and Total crashes respectively.

The key findings in the WCLT evaluation for rural highway sections were reductions of 33% in HOCL injury crashes and 21% for all injury crashes, providing positive economic returns with a BCR of 6.4. Effectiveness by crash types are as follows:

Crash type	FSI crash reduction	All injury crash reduction
HOCL	30%	33%
RORL	24%	21%
Total crashes	8%	21%

Further investigation with more sites may refine the estimates determined in this project. The SPFs may be used in future projects to estimate safety on rural highways with similar characteristics. The effect of WCLT on heavy vehicles could be examined in future studies when the data becomes available.

REFERENCES

- Austroads 2010, Road Safety Engineering Risk Assessment: Part 6: Crash Reduction Factors, AP-T151/10, prepared by B Turner, K Imberger, P Roper, V Pyta & J McLean, Austroads, Sydney, NSW.
- Cameron, M & Elvik, R 2008, 'Nilsson's power model connecting speed and road trauma: does it apply on urban roads?', Australasian road safety research policing and education conference, 19th, 2008, Adelaide, South Australia, Department for Transport, Energy and Infrastructure, Walkerville, SA, pp. 59-68.
- Elvik, R, Christensen, P & Amundsen, A 2004, 'Speed and road accidents: an evaluation of the power model', TOI report 740/2004, Institute of Transport Economics, Oslo, Norway.
- Elvik, R 2008, 'The predictive validity of empirical Bayes estimates of road safety', Accident Analysis & Prevention, vol. 40, no. 6, pp. 1964-9, viewed 9 May 2017, <<http://www.sciencedirect.com/science/article/pii/S0001457508001528>>.
- Fox, J 2008, 'Generalized linear models', in Applied regression analysis and generalized linear models, 2nd edn, Sage Publications Inc., California, USA, pp. 379-424.
- Hauer, E, Harwood, D, Council, F & Griffith, S 2002, 'Estimating safety by the empirical Bayes method', Transportation Research Record, no. 1784, pp. 126-31.
- Hennessey, S, Bilker, W, Berlin, J & Strom, B 1999, 'Factors Influencing the Optimal Control-to-Case Ratio in Matched Case-Control Studies', American Journal of Epidemiology, vol. 149, no. 2, pp. 195-97.
- Land Transport Safety Authority 1995, 'Install Flush Median', NZ Transport Agency, Wellington, NZ, viewed 25 May 2017, <<http://www.nzta.govt.nz/resources/crash-reduction/docs/flush-median.pdf>>.
- Linden, S & Samuels, S 2013, 'Using balance statistics to determine the optimal number of controls in matching studies', Journal of Evaluation in Clinical Practice, pp. 968-75, doi: 10.1111/jep.12072.
- Nilsson, G 1981, 'The Effects of Speed Limits on Traffic Accidents in Sweden', Proceedings of the international symposium on the effects of speed limits on traffic accidents and transport energy use, Dublin, Ireland.
- Persaud, B & Lyon, C 2007, 'Empirical Bayes before-after studies: lessons learned from two decades of experience and future directions', Accident Analysis & Prevention, vol. 39, no. 3, pp. 546-55, viewed 9 May 2017, <<http://www.sciencedirect.com/science/article/pii/S0001457506001734>>.
- Persaud, B, Retting, R & Lyon, C 2004, 'Crash reduction following installation of centerline rumble strips on rural two-lane roads', Accident Analysis & Prevention, vol. 36, no. 6, pp. 1073-9, viewed 9 May 2017, <<http://www.sciencedirect.com/science/article/pii/S0001457504000302>>.
- Patel, R, Council, F & Griffith, M 2007, 'Estimating safety benefits of shoulder rumble strips on two-lane rural highways in Minnesota', Transportation Research Record, no. 2019, pp. 205-11.
- Whittaker, A 2012, 'The safety benefit of continuous narrow painted median strips', BEng thesis, University of Southern Queensland, Brisbane, Qld.

APPENDIX A TREATMENT SITES LIST

Table A 1: List of treatment sites with their crash list ID

Crash list ID	Road ID	Start chainage (km)	End chainage (km)	Length (km)
A	10A	102.24	108.27	6.03
B	10A	108.27	108.93	0.66
I	10A	127.18	128.04	0.86
J	10A	128.52	130.27	1.75
K	10A	130.9	135.86	4.96
L	10A	136.24	139.38	3.14
M	10B	3.05	3.63	0.58
N	10B	3.85	5.11	1.26
O	10B	5.45	5.76	0.31
P	10B	6.02	6.85	0.83
Q	10B	7.3	9.09	1.79
R	10B	9.58	10.46	0.88
S	10B	10.58	12.1	1.52
T	10B	12.41	12.8	0.39
U	10B	12.8	13.17	0.37
			Total	25.33

