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The effectiveness of wire rope barriers in Victoria

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Abstract

Run-off-road crashes represent half of all fatal crashes in rural Victoria and many of these crashes involve collisions with fixed roadside objects. Wire rope barriers are proving to be highly effective in addressing this crash problem internationally. To date no comprehensive Victorian evaluation had been undertaken on the effectiveness of this barrier. A quasi-experimental 'before and after' study design was employed to evaluate the effectiveness of these barriers in addressing this crash problem. Results indicated that barriers were associated with statistically significant reductions program-wide. In addition, along two specific routes, reductions of up to 87% in targeted serious casualty crashes were indicated.

Keywords

Effectiveness, Evaluation, Run-off-road crashes, Wire rope barrier

Introduction

Single vehicle run-off-road crashes represent a major source of serious road trauma resulting from factors such as road curvature, excessive speed, driver fatigue and alcohol consumption [1]. In the five years to 2010, nearly 70% of all fatal and serious injury crashes in rural Victoria, Australia, were the result of vehicles being driven off the road or crashing into oncoming vehicles, accounting for nearly 5000 crashes. Of these, 60% involved collision with a fixed roadside object [2]. The issue is not confined to Victoria or indeed Australia. In New South Wales, an annual average of 80 fatal crashes were the result of run-off-road crashes on high speed undivided roads [3] while in Western Australia in the five years to 2007, run-off-road crashes comprised 56% of all casualty crashes on the rural network [4]. Internationally, single vehicle crashes in 2008 (often the result of vehicles running off the road) contributed to over a third of fatalities in the European Union, accounting for around 8000 deaths [5]. In the United States in 2009, over 18,000 fatalities - 53% of fatal crashes - were the result of vehicles running off the road, and nearly 60% of these involved fixed roadside objects [6].

Wire rope or cable barriers have been commonly utilised in Europe to address this crash type on high-speed rural roads, and were investigated for widescale use in Victoria by Corben and Johnston [7], among others. Commonly referred to as 'flexible barriers' for their ability to deflect and absorb much of the crash force, the barriers consist of highly-tensioned wire rope supported by frangible metal posts. In Victoria, wire rope barriers are currently in use in one of two main forms: three to four wire ropes either placed parallel to the road surface, or with the two upper wire ropes parallel to the road surface and the lower two intertwined with each other. Upon impact, the tensioned wires deflect, absorbing much of the energy of the crash while the frangible posts yield, minimising excessive force being imparted onto the vehicle and its occupants, and often effectively capturing and decelerating the vehicle [8, 9].

International evaluations of the effectiveness of these barriers have been highly promising. Many evaluations in Europe and the US indicate large reductions in injurious crashes associated with wire rope barrier use, with up to 70-90% reductions in serious casualty crashes for particular crash types [10-12]. Swedish use of the barrier in the innovative 2+1 barrier format - which contains a centre lane that alternates travel direction with the wire rope barrier separating the two directions of travel - found reductions in risk of fatality of between 76% and 82% when compared to 13 metre roads without the wire rope barrier and road geometry treatment [13].

At the time of study, no comprehensive evaluation had been undertaken on the effects of the barrier on Victorian roads, although Szwed provided early indications of barrier effectiveness of 92% reduction in casualty run-off-road crashes [14]. In the Victorian Parliamentary Inquiry into Crashes with Roadside Objects (2005), several recommendations pertinent to wire rope barrier usage in Victoria were made, including 'that VicRoads undertake a detailed analysis of the requirement for widespread installation of flexible roadside safety barriers on high speed Victorian highways. If appropriate, a long-term large-scale installation program should be proposed'[15]. The Transport Accident Commission (TAC) reiterated this in its submission to the Inquiry with its recommendation that '…the systemic application of (flexible) barrier treatments known to be effective in reducing collisions with roadside objects should be actively encouraged and supported'[16]. To this end, this Victorian study was completed in 2009 to investigate how effectively wire rope barriers reduce crashes in Victoria. Particular emphasis was placed on the reductive effects of barriers on serious casualty crashes, in line with the Victorian Government road safety strategy focus of reducing serious casualties [17]. This paper presents the results of the evaluation in relation to estimated reduction in reported serious and fatal injury run-off-road crashes, after the installation of wire rope barriers on Victorian roads, as well as the overall effects on all casualty crashes.

