Quantifying the likelihood of barrier strike maintenance

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ABSTRACT

Recent research both in New Zealand and Australia has identified the benefits associated with the installation of various barrier types and in particular the significant benefits associated with wire rope barriers (WRBs). A result of that research will be an increase in the use of barriers, and in particular, WRB.

This paper presents NZ Transport Agency funded research undertaken by Abley Transportation Consultants investigating the occurrence and corresponding maintenance costs associated with vehicle strikes on W-beam and WRB installations. The likelihood and cost of Nuisance Barrier Strikes (NBSs) have been evaluated in isolation from all barrier strikes as they result in significant maintenance costs on the state highway network. NBSs are events whereby the barrier is struck by a vehicle that is then able to drive away.

The environmental and operational variables that significantly influence the rate at which barrier strikes occur are determined and a predictive spreadsheet tool has been developed to model the likely strike rate and maintenance costs associated with various barrier installation types. This tool is intended to assist practitioners with:

- the decision to install a barrier
- the selection of barrier type
- whether a carriageway or median should be widened to reduce future maintenance costs.

INTRODUCTION

The purpose of the research presented in this paper was to identify significant variables influencing barrier strike rate and the cost of associated collision maintenance, and subsequently produce a predictive model to assist the New Zealand Transport Agency (the Transport Agency) to better understand the relationship between collision maintenance costs, barrier installation, barrier type and environmental factors including median and carriageway width. This research investigated the occurrence and corresponding maintenance costs associated with vehicle strikes on W-beam and WRB installations.

WRBs consist of steel cables mounted on weak steel posts. They have a low initial installation cost, low impact severity, and occupy less road space due to their thin profile. WRBs provide effective vehicle containment and their open design prevents snow accumulation and provides good visibility through the barrier. Vehicles which strike WRBs tend to be deflected back into the traffic stream. This generally prevents vehicles vaulting or under-riding the barrier. Figure 1 shows an example of a WRB.

W-beam barriers consist of a steel beam with a w-shaped guard rail profile, mounted on wooden or steel posts. Due to their rigidity, they have the ability to maintain a degree of efficiency after minor impacts; however, they have a high sensitivity to placement to ensure the risk of vehicles vaulting or under-riding the barrier is minimised. Figure 2 shows an example of a W-beam barrier.


Figure 1 Example of a wire rope barrier


Figure 2 Example of a W-beam barrier

The likelihood and cost of strikes on barriers have been assessed in this research using comprehensive datasets received from Transport Agency representatives. Nuisance Barrier Strikes (NBSs) have been evaluated in isolation as they result in significant maintenance costs on the state highway network. A NBS is defined as 'an impact to a barrier that does not cause injury and the vehicle is able to drive away, but inflicts damage to the barrier that requires maintenance'.

BACKGROUND

Literature Review

A targeted review of national and international literature was undertaken to identify the relevant factors that influence crash risk for roadside safety barriers, focusing on WRBs and W-beam barriers.

The extent of research from both international and New Zealand sources directly relating to the variables influencing NBSs in isolation from non-drive away strike events has been found to be limited. However, there are a number of research papers which although not directly relating to NBSs, provide valuable background to understanding factors influencing the likelihood of all strike events. International research relating to the frequency of barrier strikes as a function of traffic exposure and the physical characteristics of their surrounds has found there is a direct association between barrier crash frequency and some or all of the operational and environmental factors listed in Table 1.