APPENDIX B REFERENCE SITES LIST

Table B 1: List of road sections used to develop SPFs

Road segment ID	Road ID	Start chainage (km)	End chainage (km)	Length (km)	Location type
1	10A	102.24	108.27	6.03	Treatment / Reference
2	10A	108.27	108.93	0.66	Treatment / Reference
3	10A	112.18	117.1	4.92	Reference
4	10A	118.5	119.33	0.83	Reference
5	10A	119.79	120.86	1.07	Reference
6	10A	121.43	121.69	0.26	Reference
7	10A	122.06	124.52	2.46	Reference
8	10A	124.99	125.32	0.33	Reference
9	10A	127.18	128.04	0.86	Treatment / Reference
10	10A	128.52	130.27	1.75	Treatment / Reference
11	10A	130.9	135.86	4.96	Treatment / Reference
12	10A	136.24	139.38	3.14	Treatment / Reference
13	10B	3.05	3.63	0.58	Treatment / Reference
14	10B	3.85	5.11	1.26	Treatment / Reference
15	10B	5.45	5.76	0.31	Treatment / Reference
16	10B	6.02	6.85	0.83	Treatment / Reference
17	10B	7.3	9.09	1.79	Treatment / Reference
18	10B	9.58	10.46	0.88	Treatment / Reference
19	10B	10.58	12.1	1.52	Treatment / Reference
20	10B	12.41	12.8	0.39	Treatment / Reference
21	10B	12.8	13.17	0.37	Treatment / Reference
22	10B	13.59	14.02	0.43	Reference
23	10B	14.02	16.6	2.58	Reference
24	10B	17.32	20	2.68	Reference
25	10B	20.68	23.81	3.13	Reference
26	10B	24.76	27.04	2.28	Reference
27	10B	28.75	28.88	0.13	Reference
28	10B	29.37	30.25	0.88	Reference
29	10B	34.66	36.25	1.59	Reference
30	10B	36.77	39.86	3.09	Reference
31	10B	40.75	46.35	5.6	Reference
32	10B	46.9	59.3	12.4	Reference
33	17B	23.3	23.6	0.3	Reference
34	17B	24.07	27.56	3.49	Reference
35	17B	27.97	30.14	2.17	Reference
36	17B	30.56	32.13	1.57	Reference
37	17B	115.62	115.92	0.3	Reference
38	17B	116.17	118.28	2.11	Reference
39	17B	119.4	120	0.6	Reference
40	17B	120.32	122.27	1.95	Reference
41	17B	122.7	123.05	0.35	Reference
42	18B	11.18	12.91	1.73	Reference

Road segment ID	Road ID	Start chainage (km)	End chainage (km)	Length (km)	Location type
43	18B	14.25	16.04	1.79	Reference
44	18B	16.44	17.63	1.19	Reference
45	18B	18.35	20.49	2.14	Reference
46	18B	21.74	26.74	5	Reference
47	22B	18.5	19.71	1.21	Reference
48	22B	24.28	25.52	1.24	Reference
49	22B	20.04	23.41	3.37	Reference
50	22B	14.58	18.2	3.62	Reference
51	40A	0.89	2.14	1.25	Reference
52	40A	4.23	7.2	2.97	Reference
53	40A	7.6	10.96	3.36	Reference
54	40A	13.5	21.4	7.9	Reference
55	40A	22.7	25	2.3	Reference
56	40A	27.4	29.9	2.5	Reference
57	40A	30	49.25	19.25	Reference
58	42A	0.5	3.27	2.77	Reference
59	42A	3.8	5.73	1.93	Reference
60	42A	5.98	12.95	6.97	Reference
			Total	155.32	

APPENDIX C FSI CRASHES BY SITE

Table C 1: HOCL FSI crashes by site

Site	Fatal			Hospitalisation			FSI crashes		
	Before	After	% Change	Before	After	% Change	Before	After	% Change
A	0	0	N/A	2	0	-100%	2	0	-100%
B	0	0	N/A	0	0	N/A	0	0	N/A
I	0	0	N/A	0	0	N/A	0	0	N/A
J	0	0	N/A	1	0	-100%	1	0	-100%
K	1	0	-100%	1	3	200%	2	3	50%
L	0	2	Infinite	0	0	N/A	0	2	Infinite
M	0	0	N/A	0	0	N/A	0	0	N/A
N	0	0	N/A	1	0	-100%	1	0	-100%
O	0	0	N/A	0	0	N/A	0	0	N/A
P	0	0	N/A	0	2	Infinite	0	2	Infinite
Q	0	0	N/A	2	0	-100%	2	0	-100%
R	0	0	N/A	0	0	N/A	0	0	N/A
S	0	0	N/A	1	0	-100%	1	0	-100%
T	0	0	N/A	0	0	N/A	0	0	N/A
U	0	0	N/A	0	0	N/A	0	0	N/A
Total	1	2	100%	8	5	-37.5%	9	7	-22.2%