Method

A quasi-experimental evaluation design incorporating the use of control groups was used in the study for the assessment of changes to casualty crash frequency and fatal and serious injury crash frequency attributable to wire rope barrier installation. This study design estimated treatment effect by comparing crash frequency at each treated length to those at untreated sections of the same length over the same time periods, both before and after the treatment was implemented. Use of control groups was necessary to give an adequate measure of the reductions in crash frequency due to factors other than the treatments, over the period of data analysed in the study.

Count data assembled for analysis in a quasi-experimental before and after-treatment/control design define a two by two contingency table. Apart from the lack of treatment and control group randomisation, this is the same analysis framework used in the analysis of clinical trials where a randomised treatment-control structure is used.

Medical literature shows the most appropriate means of analysing count data from trials to estimate net treatment effects relative to a control is via a log-linear analysis with a Poisson error structure [18]. The estimate resulting from the analysis in the case of casualty crash data being analysed here is not a relative risk of an outcome, such as cancer in a clinical trial, but the relative casualty crash change in treatment group compared to the control. The distributional assumptions about casualty crash frequency made in the use of this method are consistent with those proposed by Nicholson [19, 20].

The log-linear Poisson regression approach to analysing quasi-experimental road safety evaluation designs was originally proposed by Brühning and Ernst [21]. Modifications of the method have been successfully applied by Newstead and Corben in their evaluation of the TAC-funded Accident Black Spot program implemented in Victoria between 1992 and 1996 [22], and more recently in the evaluation of crash effects of strip shopping centre treatments in Victoria [23].

The analysis method demonstrated by Brühning and Ernst can be described as follows: data defined by the quasi-experimental study design with before and after data in each of L treatment and control pairs can be summarised in a series of L two by two contingency tables, represented in Table 1.

Table 1. Contingency table format used in the analysis method

Section	Control Group		Treatment Group	
	Before	After	Before	After
1	n_{111}	n_{112}	n_{121}	n_{122}
...	...	...	...	...
L	n_{L11}	n_{L22}	n_{L21}	n_{L22}

A log-linear model with Poisson error structure, appropriate for the variability in the casualty crash data is then fitted to the data, with the model form given by Equation 1. The log-linear model form of this equation can easily be fitted in common statistical software packages such as SAS.

$$\ln(n_{ijk}) = \beta_0 + \beta_i + \beta_{ij} + \beta_{ik} + \beta_{ijk}$$

In Equation 1, i is the site number, j is the treatment or control group index, k is the before or after index, the β values are the model parameters and n_{ijk} is the cell casualty crash count. The percentage casualty crash reduction at site i attributable to the treatment, adjusted for the corresponding change in casualty crash frequency at the control site is given by Equation 2.

$$\Delta_i = 100 \times (1 - \exp(\beta_{ijk}))\%$$

Statistical significance of Δ_i is equal to the statistical significance of β_{ijk} obtained directly from the fitted log-linear model. Confidence limits for Δ_i are computed in the normal way using the estimated standard error of β_{ijk} obtained from the fitted log-linear model and using the transformation given by Equation 2. Subtle modifications of the above model can be made to estimate the average treatment effect across a number of treated sites. These modifications are detailed in Brühning and Ernst [21] and were used to estimate the overall program effect of the analysed sections of road treated with flexible barrier.

Dataset

Treatment sites were defined as road lengths that contained installed lengths of wire rope barrier, and the sites were constrained to those within 100 km/h and 110 km/h speed zones. VicRoads provided data of the lengths of road that were installed with wire rope barrier, with barrier location detail provided either in chainage or GIS coding. Most of the installations were completed over an extended time period, and the data period considered ranged from December 2000 to 2006.

Crashes occurring within a 50 metre arc of a treatment site were included for analysis using the police-reported crash dataset of VicRoads, Road Crash Information System (RCIS). In Victoria, only crashes that involve injury are recorded in the police database. Injury outcome in police-reported crashes in Victoria is classified into one of three levels, namely 'fatal', 'serious injury' (where there has been at least one hospital admission) and 'other (minor) injury'. The severity of a crash is defined by the most serious injury level sustained by any person involved in the crash. In this report, 'serious casualty' refers to crashes involving either a fatal or serious injury outcome, while 'casualty crash' refers to all crashes involving any injury. The results refer to effects on crash numbers, not the number of road users involved.