Variable type	Variable	Source(s)
Operational	Impact angles and impact speeds	Karim et al (2011)
	Speed limit	Chimba et al (2014), Karim et al (2011)
	Vehicle type and mass	Karim et al (2011)
	Increased curvature	Chimba et al (2014), Levett et al (2008), Crowther and Swears (2010), Cenek et al (2012)
	Barrier placement	Karim et al (2011), Crowther and Swears (2010)
Environmental/ Physical	Lateral offset of the barrier	Chimba et al (2014), Crowther and Swears (2010), Jamieson et al (2013)
	Road type, alignment and cross section	Chimba et al (2014), Karim et al (2011), Crowther and Swears (2010), Turner et al (2009)
	Median width	Chimba et al (2014), Crowther and Swears (2010)
	Number of traffic lanes	Chimba et al (2014), McCarthy and Underwood (2013)
	Audio Tactile Paving (ATP) centreline markings	Crowther and Swears (2010), Marsh and Pilgrim (2010)
	Regional characteristics	Karim et al (2011)
	Seasonal effects	Karim et al (2011)

Table 1 Variables affecting barrier crash frequency

The extent to which these, and potentially other, factors influence the rate of barrier repairs and their costs was unclear.

CONSULTATION WITH PRACTITIONERS

A selection of international and New Zealand practitioners were contacted and asked to share their experiences and knowledge specifically relating to NBSs. Responses were received from Sweden, Australia and New Zealand.

The Swedish Transport Administration is undertaking research to reduce the impact of run-off road crashes, which considers road design elements and other factors of interest to this research. Australian authorities expressed concern that maintenance funding restrictions are causing cost-focused rather than safety-focused decision making rather than following the Safe Systems approach which regards life and health of the utmost importance.

Factors considered by the various Road Controlling Authorities (RCAs) throughout New Zealand affecting the rate of NBSs generally corresponded with the factors investigated and identified in existing international and New Zealand research. However, certain RCAs found they do have what they consider to be a high level of NBSs, usually located on specific points of their network, while other RCAs do not consider these types of strikes as being a particularly significant issue. The general consensus was that WRBs are preferred, where possible, given the reduced installation and maintenance costs and the ease of repair following crashes.

METHODOLOGY

Overview

In order to prepare a predictive model of barrier strike rates and associated maintenance costs, a comprehensive database of NBS information has been prepared. Variables identified as contributing to higher barrier strike rates from the literature review and informed through the experiences of practitioners were considered when preparing the predictive models.

A formal request was made to multiple transport operation centres for the supply of raw data on NBSs in their region over the past five years. The following specifics on each barrier strike were requested:

- date and time of the barrier strike
- specific barrier location
- barrier type
- extent of repair (including the length of the barrier affected, number of posts etc.)
- cost of repair including labour and traffic management.

Comprehensive barrier strike datasets were received from ten Transport Agency representatives (or their network maintenance contractors) and all of the data collected corresponds to the New Zealand state highway network. Eight of the respondents were from the North Island, and the remaining two were from the top of the South Island. Figure 3 provides an overview of the location and frequency of the state highway barrier strikes in New Zealand based on the raw data received. Efforts were made to contact Australian road authorities; however, the research team was not successful in obtaining any comprehensive sets of maintenance, repair or strike data

The data sources are a combination of contractor maintenance repair archives and specific strike records covering a repair period from November 2005 to March 2014. The raw data received encompassed strike information for both median and shoulder barriers. It was evident from the responses received, that there was no common template or process for the collection of barrier strike maintenance information within the Transport Agency.