Table C 2: RORL FSI crashes by site

Site	Fatal			Hospitalisation			FSI crashes		
	Before	After	% Change	Before	After	% Change	Before	After	% Change
A	0	0	N/A	1	1	0%	1	1	0%
B	0	0	N/A	0	0	N/A	0	0	N/A
I	0	0	N/A	0	0	N/A	0	0	N/A
J	0	0	N/A	0	0	N/A	0	0	N/A
K	0	0	N/A	2	1	-50%	2	1	-50%
L	0	0	N/A	1	1	0%	1	1	0%
M	0	0	N/A	0	0	N/A	0	0	N/A
N	0	0	N/A	0	0	N/A	0	0	N/A
O	0	0	N/A	1	0	-100%	1	0	-100%
P	0	0	N/A	0	1	Infinite	0	1	Infinite
Q	0	0	N/A	2	0	-100%	2	0	-100%
R	0	0	N/A	0	0	N/A	0	0	N/A
S	0	0	N/A	0	0	N/A	0	0	N/A
T	0	0	N/A	0	0	N/A	0	0	N/A
U	0	0	N/A	0	0	N/A	0	0	N/A
Total	0	0	N/A	7	4	-42.9%	7	4	-42.9%

Table C 3: Total FSI crashes by site

Site	Fatal			Hospitalisation			FSI crashes		
	Before	After	% Change	Before	After	% Change	Before	After	% Change
A	0	0	N/A	5	2	-60%	5	2	-60%
B	0	0	N/A	0	0	N/A	0	0	N/A
I	0	0	N/A	1	2	100%	1	2	100%
J	1	0	-100%	2	2	0%	3	2	-33.3%
K	2	0	-100%	4	9	125%	6	9	50%
L	0	3	Infinite	2	3	50%	2	6	200%
M	0	0	N/A	0	0	N/A	0	0	N/A
N	0	0	N/A	3	1	-66.7%	3	1	-66.7%
O	0	0	N/A	1	0	-100%	1	0	-100%
P	0	0	N/A	1	3	200%	1	3	200%
Q	2	0	-100%	7	2	-71.4%	9	2	-77.8%
R	0	0	N/A	0	0	N/A	0	0	N/A
S	0	0	N/A	1	3	200%	1	3	200%
T	0	0	N/A	1	0	-100%	1	0	-100%
U	0	0	N/A	0	0	N/A	0	0	N/A
Total	5	3	-40%	28	27	-3.6%	33	30	-9.1%

APPENDIX D ALL INJURY CRASHES BY SITE

Table D 1: HOCL all injury crashes by site

Site	Fatal			Hospitalisation			Medical treatment			Minor injury			All injury crashes		
	Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change
A	0	0	N/A	2	0	-100%	1	1	0%	1	0	-100%	4	1	-75%
B	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
I	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
J	0	0	N/A	1	0	-100%	0	0	N/A	0	0	N/A	1	0	-100%
K	1	0	-100%	1	3	200%	2	1	-50%	0	0	N/A	4	4	0%
L	0	2	Infinite	0	0	N/A	0	0	N/A	0	0	N/A	0	2	Infinite
M	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
N	0	0	N/A	1	0	-100%	0	0	N/A	0	0	N/A	1	0	-100%
O	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
P	0	0	N/A	0	2	Infinite	0	0	N/A	0	0	N/A	0	2	Infinite
Q	0	0	N/A	2	0	-100%	1	0	-100%	0	0	N/A	3	0	-100%
R	0	0	N/A	0	0	N/A	0	1	Infinite	0	0	N/A	0	1	Infinite
S	0	0	N/A	1	0	-100%	0	0	N/A	1	0	-100%	2	0	-100%
T	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
U	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
Total	1	2	100%	8	5	-37.5%	4	3	-25%	2	0	-100%	15	10	-33.3%

Table D 2: RORL all injury crashes by site

Site	Fatal			Hospitalisation			Medical treatment			Minor injury			All injury crashes		
	Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change
A	0	0	N/A	1	1	0%	2	1	-50%	0	0	N/A	3	2	-33.3%
B	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
I	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
J	0	0	N/A	0	0	N/A	2	0	-100%	0	0	N/A	2	0	-100%
K	0	0	N/A	2	1	-50%	0	0	N/A	0	0	N/A	2	1	-50%
L	0	0	N/A	1	1	0%	0	0	N/A	0	0	N/A	1	1	0%
M	0	0	N/A	0	0	N/A	0	1	Infinite	0	0	N/A	0	1	Infinite
N	0	0	N/A	0	0	N/A	0	1	Infinite	1	0	-100%	1	1	0%
O	0	0	N/A	1	0	-100%	1	0	-100%	0	0	N/A	2	0	-100%
P	0	0	N/A	0	1	Infinite	0	0	N/A	0	0	N/A	0	1	Infinite
Q	0	0	N/A	2	0	-100%	0	0	N/A	0	0	N/A	2	0	-100%
R	0	0	N/A	0	0	N/A	1	0	-100%	0	0	N/A	1	0	-100%
S	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
T	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
U	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
Total	0	0	N/A	7	4	-42.9%	6	3	-50%	1	0	-100%	14	7	-50%