Crashes were identified for the period January 1995 to October 2007, inclusive. The 'before' data period included at least five years of pre-treatment crash data across all sites (the minimum period was five years and 11 months). Between ten months and over six years of after-treatment data were utilised across the road sections. A total of 2576 casualty crashes were included in the study and analysed in the following four categories: all casualty crashes, fatal and serious injury crashes (serious casualty crashes), and 'targeted crashes'. Road crashes in Victoria are classified under the Victorian Definitions for Classifying Accidents coding (DCA) [24]. Crashes in the 'target crash' category were defined by the following DCAs: 120 (head-on), 150 (head-on, overtaking), 151 (out-of-control, overtaking), 170 (off-path to the left on straight carriageway), 171 (off-path to the left into parked vehicle or object on straight carriageway), 172 (off-path to the right on straight carriageway), 173 (off-path to the right into parked vehicle or object on straight carriageway), 180 (off-path on right bend), 181 (off right bend in to parked vehicle/object), 182 (off-path on left bend), 183 (off left bend into parked vehicle/object). The 'all crash' category included all DCAs. Due to limited detail in the data, all crashes within the entire treatment length were included in the analysis, irrespective of whether the crash was a median or roadside crash or involved barriers.

Crash frequency at each treated road section was compared to that at untreated road sections of the same route (control sites) over the same time periods, before and after treatment. Provided control sites are carefully chosen, comparing casualty and fatal and serious injury crash changes at treated sites against those at non-treated sites enables the effects of treatments on crash counts to be isolated from other factors that may affect crash counts in the post-treatment period. Control sites for this study were selected using postcodes or an adjacent section of the same road. The general independence of the control sites from potential confounding factors or concurrent construction projects were confirmed through VicRoads' advice.

Regression-to-the-mean is a potentially confounding influence on estimations of Black Spot and Black Length treatment effectiveness. It is caused by selecting Black Spot/Length sites for treatment that have a high casualty crash frequency measured over a narrow window in time, due to the expression of an extreme in random variation but which have the same underlying crash rate as sites not selected for treatment. Selecting sites for treatment on such a basis means that the likelihood of the casualty crash frequency at the selected site reducing in the immediate next period, merely due to chance, is high. A number of measures have been taken to limit the possibility of regression-to-the-mean effects confounding the estimates of treatment effectiveness made in this study. Firstly, a five-year time span of pre-treatment crash data has been analysed to ensure accurate estimates of pre-treatment crash frequency. In addition, overlaps were avoided between the before data period and the crash data period from which the treated sites were selected. Finally, an analysis technique was used that fully recognises the level and distribution of random variation in the data and computes confidence limits and significance probability levels that suitably reflect this [21, 22].

Results

Analysis of barrier effect was based on around 100 kilometres of wire rope barrier installed on ten prominent routes in Victoria (see Table 2). Hume Highway had the longest length of barrier in this particular analysis followed by Western Ring Road, Monash Freeway and Western Highway. Midland Highway had the least amount of wire rope barrier that adhered to the criteria for data inclusion. Within the current dataset, around 40% of the wire rope barrier was installed along the median and the remainder more or less divided evenly between the left and right roadsides (Table 3).

Table 2. Lengths of wire rope barrier

Routes	Metres
Hume Highway	19,923
Western Ring Road	18,972
Monash Freeway	17,685
Western Highway/Freeway	16,167
Calder Highway	9,031
Eastern Freeway	7,106
Metropolitan Ring Road	5,394
Goulburn Valley Highway	3,815
Princes Highway	3,343
Midland Highway	235
Total	**101,671**

Table 3. Location of barrier within road cross-section

Barrier Location	Metres
Total Left	31%
Total Median	40%
Total Right	29%

Table 4. Results for casualty crashes – all crashes

Road Section	Relative Risk	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Statistical Significance
Overall	*0.71*	*0.59*	*0.85*	*0.0003*
Monash Freeway	1.08	0.79	1.5	0.6195
Princes Highway West	1.54	0.53	4.46	0.425
Princes Highway	1.03	0.29	3.65	0.9696
Western Freeway	1.24	0.23	6.73	0.8046
Western Highway	0.92	0.11	7.62	0.9398
Calder Highway	0.27	0.03	2.23	0.2264
Hume Highway	0.23	0.08	0.64	0.005
Midland Highway	0.68	0.01	48.1	0.6895
Goulburn Valley Highway	0.46	0.09	2.27	0.3374
Eastern Freeway	0.25	0.15	0.41	<0.0001
Metropolitan Ring Road/ Western Ring Road	0.85	0.61	1.17	0.3215

Evaluation results are presented in terms of effect on all casualty crashes, serious casualty crashes, all crash types and targeted crash types. Highlighted in each table are the results that produced statistically significant results. Given the limited availability of data and the possibility that insufficient sample size could produce insignificant findings [25], the paper refrains from making conclusions on findings that did not produce statistically significant findings irrespective of whether the findings were positive or negative. The discussion section explores potential reasons for other routes not producing statistically significant findings.