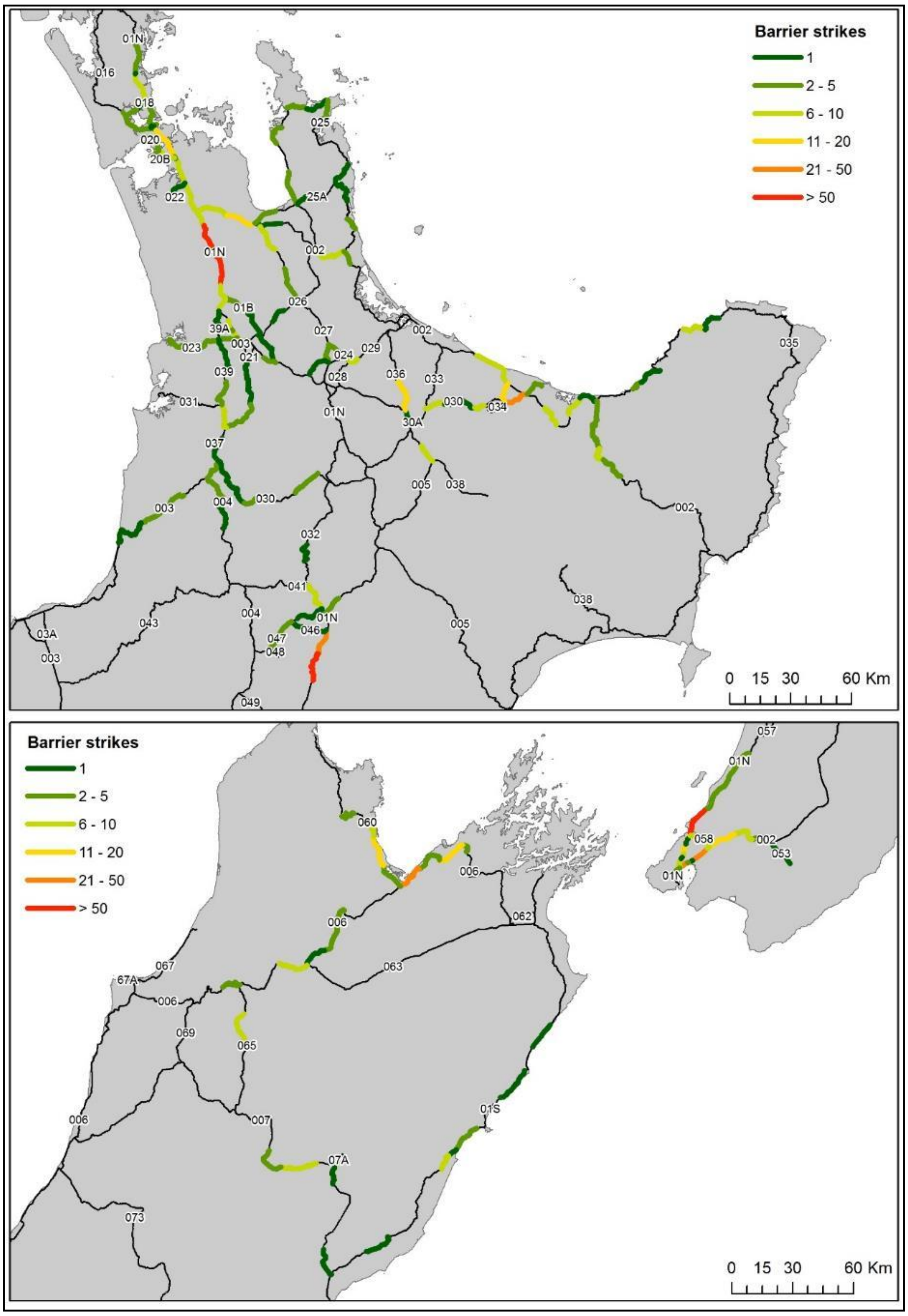

Figure 3 Location of raw barrier strike data received

Dataset collation

The raw repair records were cleaned to a set of 1,198 NSB records by removing duplicate or incomplete records. In Table 2, a summary of key statistics from the resultant Barrier Strike Database (BSD) provides an overview of the information which was collated from the datasets supplied by Transport Agency representatives. All data was linked to Transport Agency KiwiRAP Assessment Tool (KAT) data and Railing Database sources to provide a comprehensive set of variables for subsequent analysis.

Nearly 90% of the data was confirmed as NBSs and most were for wire rope installations. A relatively small number of crash strikes were removed from analysis and carried forward for subsequent analysis. A very small number of concrete barrier strikes were also discounted from further analysis. A total of 702 wire rope and 344 W-beam NBS records were carried forward into the analysis to prepare predictive models.