Table D 3: Total all injury crashes by site

Site	Fatal			Hospitalisation			Medical treatment			Minor injury			All injury crashes		
	Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change
A	0	0	N/A	5	2	-60%	7	4	-42.9%	1	1	0%	13	7	-46.2%
B	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	N/A
I	0	0	N/A	1	2	100%	2	0	-100%	1	0	-100%	4	2	-50%
J	1	0	-100%	2	2	0%	4	4	0%	0	0	N/A	7	6	-14.3%
K	2	0	-100%	4	9	125%	5	6	20%	2	0	-100%	13	15	15.4%
L	0	3	Infinite	2	3	50%	1	5	400%	1	0	-100%	4	11	175%
M	0	0	N/A	0	0	N/A	0	1	Infinite	0	0	N/A	0	1	Infinite
N	0	0	N/A	3	1	-66.7%	3	2	-33.3%	1	0	-100%	7	3	-57.1%
O	0	0	N/A	1	0	-100%	1	0	-100%	1	0	-100%	3	0	-100%
P	0	0	N/A	1	3	200%	0	0	N/A	0	0	N/A	1	3	200%
Q	2	0	-100%	7	2	-71.4%	2	1	-50%	0	0	N/A	11	3	-72.7%
R	0	0	N/A	0	0	N/A	1	1	0%	0	0	N/A	1	1	0%
S	0	0	N/A	1	3	200%	1	0	-100%	1	0	-100%	3	3	0%
T	0	0	N/A	1	0	-100%	2	0	-100%	1	0	-100%	4	0	-100%
U	0	0	N/A	0	0	N/A	1	0	-100%	0	0	N/A	1	0	-100%
Total	5	3	-40%	28	27	-3.6%	30	24	-20%	9	1	-89%	72	55	-23.6%

APPENDIX E SPF MODELS

All SPF models shown should only be used for road section lengths of 20km or less, as this was the range of road lengths for which data was available to develop the models. Attempting to apply the models to far longer road sections is not appropriate.

E.1 FSI SPF Models

The SPFs generated for HOCL, RORL and Total FSI crashes are shown in tables Table E 1, Table E 2, and Table E 3 respectively. These findings form the equivalent of the comparison group in the study.

Table E 1: SPFs modelled for HOCL FSI crashes

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
1	Negative Binomial (MLE)	$\text{EXP}(A + C \cdot \text{Length}) \cdot \text{AADT}^B$	-12.320	1.080	0.153	All	289.316		1.0936E-07
2	Negative Binomial (fixed)	$\text{EXP}(A + C \cdot \text{Length}) \cdot \text{AADT}^B$	-12.435	1.087	0.169	All	289.720		1.000
3	Negative Binomial (MLE)	$\text{EXP}(A + B \cdot \text{AADT} + C \cdot \text{Length})$	-3.301	8.964E-05	0.148	All	291.481	–	4.831E-08
4	Negative Binomial (fixed)	$\text{EXP}(A + B \cdot \text{AADT} + C \cdot \text{Length})$	-3.371	9.053E-05	0.165	Constant, Length	291.555	–	1.000
5	Nonlinear	$\text{EXP}(A + B \cdot \text{AADT} + C \cdot \text{Length})$	-2.936	7.356E-05	0.119			0.105	
6	Nonlinear	$\text{EXP}(A + B \cdot \text{AADT} \cdot \text{Length})$	-2.349	1.739E-05				0.127	
7	Nonlinear	$A \cdot (\text{AADT}^B) \cdot \text{Length}$	2E-05	8.880E-01				0.157	
8	Linear	$A + B \cdot \text{Length} + C \cdot \text{AADT}$	-0.079	1.146E-05	0.047	Length		0.143	

Table E 2: SPFs modelled for RORL FSI crashes

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
1	Negative Binomial (MLE)	$\text{EXP}(A + C \cdot \text{Length}) \cdot \text{AADT}^B$	-12.991	1.051	0.145	Length	160.795		0.234
2	Negative Binomial (fixed)	$\text{EXP}(A + C \cdot \text{Length}) \cdot \text{AADT}^B$	-12.735	1.021	0.150	Length	155.260		1.000
3	Negative Binomial (MLE)	$\text{EXP}(A + B \cdot \text{AADT} + C \cdot \text{Length})$	-4.357	9.932E-05	0.143	Constant, length	161.156		0.282
4	Negative Binomial (fixed)	$\text{EXP}(A + B \cdot \text{AADT})$	-4.353	9.710E-05	0.148	Constant, length	155.583		1.000
5	Nonlinear	$\text{EXP}(A + B \cdot \text{AADT} + C \cdot \text{Length})$	-4.588	0.000E+00	0.124			0.031	
6	Nonlinear	$\text{EXP}(A + B \cdot \text{AADT} \cdot \text{Length})$	-3.320	1.726E-05				0.047	

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
7	Nonlinear	$A*(AADT^B)*Length$	2.000E-08	1.501E+00				0.061	
8	Linear	$A + B*Length + C*AADT$	-0.031	4.951E-06	0.016	Length		0.041	