Table 4 presents results for reduction in casualty crashes (all crashes) associated with wire rope barrier installation. Relative risk refers to the risk of a casualty crash after treatment *relative* to the risk prior to treatment, taken as one. The risk of a casualty crash over all the evaluated routes after treatment was 0.71 (p=0.0003), or the risk of a casualty crash was reduced by an estimated 29% as a result of barrier installation. The risk of a casualty crash on the Hume Highway at the treated sites was 0.23, relative to the risk of one prior to treatment, indicating an estimated reduction of 77% (p=0.005) in the risk of a casualty crash associated with wire rope barrier use. A similar reduction of 75% (p<0.0001) in casualty crash risk was evidenced on the Eastern Freeway at treated sites.

Table 5 presents reductions in serious casualty crashes of all crash types associated with wire rope barrier installation. Overall risk of a fatal or serious injury crash reduced by 42% (p=0.0005) across all routes considered. Risk on the Hume Highway reduced by 77% (p=0.0165) and on the Eastern Freeway by 76% (p=0.0003).

Table 6 presents the associated reductions when considering only the crashes expected to be addressed by the barrier, namely, run-off-road or head-on crashes. Casualty crashes across all the routes considered were estimated to be reduced by 44% (p=0.0013). Considering each individual route, targeted crashes along the Hume Highway were expected to reduce by 79% (p=0.0322) and along the Eastern Freeway by 86% (p<0.0001).

Table 5. Results for fatal and serious injury crashes – all crashes

Road Section	Relative Risk	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Statistical Significance
Overall	*0.58*	*0.43*	*0.79*	*0.0005*
Monash Freeway	0.92	0.54	1.57	0.7713
Princes Highway West	0.65	0.16	2.61	0.5486
Princes Highway	2.5	0.43	14.4	0.3046
Western Freeway	0.75	0.07	8.36	0.8151
Western Highway	0.29	0.01	16.4	0.549
Calder Highway	0.4	0.04	3.7	0.4195
Hume Highway	0.23	0.07	0.76	0.0165
Midland Highway	0.71	0.01	54.1	0.8761
Goulburn Valley Highway	0.13	0.002	8.19	0.3376
Eastern Freeway	0.24	0.11	0.53	0.0003
Metropolitan Ring Road/ Western Ring Road	0.75	0.42	1.34	0.3267

Table 6. Results for casualty crashes – targeted crashes

Road Section	Relative Risk	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Statistical Significance
Overall	*0.56*	*0.40*	*0.80*	*0.0013*
Monash Freeway	1.12	0.54	2.34	0.7609
Princes Highway West	1.69	0.10	27.90	0.7148
Princes Highway	0.73	0.16	3.43	0.6912
Western Freeway	2.42	0.36	16.30	0.3656
Western Highway	2.37	0.23	23.90	0.4650
Calder Highway	0.69	0.07	6.62	0.7457
Hume Highway	0.21	0.05	0.87	0.0322
Midland Highway	1.50	0.01	154.00	0.8638
Goulburn Valley Highway	0.57	0.10	3.38	0.5369
Eastern Freeway	0.14	0.06	0.33	<0.0001
Metropolitan Ring Road/ Western Ring Road	0.80	0.41	1.57	0.5170

The greatest reductions were evident when only targeted crashes that produced either serious or fatal injury outcomes were considered (Table 7). Reductions in this crash category across the sites were estimated at 56% (p=0.0023), while the individual routes experienced reductions of 87% (Hume Highway, p=0.0484) and 83%, (Eastern Freeway, p=0.0023).

A summary of the statistically significant findings is presented in Table 8.

These reductions were converted into the approximate number of crashes saved as a result of barrier installation (Table 9).

