MONASH University
Accident Research Centre

EVALUATION OF THE EFFECTIVENESS OF FLEXIBLE BARRIERS ALONG VICTORIAN ROADS

Final Report

By

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Abstract:

Flexible barrier use is on the increase in Victoria as well as in many countries overseas. To date, little Victorian, or Australian, analysis has been undertaken of the effectiveness of these barriers in reducing, in particular, loss-of-control crashes. MUARC completed a before-and-after study of crashes at several Victorian sites treated with flexible barrier. The results are presented in this report.

Key Words:

Flexible barrier, wire rope barrier, cable barrier, effectiveness, Victorian evaluation, off-road crashes, head-on crashes, loss-of-control crashes

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Preface

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Contributorship Statement

Proposal/study design - NC, BC, SN
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EXECUTIVE SUMMARY

Loss-of-control crashes are a major and persistent crash category in Victoria that can comprise over fifty percent of fatalities in rural Victoria. While flexible barrier systems have been used nationally and internationally to address this crash type, little evaluation of the effectiveness of this particular barrier type has been undertaken in Australia.

An evaluation was commissioned by MUARC's Baseline Committee, with the primary objective of determining how effectively flexible barriers reduce casualty and serious casualty off-road crashes.

A total of 101,670 metres of road length installed with flexible barriers was included in the analysis along ten routes, namely, Monash Freeway, Princes Highway, Western Freeway/Highway, Calder Freeway, Hume Highway, Midland Highway, Goulburn Valley Highway, Eastern Freeway, Metropolitan Ring Road and Western Ring Road.

A quasi-experimental evaluation design was used in the study, comparing crash frequency at each treated road section to that at untreated road sections of the same route (control sites) over the same time periods, both before and after the treatment. Barrier installation was generally confined to either one side of the road (rarely being placed on both sides of a road section), or along the median. For crashes occurring within a treated road section, this evaluation was unable to differentiate between crashes in which the barrier was struck by the errant vehicle, and crashes in which the errant vehicle left the roadway in a direction that was away from the barrier. As a consequence, the results of estimating the true effectiveness of barriers in reducing injury severity along treated road sections are expected to be conservative.

Results indicate that barriers were associated with significant reductions in the risk of both casualty and serious casualty crashes. When effect estimates are considered for the two individual routes that produced statistically significant results, the Eastern Freeway experienced estimated reductions of 75% in all casualty crashes, 76% in serious casualty crashes, 86% when including only target (off-road and head-on) casualty crashes, and 83% for serious casualty target crash types. The Hume Highway experienced very similar effects, with 77% for all casualty crashes, 77% for all serious casualty crashes, 79% for target casualty crashes, and 87% for serious casualty target crashes.

These reductions align closely with findings overseas. Evaluations of flexible barriers in Sweden indicate savings of up to 76% in fatalities on an undivided road, and up to 90% on a freeway (Larsson, Candappa and Corben, 2003). A preliminary study on the effect of cable median barrier use on crash numbers in Oklahoma, U.S., found that fatalities reduced from six to one, and injuries reduced from 77 to eight, post flexible barrier installation (FHWA, 2008) – approximate reductions of between 80% and 90%. Preliminary results from a Canadian study of a 11 km median barrier suggested fatal and injury crashes decreased from seven fatal crashes over a five-year period to no fatal injury consequences over the evaluated ten-month period, (McGregor, Hassan and Lahey, 2008). While this Victorian analysis does not distinguish between fatal and serious injury crashes, the study findings are still comparable in proportions, with over three out of four casualty crashes being reduced as a result of flexible barrier implementation. Should only fatalities be considered, this figure is likely to be greater.

When considering the aggregate effects across all routes, an overall reduction of 29% in casualty crash frequency was estimated. An estimated reduction of 44% in crash frequency was found for all casualty crashes of the targeted crash types – off-road crashes and head-on crashes, across all sites.

When overall effects on serious casualty crashes alone were considered, the associated reductions estimated for all crash types increased from 29% to over 40%. Estimated reductions in risk in serious casualty crashes for the targeted crash types were also more pronounced at 56%.

Results are provided with respect to individual routes and then additional analysis undertaken to give an overall indication of effectiveness across all sites included in the analysis. The overall findings are based on substantially greater quantities of data than estimates for individual routes and hence can potentially be considered a more reliable indicator of treatment outcome. 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 no basis for assuming a difference in the performance of barriers along the individual routes, and the barriers forming the overall sample.