Barrier type	NBSs	Non-drive away strikes	Total strikes	Percentage
Wire rope	702	63	765	64%
W-beam	344	76	420	35%
Other (concrete)	13	0	13	1%
Total strikes	1059	139	1198	100%
Percentage	88%	12%	100%	

Table 2 Summary of BSD by barrier type

The strike records in the BSD cover up to a ten year repair period, from November 2005 to March 2014 with 60% of the data recording barrier strike repairs in the years from 2011 to 2013. This provided a mix of old and new maintenance data to consider in the technical analysis. With more wire rope installations in recent years, this could explain the greater proportion of recent data, or it could also be due to the improved recording of strike information over time. The specific data ranges of the strike data repair date distribution are shown in Table 3.

Year	Number of strikes	Year	Number of strikes
2005 (2 months)	10	**2010**	99
2006	51	**2011**	196
2007	47	**2012**	221
2008	51	**2013**	301
2009	90	**2014 (3 months)**	132

Table 3 Summary of barrier strike data date ranges

The NBSs from the BSD were combined with data extracted from the Transport Agency's Crash Analysis System (CAS) to source the non-drive away strike events for a total of 2,449 barrier installations along the state highway with the majority (61%) of these being LHS W-beam installations. Table 4 provides a summary of available data for each barrier type.

Barrier type	NBSs	CAS crash strikes	Total strikes	Total installations	Installations with NBSs or CAS strikes	Unstruck installations	% of barrier installations struck
Median wire rope	658	263	921	67	52	15	78%
LHS wire rope	42	42	84	37	32	5	86%
Median W-beam	3	47	50	60	18	42	30%
LHS W-beam	299	371	670	1,497	330	1,167	22%
Total	1,002	723	1,725	1,661	432	1,229	26%

Table 4 Summary of data in final analysis

A number of limitations relating to the barrier strike location and the representation of the dataset were highlighted during the research. The greatest risk was in the consistency and interpretation of the data received in the absence of any common method of recording NBSs and their associated costs across regions. Overall the research team was confident that the dataset created provided a robust, representative dataset to inform the development of predictive models for NBSs in isolation and for all-strike events.

Model Development

Using the BSD, an analysis of the frequency of barrier strikes against a range of input variables was undertaken. Linear and non-linear multivariate regression analysis was undertaken to determine the operational and environmental variables which are statistically significant factors in the rate of barrier strikes and consequent maintenance costs. The key (independent) variables tested in the regression analysis were:

- Annual Average Daily Traffic (AADT) volume
- median and carriageway widths
- barrier offset from centreline
- horizontal alignment
- terrain
- length of barrier
- posted speed
- percentage of heavy vehicles
- presence of Audio Tactile Profiled markings

The modelling process then proceeded by converting the number of NBSs to strikes per annum and strikes per million Vehicle Kilometres Travelled (VKT) by determining the barrier length, AADT and the number of years of NBS data available. These are the dependent variables considered in the regression modelling. Correlation coefficients between each of the independent variables were calculated and any redundant variables that exhibited a high degree of correlation were removed.

The Microsoft Excel Data Analysis Toolpak was used to undertake multivariate regression analysis. A combination of linear, non-linear, binary and step functions were tested to enable a range of relationships to be explored and where significant, evaluated.

RESULTS

The results of the multivariate regression analysis were used to form predictive equations to determine which variables had a significant effect on the rate of NBSs or on all barrier strikes events for each barrier type and to calculate strike rates and corresponding maintenance costs. Table 5 shows the regression equations for Left Hand Side (LHS) and median barriers by barrier type. Table 6 provides definitions for each of the variables used in the regression equations.