Table 7. Results for fatal and serious injury crashes – targeted crashes

Road Section	Relative Risk	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Statistical Significance
Overall	*0.44*	*0.26*	*0.75*	*0.0023*
Monash Freeway	0.71	0.24	2.14	0.545
Princes Highway West	1.47	0.08	25.30	0.7921
Princes Highway	2.86	0.44	18.70	0.2732
Western Freeway	2.25	0.11	45.70	0.5977
Western Highway	0.49	0.01	30.40	0.7372
Calder Highway	1.06	0.09	12.10	0.9654
Hume Highway	0.13	0.02	0.99	0.0484
Midland Highway	2.00	0.02	256.00	0.7794
Goulburn Valley Highway	0.20	0.003	14.00	0.4545
Eastern Freeway	0.17	0.06	0.53	0.0023
Metropolitan Ring Road/ Western Ring Road	0.53	0.17	1.63	0.2702

Table 8. Crash reduction summary (statistically significant findings)

	Casualty Crashes		Serious Casualty Crashes	
	All Crashes (%)	Targeted Crashes (%)	All Crashes (%)	Targeted Crashes (%)
Overall	29	44	42	56
Hume Highway	77	79	77	87
Eastern Freeway	75	86	76	83

Table 9. Number of casualty and serious casualty crashes potentially saved over the treatment periods (all crash types and targeted crashes)

	Casualty Crashes							
	All Crash Types				Targeted Crash Types			
	After	Reduction Factor (%)	Expected	Saved	After	Reduction Factor (%)	Expected	Saved
Overall	501	29	705	204	99	44	176	77
Hume Highway	4	77	18	14	2	79	10	8
Eastern Freeway	89	75	359	270	18	86	124	106

	Serious Casualty Crashes							
	All Crash Types				Targeted Crash Types			
	After	Reduction Factor (%)	Expected	Saved	After	Reduction Factor (%)	Expected	Saved
Overall	166	42	284	118	44	56	99	55
Hume Highway	3	77	13	10	1	87	8	7
Eastern Freeway	31	76	129	98	9	83	53	44

In terms of implied crash savings, 270 casualty crashes and 98 serious casualty crashes were estimated to be saved on the Eastern Freeway alone over an approximate period of six and a half-years; along the Hume Highway, 14 casualty crashes and ten serious casualty crashes can be expected to be saved over a 21-month period. Extrapolated to annual crash saving rates, around 43 casualty crashes on the Eastern Freeway and eight casualty crashes on the Hume Highway can be expected to be saved per year of treatment. With respect to serious injury, indicative serious injury crash savings per year were 15 for the Eastern Freeway and six for the Hume Highway.

Discussion

Wire rope barrier lengths across Victoria were evaluated to determine their effectiveness on crash reduction at the installed sites. Around 100 kilometres of barrier across ten major routes were included in the analysis, with varying lengths of barriers on the left, right and road median. Results were presented in terms of overall and individual route effects on all crash types and targeted crash types, with respect to both casualty and serious casualty injury outcomes. Overall program findings suggest reductions of 29% in all casualty crashes, 44% in targeted casualty crashes, 42% serious casualty crashes, and 56% targeted serious casualty crashes. When effect estimates were considered for the two individual routes that produced statistically significant results, reductions of around three quarters in all casualty crashes and serious casualty crashes were estimated for both the Eastern Freeway and Hume Highway, and between 79% and 87% for targeted (off-road and head-on) casualty crashes and targeted serious casualty crash types. The findings focused only on reduction in injury crashes. It is noted that the implementation of continuous lengths of wire rope barrier is likely to increase the frequency of crash occurrence overall [26].

In a study design such as this, inaccuracies within the data and limited data can affect overall findings. For example, study findings depend heavily on accurate location details of the treatment. Some verification of the barrier location details was undertaken to address this through video records of road infrastructure available from VicRoads. Where there appeared to be a definite discrepancy between data and on-road barrier location details, clarification was made through VicRoads communication. Similarly, the dataset did not permit differentiation between barrier-involved crashes and crashes occurring within a treated road section, suggesting that if only those affected by the treatment were considered, the reductions are likely to be greater. Moreover, the study results are based on crash number reductions only and have not taken into account effect of changes in traffic volumes.

Nevertheless, the study results are generally comparable with some of the overseas evaluations undertaken by Sweden, Canada, the US, NZ, and in New South Wales. Direct comparison has not been made, as comparison is difficult due to variations in parameters from one study to another. For fatalities in *all crash types*, evaluations in Sweden of a 2+1 wire rope barrier configuration indicate savings of up to 76% of fatalities on an 'undivided' 2+1 road, and up to 90% on freeways [11]. A subsequent evaluation of the effectiveness of cable barriers within 2+1 road layouts in Sweden indicated similar reductions, estimating a reduction in fatality rates of up to 82% on a 90 km/h road length [13]. A study in Alberta, Canada, of an 11 km long high-tension cable barrier installed on a median, produced preliminary results of 30 hits to the barrier over a ten-month period, none of which produced fatal injury consequences compared to the recent seven-year period prior to barrier installation along the same section of road which produced seven fatal crashes [27].