Table E 3: SPFs modelled for Total FSI crashes

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
1	Negative Binomial (MLE)	$EXP(A + C*Length)*AADT^B$	-8.809	0.817	0.197	All	605.405		0.523
2	Negative Binomial (fixed)	$EXP(A + C*Length)*AADT^B$	-8.885	0.819	0.214	All	603.303		1.000
3	Negative Binomial (MLE)	$EXP(A + B*AADT + C*Length)$	-2.025	6.991E-05	0.197	All	608.668		0.563
4	Negative Binomial (fixed)	$EXP(A + B*AADT + C*Length)$	-2.099	7.112E-05	0.213	All	605.924		1.000
5	Nonlinear	$EXP(A + B*AADT + C*Length)$	-1.567	5.923E-05	0.138			0.340	
6	Nonlinear	$EXP(A + B*AADT*Length)$	-1.219	2.109E-05				0.374	
7	Nonlinear	$A*(AADT^B)*Length$	0.006	4.080E-01				0.422	
8	Linear	$A + B*Length + C*AADT$	-0.307	2.928E-05	2.25E-01	All		0.417	

E.2 All Injury SPF Models

The SPFs generated for all injury crashes of HOCL, RORL, and Total crash types are shown in Table E 4, Table E 5, and Table E 6 respectively.

Table E 4: SPFs modelled for HOCL all injury crashes

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
1	Negative Binomial (MLE)	$EXP(A + C*Length)*AADT^B$	-11.751	1.057	0.157	All	366.985		0.312
2	Negative Binomial (fixed)	$EXP(A + C*Length)*AADT^B$	-11.726	1.049	0.171	All	363.378		1.000
3	Negative Binomial (MLE)	$EXP(A + B*AADT + C*Length)$	-2.958	8.981E-05	0.154	All	369.54		0.367
4	Negative Binomial (fixed)	$EXP(A + B*AADT + C*Length)$	-3.010	8.981E-05	0.168	All	365.54		1.000
5	Nonlinear	$EXP(A + B*AADT + C*Length)$	-2.623	7.972E-05	0.115			0.109	
6	Nonlinear	$EXP(A + B*AADT*Length)$	-1.982	1.718E-05				0.145	

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
7	Nonlinear	$A*(AADT^B)*Length$	5.999E-06	1.044E+00				0.178	
8	Linear	$A + B*Length + C*AADT$	-0.108	1.676E-05	0.064	AADT, length		0.153	

Table E 5: SPFs modelled for RORL all injury crashes

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
1	Negative Binomial (MLE)	$EXP(A + C*Length)*AADT^B$	-12.609	1.097	0.156	All	274.532		1.626E-04
2	Negative Binomial (fixed)	$EXP(A + C*Length)*AADT^B$	-12.785	1.109	0.173	All	266.633		1.000
3	Negative Binomial (MLE)	$EXP(A + B*AADT + C*Length)$	-3.525	9.749E-05	0.152	All	275.96		1.560E-04
4	Negative Binomial (fixed)	$EXP(A+B*AADT)$	-3.598	9.823E-05	0.169	Constant, length	267.925		1.000
5	Nonlinear	$EXP(A + B*AADT + C*Length)$	-3.084	7.791E-05	0.117			0.076	
6	Nonlinear	$EXP(A + B*AADT*Length)$	-2.426	1.663E-05	0.138			0.089	
7	Nonlinear	$A*(AADT^B)*Length$	-1.431E-05	8.970E-01				0.117	
8	Linear	$A + B*Length + C*AADT$	-0.081	1.096E-05	0.043	Length		0.109	

Table E 6: SPFs modelled for Total injury crashes

No.	Method	Model	Coefficients			Significant variables	BIC	R ²	Over-dispersion (k)
			A	B	C				
1	Negative Binomial (MLE)	$EXP(A + C*Length)*AADT^B$	-8.633	0.874	0.178	All	854.063		0.092
2	Negative Binomial (fixed)	$EXP(A + C*Length)*AADT^B$	-9.190	0.909	0.241	All	824.666		1.000
3	Negative Binomial (MLE)	$EXP(A + B*AADT + C*Length)$	-1.350	7.404E-05	0.173	All	865.467		0.078
4	Negative Binomial (fixed)	$EXP(A + B*AADT + C*Length)$	-1.673	8.069E-05	0.241	All	828.864		1.000
5	Nonlinear	$EXP(A + B*AADT + C*Length)$	-0.908	5.862E-05	0.132			0.366	
6	Nonlinear	$EXP(A + B*AADT*Length)$	-0.532	1.990E-05				0.408	
7	Nonlinear	$A*(AADT^B)*Length$	0.005	4.810E-01				0.485	
8	Linear	$A + B*Length + C*AADT$	-0.572	5.908E-05	0.402	All		0.69	

APPENDIX F SPF GRAPHS

Figure F 1: Total FSI crash SPF with speed AMF applied for different section lengths and AADT