	Barrier type	**Equation**	**Regression coefficient (R^2)**
NBSs	Median wire rope	$\text{Strikes per million VKT} = 0.0792\ H + 0.8056\ M1 - 0.1432\ A - 0.2694\ P$	*0.71*
	LHS wire rope	$\text{Strikes per million VKT} = 0.1556\ H - 0.5906\ A + 2.074\ F$	*0.63*
	Median W-beam	$\text{Strikes per annum} = 0.0125T$	*0.03*
	LHS W-beam	$\text{Strikes per annum} = 0.00825e^{T}$	*0.06*
All-Strikes	Median wire rope	$\text{Strikes per million VKT} = 0.122\ H + 0.00401e^{M2} - 0.423\ P - 0.132\ A$	*0.71*
	LHS wire rope	$\text{Strikes per million VKT} = 0.177\ H - 0.413\ A + 2.00\ F$	*0.65*
	Median W-beam (>40m)	$\text{Strikes per annum} = 0.236T - 0.324L + 0.00000529AADT$	*0.32*
	Median W-beam (≤40m)	$\text{Strikes per annum} = 0.0257H$	*0.08*
	LHS W-beam (>40m)	$\text{Strikes per annum} = 0.0842T - 0.118L + 0.00000683AADT + 0.0104H$	*0.16*
	LHS W-beam (≤40m)	$\text{Strikes per annum} = 0.00963H + 0.0205T - 0.188/PC + 0.000000672AADT$	*0.08*

Table 5 Regression equations for each barrier type

A P-statistic of 0.1 was used as a general guideline to ascertain whether an independent variable was considered to be significant (that is the probability of a variable not being statistically significant is no greater than 0.1). The resultant regression equations by barrier type have formed the basis for a spreadsheet-based barrier strike cost prediction model. This model has been designed to be used interactively to predict the strike rate and maintenance cost implications of barrier installation, changes in barrier types (flexible, semi-rigid and rigid), and change in carriageway width and barrier offset variables.

Symbol	Description
A	A = 1 if ATP road markings are present, otherwise A = 0.
AADT	AADT is the annual average daily traffic count for both sides of the road if the section is undivided. If the road section is divided then it is the AADT for the side of the road where the barrier is located.
F	F is a function to represent offset to the LHS barrier where F = 0 if the offset is greater than or equal to 5m, otherwise F = 5 less offset to LHS barrier if the offset is less than 5m. The offset should be measured as the distance between the centreline and the LHS barrier (in m) for single-lane roads, or measured as the distance between the right-hand edge of the lane furthest to the left for multilane corridors.
H	Horizontal alignment variable which can be found directly from KiwiRAP Analysis Tool data (mode across length of installation).
L	L = 1 if the length of the section is less than 400m, otherwise L = 0.
M1	M1 = 1 if median width is less than 2m, otherwise M1 = 0.
M2	M2 = 7 less median width (in metres) or zero, whichever value is larger.
P	P = 1 if posted speed is less than 100km/h, otherwise P = 0.
PC	Percentage of vehicles traversing the section classified as heavy vehicles.
T	Terrain variable directly from KAT data (mode across length of installation).

Table 6 Description of regression equation variables

The wire rope equations generally show good fit with R^2 statistics in the range of 0.6-0.8 however the W-Beam equations exhibit relatively poor fit and should be used with caution. All of the LHS and median W-beam regression equations had low adjusted R^2 values and as such the number of strikes these equations calculate should be assumed to include a high degree of uncertainty. The poor fit is largely a consequence of the large number of W-Beam barriers in the underlying datasets used in the regression which had not been struck[1].

DISCUSSION

W-Beam Nuisance Barrier Strikes

Analysis of the locations of barriers with NBS rates was undertaken with three sites on SH1 isolated as the worst performing locations from the data collected in the research. Figures 4 to 6 provide pictures of these locations taken from Transport Agency state highway video footage.

All three sites are located in rolling terrain, with no ATP marking and delineation through the use of W-beam barriers set within 1-2m of the edge marking. The sites in Figures 4 and 6 are located in areas with moderate to tight corners and the site in Figure 5 is on an approach to a narrow bridge.

State highway video footage indicated that sites with high incidence rates of NBSs are generally on either a sharp horizontal curve or narrow undulating (uneven vertical alignment) sections of road.

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[1] WRB installations were generally significantly longer than W-beam installations (WRB installations often exceeded 1km in length). As a result, there were a large number of short sections of W-beam with no recorded strikes.