A preliminary study on the effect of wire rope barrier use on crash numbers in Oklahoma, US, found that fatalities reduced from six to one, and injuries reduced from 77 to eight, post-wire rope barrier installation [28] (approximate reductions of between 80 and 90%). Another US study of wire rope barrier effectiveness in Washington found average annual fatal median crash rates dropped from 7.2 per year to 0.8 per year (equating to a reduction of 89%) [29]. A study of 407 miles (655 km) of median cable barrier in Texas recorded a reduction of 18 fatalities and 26 incapacitating injuries (akin to serious injury definition of Victoria) [30] , in the first 12 months after barrier installation (a reduction of around 95%) [8]. Whole life cycle costs calculated in this study suggested a more favourable result for wire rope barriers over concrete barriers, contradictory to a UK study that found a form of concrete barrier, the Dutch Step Barrier, to produce a lower whole life cycle cost over a period of 50 years [31]. A NZ evaluation of around 3.5 km of median wire rope barrier estimated reductions in social costs of crashes at the site from $5,796,889 to $65,400 per year as a result of the installed wire rope barrier and reduced speed [32]. It was reported that maintenance costs increased post-barrier installation but that these costs were significantly offset by the savings in crash costs. Other potential disadvantages of the barrier when comparing it to alternatives such as concrete barriers include the potential ineffectiveness of a barrier after impact, thus requiring quicker repair time, periodic re-tensioning and the need for greater working width [33]. Table 10 summarises some of the above studies with respect to key parameters and findings.

In Australia, preliminary findings of the effectiveness of centre median wire rope barrier on the Pacific Highway in New South Wales suggest reductions of casualty crashes and cross-over crashes upon the installation of wire rope barrier [3, 34]. The results are expected to be confirmed through a subsequent study that will include a longer

Table 10. Summary of studies quoted and respective crash reductions

Country of Study	Key Parameters Evaluated	Findings
Sweden	Fatalities, All Crash Types	76%*, 90%^, 82%#
Canada	All Crash Types and Fatal Crashes	Reduction from seven fatal crashes to nil (100% reduction)
US (Oaklahoma)	All Crash Types, Fatalities, All Injuries	Reduction from six fatalities to one (83% reduction), 77 injuries to eight (90% reduction)
US (Washington)	Fatal Median Crash Rates	Reduction from 7.2 fatal median crashes annually to 0.8 (89% reduction)
US (Texas)	Fatalities and Incapacitating Injuries	Reduction of 18 fatalities and 26 incapacitating injuries (95% reduction)
NZ	Social cost savings among others	Reduction in social costs+ from $5.8M annually to $65,400 (99% reduction in costs)

* on "undivided" 2+1 roads; ^ on freeways; # on 2+1 roads with 90 km/h speed limits
+ as a result of barriers, and speed reductions

after-data period. As mentioned in the introduction, an early study completed by Szwed [14] on Victorian data produced reduction figures of approximately 92% of all run-off-road casualty crashes.

While the current study looked at combined reductions in both median and roadside crashes, most of the above studies looked predominantly at median crash reductions. Potential variations in crash dynamics of the two crash types including climbing any kerbs on the median, the respective proportions of run-off-road crashes on to the roadside and to the median along the treatment length, and driver behaviour on divided roads compared to undivided roads may each affect interaction with barrier and subsequent effect; no literature was available on this at time of publishing.

Based on the available data and budget constraints, project scope was restricted to the following: crash outcome categories were restricted to casualty and serious casualty only, with no distinction made between fatal and serious injury crashes. In addition, vehicle-specific analysis was not undertaken due to limited data. In particular, safety concerns raised by motorcyclists in relation to wire rope barriers have not been addressed in this paper, due in part to lack of adequate data within the existing dataset. This limited data on motorcyclist collisions with wire rope barriers in Australia creates difficulties in concluding safety effects of these barriers on motorcyclists [34, 35].
A Swedish study, however, found no evidence to suggest an increase in fatal and serious injury risk to motorcyclists as a result of wire rope barrier usage on 2+1 roads, instead, reporting a reduction of 32-35% in risk of fatal and serious injury to motorcyclists when allowing for mileage [13].
There are indications that wire rope barriers have the capacity to restrain heavy vehicles although the barriers are not specifically designed to cater for heavy vehicles [36]. Little research addresses this, however, and further study is recommended.