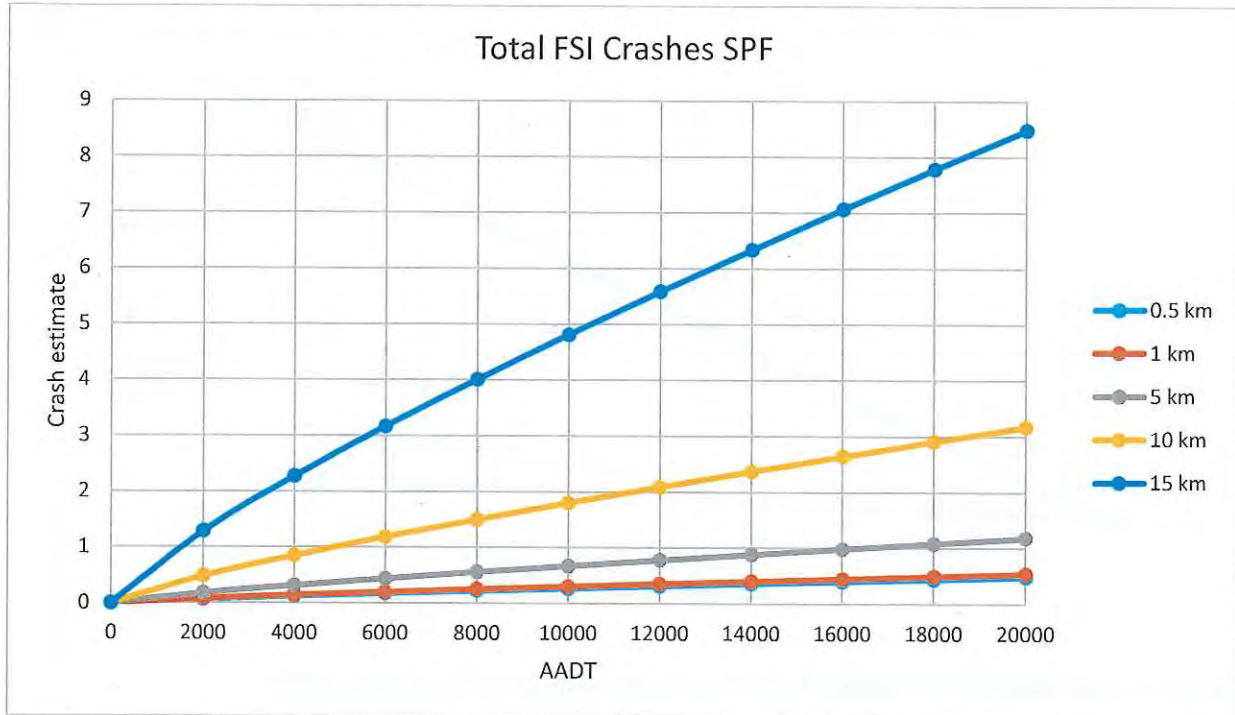


Figure F 2: HOCL FSI crash SPF with speed AMF applied for different section lengths and AADT