Figure 4 W-beam high incident site #1 SH01N RS 777 RP14110–14316

Figure 5 W-beam high incident site #2 SH01N RS 777 RP5900–5910

Figure 6 W-beam high incident site #3 SH01N RS 763 RP10000–11200

Following consultation with contractors supplying data it was understood that NBSs at these locations generally occurred due to handling errors where drivers under-estimated the degree of road curvature and/or the undulating nature of the road. Vehicles generally did not travel at high speeds due to the terrain; however, errors in driver judgement resulted in vehicles striking a barrier at a very shallow angle and then driving away.

Crash analysis literature by Crowther and Swears (2010) identified two common characteristics for crash cluster sites on the Longswamp to Rangiriri section of SH1: single-lane sections with right-hand curvature on an uphill gradient and single-lane sections with left-hand curvature on a downhill gradient. The investigation of the physical features of the crash cluster sites indicated two particular issues with the road environment, namely the lack of visibility on right-hand curves and roadside barriers located close to the edge line.

These findings were supported by feedback from consultation with practitioners, who stated that NBSs typically occur on their network when a truck cuts a tight radius corner and the rear trailer wheels connect with the barrier. Thus, the curvature of the road was the main factor in the rate of NBSs on this stretch of SH1. The W-beam barriers within the region have regular NBSs but do not warrant repair after each strike.

Wire Rope Nuisance Barrier Strikes

The highest frequency NBS locations for median WRBs were also investigated. Table 7 outlines the ten locations exhibiting the highest NBS incident rates from the data collected in this research. The Rangiriri stretch of SH1 in northern Waikato was highlighted in the research brief as having an unusually high rate of NBSs compared with other wire rope installations throughout New Zealand. The dataset confirms this, with eight out of the ten most frequently struck WRBs (including the top five locations) located along this stretch of SH1.

Eight of the ten locations in Table 7 correspond to SH1 in the vicinity of the Rangiriri Bypass and are installed on medians less than 2m in width with horizontal alignment generally regarded as easy curves. Three locations on this stretch of SH1 have ATP installed. Each barrier length on this Rangiriri section of SH1 was struck between 26 and 90 times in an approximate five-year period.

Ranking	Location SH/RP	Location start RS	Location end RS	Strikes per million VKT	Horizontal alignment	Median width	ATP present
1	01N 502	434	900	1.67	Moderate curves	< 2m	No
2	01N 486	12,528	13,101	1.51	Easy curves	< 2m	No
3	01N 502	65	398	1.38	Straight	< 2m	No
4	01N 486	11,412	12,345	1.31	Easy curves	< 2m	Yes
5	01N 486	15,888	17,059	1.00	Easy curves	< 2m	No
6	02 962	5,875	6,110	0.71	Easy curves	>2m	No
7	01N 486	9,017	11,383	0.67	Easy curves	< 2m	Yes
8	01N 486	14,875	15,853	0.63	Easy curves	< 2m	No
9	058 0	1,534	2,269	0.57	Straight	< 2m	No
10	01N 486	13,141	14,835	0.53	Easy curves	< 2m	Yes

Table 7 Ten most frequently struck WRB locations

Transport Agency state highway video footage has been examined to determine the relative characteristics or variables that may contribute to the high strike rates occurring at these locations. Figures 7 to 9 illustrate the three locations with the highest NBS rates.

Figure 7 Median wire rope high incident site #1 SH01N RS 502 RP 434–900

Figure 8 Median wire rope high incident site #2 SH01N RS 486 RP 12528–13101

Figure 9 Median wire rope high incident site #3 SH01N RS 502 RP 65–398

All of these sections of highway are confirmed by the video as having a narrow median width (less than 2m) and easy to moderate curves. The posted speed for all three median wire rope sections exhibiting the highest strike rates was 100km/h. Two of the three sites included a break in the median to allow for right-turning vehicles. The two non-SH1 locations identified in the top 10 sites in Table 7 were on lower volume roads with relatively short sections of WRB. These installation sites have a much lower NBS incidence rate with records showing they have only been struck between three and seven times each. The horizontal alignment at these two sites was generally on easy curves with no ATP markings. One of these locations has a narrow median less than 2m.