With respect to the study results, it seems somewhat unexpected that this study produced similar reductions of at least three quarters in all four categories of casualty crashes, serious casualty crashes, targeted casualty crashes and targeted serious casualty crashes on the individual routes. The following section explores potential explanations for these partly counterintuitive results. Firstly, results indicate high reductions in not only targeted crash types but *all* crash types in the vicinity of the barriers, including cross-traffic crashes, right-turn crashes and rear-end crashes - crashes less likely to be affected by wire rope barriers. The actual locations from which crashes were extracted may provide an explanation for this. As barriers are generally terminated on approach to intersections (and the individual routes being highways, few intersections would exist on the treated sections), it is likely that only a limited number of intersection crashes would have been included in the analysis. Therefore, the crash types within the 'all-crash' category and the 'targeted-crash' category are then expected to be similar, producing similar reduction factors. It could also be argued that barriers may have an overall calming effect on driving performance and hence instigate generally safer driving outcomes across all crash types.

Results also counterintuitively suggest similar reductive effects on serious casualty and all casualty crashes. As barriers paradoxically present a continuous roadside hazard while simultaneously protecting the road user from other roadside hazards, the presence of barriers would be expected to play a bigger role in reducing the severity of a crash as opposed to crash frequency itself [12, 26].
A possible explanation for this result is that the barriers potentially converted the serious casualty crashes into less severe outcomes (fatal to serious injury and serious injury

to minor), and notably, converted casualty crashes into property damage crashes, which were not included in the analysis.

The speed at which the crashes in the analysis occurred may also provide a possible explanation for the similarities in casualty and serious casualty crash reductions on the individual routes. The routes considered in the analysis were 100 km/h or 110 km/h zones. At this speed, and depending on traffic volumes, clear zone guidelines require roadside hazards to be in the vicinity of 14 metres from the edge of the carriageway [37]. At this clear zone width assuming uniform trajectory, a standard reaction time of 1.2 seconds, and typical departure angles, an errant vehicle travelling at 100 km/h is expected to collide with the object at 100 km/h, as the vehicle will travel over 30 metres prior to the driver activating the brakes[38]. Injury outcomes in these cases are expected to be serious. Proportions of casualty crashes are then likely to be similar to proportions of serious casualty crashes for targeted crash groups, hence both categories producing similar results. The study data indicated proportions of serious casualty run-off-road casualty crashes ranged from 20% to 100%; detailed crash analysis of the data would be required to investigate the extent of this influence.

Comments on differences in overall program reductions compared with individual route reductions are as follows. Results were produced with respect to individual routes and then additional analysis undertaken to give an overall indication of effectiveness across all the sites included in the analysis. The overall findings are based on substantially greater quantities of data than for individual routes, hence can potentially be considered a more reliable indicator of barrier effectiveness. However, the individual routes that produced statistically reliable findings have similar levels of statistical reliability and have confidence limits that overlap with those for overall effectiveness. This suggests that in statistical terms there is little basis for assuming a difference in the performance of barriers along the individual routes and those forming the overall sample evaluated.

Most of the routes analysed did not produce statistically significant findings. Barrier effects with non-significant results included relative risks of both greater than one and of less than one. For example, within the non-significant effects, relative risk was as low as 0.13 (p= 0.3376, ±0.002, 8.19 Goulburn Valley Highway) (Table 5), and as high as 2.86 (p=0.2732, ±0.44, 18.72, Princes Highway) (Table 7). The lack of significance and high variance in these results suggest that inadequate data exist to generate results along these routes that are credible, irrespective of effects being negative or positive. Statistical reliability in this study is influenced not only by treatment effect, but also by sample size [25] (i.e., adequate lengths of barrier, crash data quantities as well as adequate after-periods).
As barrier installation in Victoria has only gradually increased, long lengths of barrier installed early enough to provide lengthy after-periods were uncommon [39]. Additionally, barriers may not always have been introduced as a result of crash history or may be installed in short, intermittent stretches resulting in lengths of barrier with insufficient crash numbers associated with them. Such installation practices not only reduce the potential for effective barrier protection, given the degree of randomness associated with run-off-road crashes and the increased likelihood of errant vehicles slipping in between intermittent barrier lengths, it also limits the number of crashes that are appropriate to be included within the analysis. Notwithstanding these comments, it is quite possible that the lack of significance is an indication of barrier ineffectiveness. Given this uncertainty, it is suggested then that none of the non-significant effects be given much emphasis until a subsequent study can be completed with a larger dataset.