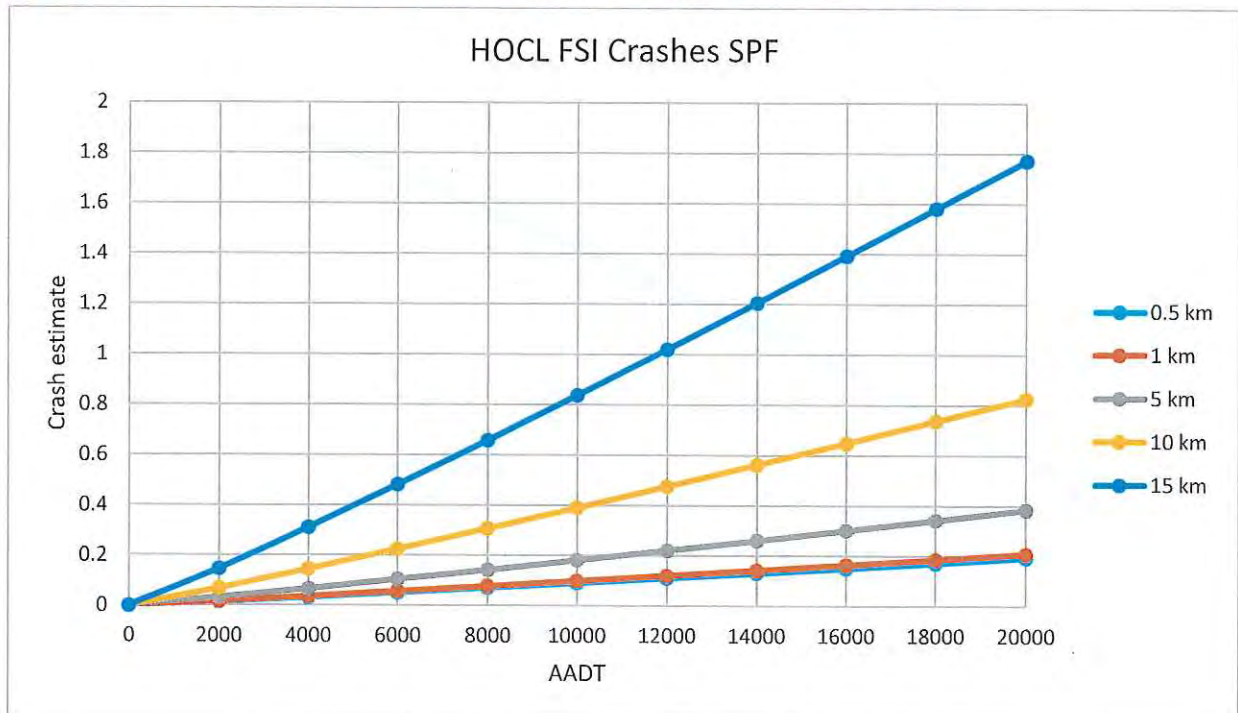


Figure F 3: RORL FSI crash SPF with speed AMF applied for different section lengths and AADT

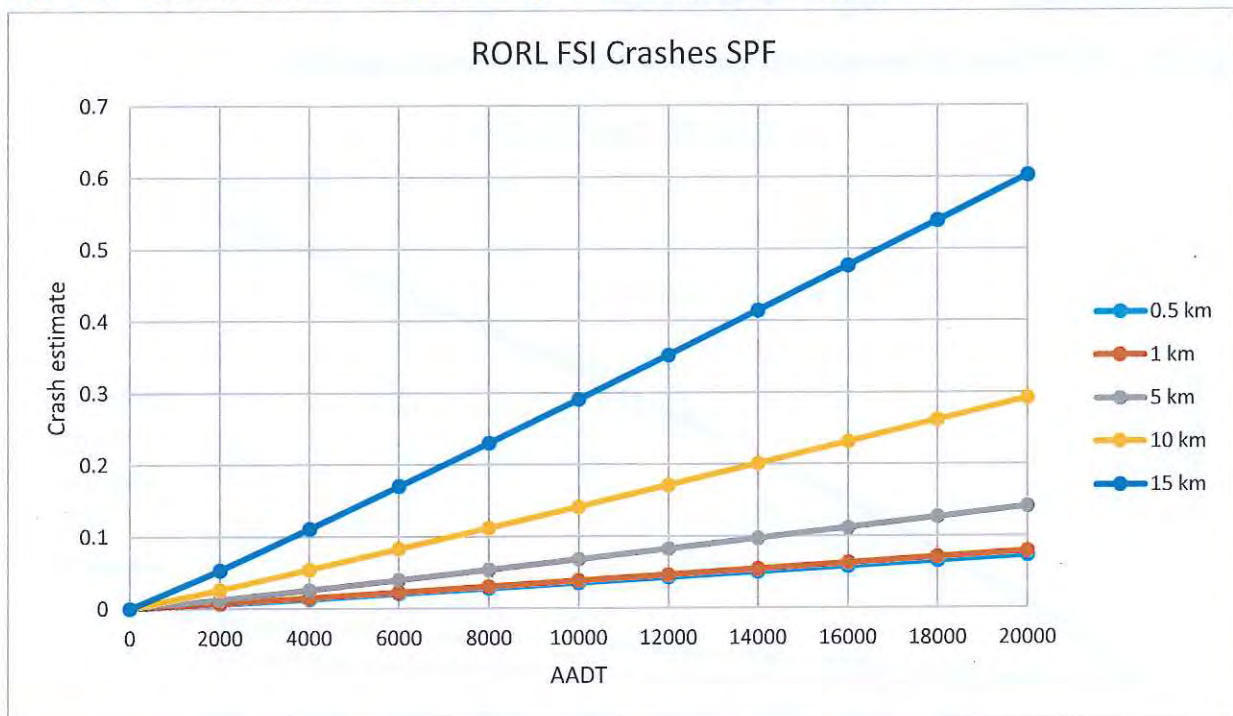


Figure F 4: Total injury crash SPF with speed AMF applied for different section lengths and AADT