PREDICTIVE SPREADSHEET TOOL

This research is accompanied by a spreadsheet tool and user guide that implements the barrier model equations discussed in the results section, within an Excel spreadsheet tool to simplify the calculation process. This provides a platform for roading authorities to enter the values of the independent variables for WRB on a section of highway and derive the strikes per million VKT, strikes per annum or likelihood of a NBS occurring in an easy to use application.

The tool also undertakes simple maintenance cost modelling by multiplying the predicted strikes by the average cost to repair damage to WRBs ($2,700 per repair) and W-beam barriers ($2,000 per repair) calculated from data barrier strike repair data collected from Transport Agency staff and contractors. These values have been assumed as the default average strike cost values in the barrier strike spreadsheet tool.

Combining the strike rate and maintenance cost estimates into one platform, the tool allows valuable information to be drawn to inform planners and local roading authorities. A user guide for the tool is incorporated into the larger research report.

CONCLUSIONS

Regression modelling has been undertaken to test the variables identified by the research and generate a set of significant variables that explain the variation in barrier strike rates and consequential maintenance costs for Wire Rope and W-Beam installations. Tables 8 and 9 summarise the significant variables for each model and barrier installation type.

Significant variables	Median wire rope	LHS wire rope	Median W-beam	LHS W-beam model 1	LHS W-beam model 2
Horizontal alignment	✓	✓			✓
Median width	✓				
ATP	✓	✓			
Posted speed	✓				
Offset from centreline		✓			
Terrain			✓	✓	✓

Table 8 Summary of significant independent variables – NBSs

Significant variables	**Median wire rope**	**LHS wire rope**	**Median W-beam (>40m)**	**LHS W-beam (>40m)**	**Median W-beam (≤40m)**	**LHS W-beam (≤40m)**
Horizontal alignment	✓	✓		✓	✓	✓
Median width	✓					
ATP	✓	✓				
Posted speed	✓					
Offset from centreline		✓				
Terrain			✓	✓		✓
AADT	✓	✓	✓	✓		✓
Length of section	✓	✓	✓	✓		
Percentage heavy vehicles						✓

Table 9 Summary of significant independent variables – All-strikes

These findings generally aligned with those identified in the literature review as being significant variables for vehicular crashes with roadside barriers, although available literature generally did not isolate NBSs from non-drive away events.

Having identified relationships between the rate of barrier strikes and the operational and environmental variables, these factors can be used to inform planners and RCAs when deciding if a barrier should be installed. The primary motivation for barrier installation is to preserve lives and maximise road user safety. There is the opportunity to also predict and consider the likely maintenance cost implications of barrier strikes as part of a wider business case to install further barrier infrastructure on the New Zealand road network.

The barrier strike spreadsheet tool that accompanies this research calculates the number of crashes per annum and corresponding maintenance costs for all-strikes on WRB and W-beam installations. This cost prediction tool can be used in conjunction with other cost components to form part of the wider economic assessment of the relative benefits (or dis-benefits) associated with the installation of a specific barrier type in a given location.

This research specifically assessed strike rates to barrier maintenance costs; however, when deciding what type of barrier should be installed, the cost of crashes should also be taken into consideration. It is anticipated that the safety benefits in most instances will far outweigh the likely maintenance costs from a purely economic perspective.

In the technical assessment in this research, few relationships were established between W-beam barrier strike rates and the underlying variables. It is, however, evident that the high frequency W-beam barrier strike locations are generally those with undulating terrain, poor horizontal alignment and where the barriers are installed close to the edge marking. By moving the barriers further away from the edge marking where practicable in these areas with challenging terrain, maintenance costs are likely to be reduced.

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