Conclusions

Roadside crashes continue to persist and a large-scale approach to address this severe crash problem is required. An evaluation was completed of limited sections of wire rope barriers installed on Victorian high-speed roads. Findings for the overall program suggested up to 56% reductions in specific crash types, and statistically significant results were produced for two of the ten individual routes; reductions of between 76% and 87% were estimated for these two routes. These reduction estimates compare well with other international studies, and as more data become available, further analysis is recommended to increase the likelihood of significant findings on individual routes. Wire rope barriers are proving to be particularly effective in reducing the severity of a run-off-road crash, while increases are predicted for property damage crashes. In response to the Victorian Parliamentary recommendations of 2010, should a large-scale mass implementation of these barriers be considered along high-speed roads, a structured, systemic implementation program rather than solely a crash-based approach is considered advantageous, capitalising on the safety and financial benefits to be gained from continuous, whole-route barrier installation. Further research to gain a more comprehensive understanding of this countermeasure is recommended, incorporating a larger and more detailed dataset, as well as evaluating the effects of barriers on all road users and the effects of barrier location.

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Crash performance of safety barriers on high-speed roads

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Abstract

The findings presented in this paper are based on Austroads-funded investigations of the in-service effectiveness of safety barriers on high-speed roads (that is, roads with 100 and 110 km/h speed limits). Based on past evaluations, the most promising was continuous application of flexible barriers on freeways addressing up to 86% of run-off-road and cross-median casualty crashes. Analysis of Victorian barrier crash data from high-speed roads suggested that the severity index for run-off-road casualty crashes (FSI ratio) was 0.58 for semi-rigid barrier crashes compared with 0.75 for tree crashes. Severity of run-off-road casualty crashes into semi-rigid barriers was comparable to those not involving a roadside hazard (FSI ratio of 0.55). In contrast, flexible barriers had the lowest FSI ratio of 0.38. Continuous flexible barriers appeared to be the most effective safety barrier solution among those reviewed.

Investigation of the effect of semi-rigid barrier offset from the edge line showed that the FSI ratio increased at a low rate with increasing barrier offset (~0.03, or 5% per m), although the relationship was not statistically robust. Combined with earlier research on barrier crash likelihood, the suggested ideal range for barrier installation could be in the range of 1.5 to 4 metres to allow for sealed shoulder provision. These findings may be useful in refinement of barrier selection and design guidance.

Keywords

Barrier offset, In-service, Run-off-road crash, Safety barriers, Severity

Introduction

This paper presents key findings arising from an investigation of the in-service effectiveness of safety barriers in controlling the likelihood and severity of run-off-road casualty crashes on high-speed roads. The findings presented here are drawn from a four-year Austroads study on improvements to roadside safety in the Safe System context. They extend on the previous research by focusing on in-service performance of barriers of different types and at different offsets.

Background

Run-off-road casualty crashes contribute significantly to the nation's road toll. Across Australia, approximately 30% of fatalities and serious injuries are caused by run-off-road crashes. Approximately half of these fatalities occur in rural and regional areas [1, 2].

The Safe System vision underpinning the national (NRSS) and Victorian (VRSS) road safety strategies [1, 2] seeks to prevent run-off-road deaths and serious injuries. This is progressed through promotion of solutions which minimise the occurrence of such crashes (e.g. electronic stability control in vehicles, improved linemarking), and through provision of more forgiving roadsides when such crashes occur. This latter approach involves the application of various roadside design and safety solutions aimed at improving the chances of recovery back onto the road (e.g. sealed shoulders). Further, it includes solutions deflecting or dissipating the kinetic energy of an errant vehicle so that occupants do not sustain life-threatening injuries. Part of this suite of solutions involves the installation of safety barriers along roadsides and medians to shield errant motorists from more severe roadside hazards.

Role of safety barriers

An assessment of roadside hazards may find that their removal, relocation or modification is not feasible (for example, where there are major structures such as bridge abutments, drop-offs or significant roadside trees). In such cases, safety barriers are typically considered. In recent years, more barriers have been applied in medians on high-speed divided and undivided roads to address run-off-road and head-on crash risk [3].