Many of the routes included in the analysis did not produce statistically significant findings. This is most likely a reflection of the limited data quantities at many individual sites, and in some cases, short after-periods of data available to the study. As flexible barriers have only relatively recently been implemented on a large scale on Victorian roads, gathering of adequate quantities of crash data to enable statistically significant findings on all routes may be a gradual process. Additionally, the potential to obtain statistically significant findings is also reduced when barriers are erected in intermittent lengths along the road, as opposed to one continuous length on both sides of the road, and where applicable, on medians.

This evaluation indicates that flexible barriers are likely to produce substantial reductions in the incidence, in particular, of off-road and head-on crashes for both casualty and serious casualty crashes. It is recommended that, to test for additional statistically reliable findings, collection of data continues and a second stage evaluation be undertaken along the same routes in this study and any other sites treated subsequent to this study at an appropriate time in the future. Consideration should also be given to obtaining more detailed data on crash and barrier interaction, to more readily establish the effectiveness of a single length of barrier.

1. INTRODUCTION

Off-road and head-on crashes are a significant crash concern on Victorian roads, comprising up to 40% of fatalities overall and over 50% in rural Victoria, (Larsson, Candappa and Corben, 2003).

Flexible barriers, also known as wire rope safety barriers and cable fences, are utilised nationally and internationally to combat these off-road and head-on crashes, and have been installed along Victorian roads for several years, with on-road installations of over 1,000 km (VicRoads, 2006).

Flexible barriers consist of highly tensioned wire rope that is supported by steel posts. The barriers are manufactured in two main forms: three to four wire ropes are either placed parallel to the road surface; or the top two wire ropes are placed parallel to the road surface and the bottom two are intertwined with each other, (Figure 1, a and b).

(a) **(b)**

Figure 1 – photos of two forms of wire rope barrier, (a) four-rope parallel and (b) two parallel, two intertwined. Sources: Candappa (a); and Larsson et. al. (2003)

Flexible barrier function entails the ropes deflecting upon vehicle impact, absorbing much of the energy of the crash. The resultant residual energy poses reduced threat to the vehicle occupant. The posts are designed to collapse upon impact, allowing the vehicle to be gradually decelerated to a standstill. There appears to be little potential for rebound due to the collapsing of the posts and rope deflection that ensues after collision.

Evaluations conducted overseas associate the use of flexible barriers with major reductions in injury consequence for targetted crash types, with some studies indicating up to 90% reductions in fatalities of some crash types (Larsson, et. al, 2003). There appears to have been no large-scale evaluation of the effectiveness of these barriers in Victoria at the time of this analysis.

To provide local statistics on the barrier effectiveness, an evaluation of Victorian data was undertaken by Monash University Accident Research Centre (MUARC), through the combined sponsorship of Victoria's Department of Justice, Transport Accident Commission, Victoria Police and VicRoads.

2. AIMS AND OBJECTIVES

The aim of this study was to establish the effectiveness of flexible barriers in targetting off-road and head-on crashes by estimating the reduction in the frequency and injury outcomes of these crashes, after barrier installation. The main focus was on serious and fatal injury off-road crashes, although the impacts on all crash types and all casualty crashes were also investigated.

Initially, aims included analysing barrier impacts on various road-user groups, including drivers, motorcyclists, trucks and tourist coaches. However, the data available on these specific road user groups were inadequate to enable any meaningful analysis by road-user category.

3. METHOD

The overall project method involved determining the location of installed flexible barriers along Victorian roads and undertaking a before and after analysis of police-reported crash data.

3.1. TREATMENT DATA

VicRoads provided MUARC with data on each of the treated sites. Individual VicRoads regions were requested to provide data details of the wire rope barrier installed within the region, based on existing records. The various regions provided data of different levels of detail.

Fields provided by VicRoads included:

- Treatment ID;
- Road name;
- Route ID and road number;
- Barrier location on carriageway (median, right roadside, left roadside);
- Barrier start and end chainage;
- Barrier type; and,
- Installation date.

Of particular importance were the location details of the barrier, in GPS coordinates; where barrier locations were supplied in chainage these were converted to GPS coordinates. Barrier lengths varied greatly depending on the hazard being protected, crash history and road geometry.