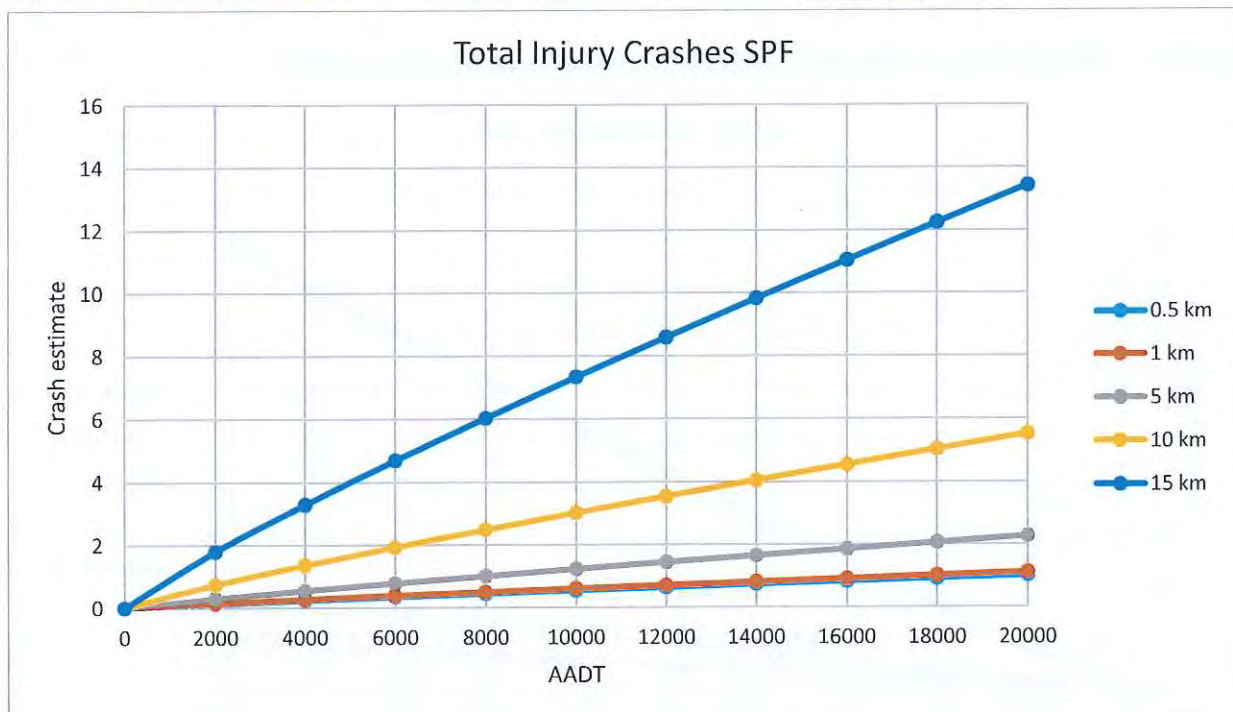


Figure F 5: HOCL injury crash SPF with speed AMF applied for different section lengths and AADT

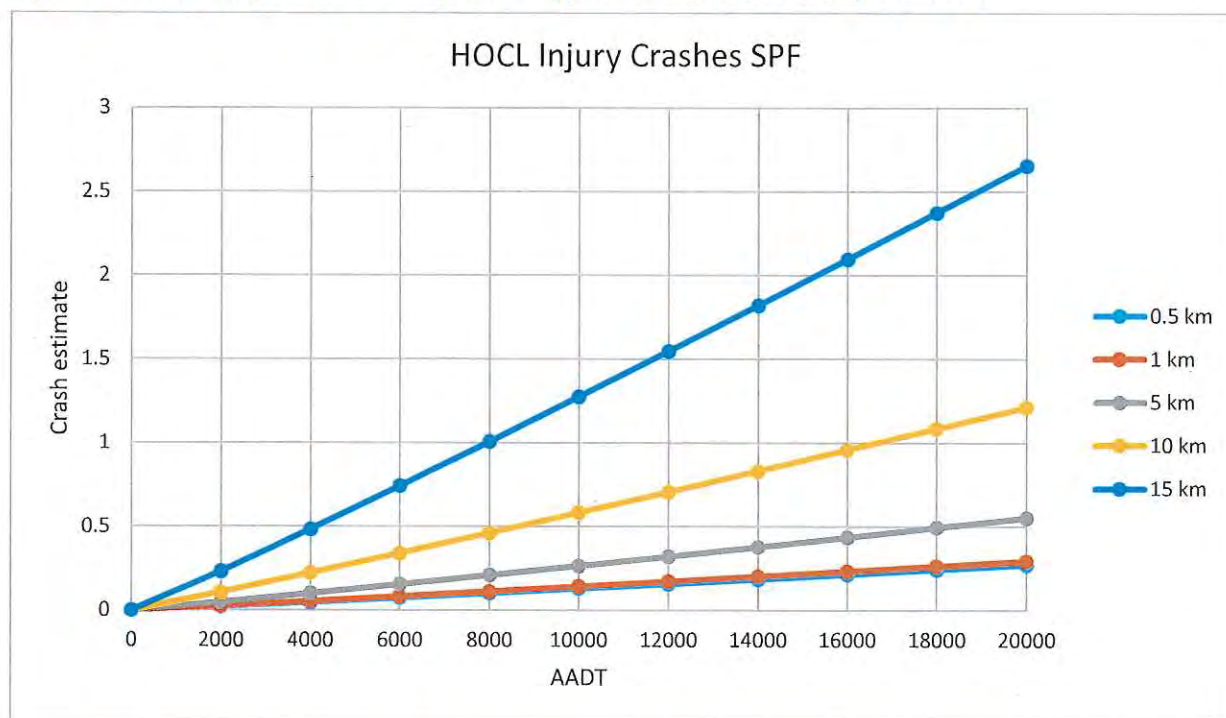


Figure F 6: RORL injury crash SPF with speed AMF applied for different section lengths and AADT