Some verification of the barrier locations was undertaken as a quality control measure, through the use of video recordings of existing road infrastructure conditions. Information such as distance from the traffic lane, and hazards in the immediate vicinity were sought where available. However, inadequate data quantities were produced to allow analysis of these parameters.

Focus was placed on analysing barriers along the major highways as these proved to provide the most reliable and readily available data records.

Casualty Crash Data

Police-reported casualty crashes in Victoria over the period January 1995 to October 2007 inclusive, were utilised for the analysis. Crash numbers of the 2,576 casualty crashes that occurred within a 50 metre arc of treated site locations were provided by VicRoads. These were matched to casualty crash data from VicRoads' Road Crash Information System (RCIS) which contains extensive information on reported casualty crashes. Critical data fields used in the study were:

- Casualty crash date;
- Crash severity;
- Road name and type;
- Speed zone;
- Postcode of crash location; and
- The Definitions for Classifying Accidents (DCA) codes.

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 casualty numbers.

Crashes of all DCAs (Definitions for Classifying Accidents) during the five years prior to the estimated installation date of the barrier were identified along with crashes in the period after treatment installation.

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 in to parked vehicle/object

The "All-Crash" category included all DCAs.

This evaluation method considered all crashes along the entire site in question, rather than isolating the crashes that would be relevant to the specific barrier length. It also did not distinguish between sites that had only one barrier length and sites that had four barrier lengths.

3.2. ANALYSIS

Study Design

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 flexible 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.

Choice of Control Groups

Selection of control groups in a quasi-experimental design is a balance between matching of specific site characteristics in order to control for confounding influences on crash trends, and maintaining a sufficient number of crashes to ensure adequate statistical power in the analysis. 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. These might include major road safety programmes and socio-economic factors affecting road trauma in Victoria (Newstead, Cameron, et al., 1995), as well as changes in the local area such as traffic flow.

Having been provided with data identifying the treated sites, control sites were selected as follows:

- For rural areas, where flexible barrier treatments were applied in a non-continuous manner, selection was made of untreated lengths of the same road that were confined to the same postcode of the treated sites (and any lengths in between);
- Where treatments were applied along whole lengths of road, as per the Eastern and Monash Freeways, another section of the same road was selected as the control;
- Control sites for the Metropolitan Ring Road/Western Ring Road were selected in the same way as for rural roads, i.e. untreated lengths of the same road section. This controlled for potential changes resulting from the fixed speed camera issue of 2003.

The Princes Freeway West was excluded from the evaluation due to the apparent removal of flexible barrier treatments during the analysis period as a consequence of road works. In addition, a small section of the Eastern freeway identified as “treated” in the supplied data was allocated to the control length due to the presence of New Jersey concrete barrier rather than flexible barriers.

Extraction of Treatment and Control Group Data

Matched casualty crash data were used to extract treatment and control crash counts during the before and after periods for each road section. **Only crashes that occurred in 100 km/h and 110 km/h speed zones were included.** This ensured that treatment and control sites had similar characteristics. For example, crashes occurring in and around rural towns that would have been otherwise allocated to the control group were not included in the analysis due to their reduced speed limits.

Before and after periods were determined using relevant installation date information for each road section (Table 1). The casualty crash data start date of January 1995 ensured that at least five years of pre-treatment crash history was included in the analysis across all sites (the minimum period was 5 years and 11 months) thus minimising the possibility of regression-to-the-mean effects. In addition to this, to further address regression to the mean, the maximum amount of available after-treatment crash data were analysed. Given casualty crash data were available until October 2007 for the analysis, this meant that between 10 months to over 6 years of after-treatment data were utilised across road sections.

Table 1 Installation Dates and Before and After Periods for each Road Section Analysed

Road Section	Installation Dates	Before Period	After Period
Monash Freeway	Aug 02 – Apr 03	Jan 95 – Jul 02	May 03 – Oct 07
Princes Highway West	Mar 06	Jan 95 – Feb 06	Apr 06 – Oct 07
Princes Highway	Jun 06	Jan 95 – May 06	Jul 06 – Oct 07
Western Freeway	2003 – 2004	Jan 95 – Dec 02	Jan 05 – Oct 07
Western Highway	2004 – 2006	Jan 95 – Dec 03	Jan 07 – Oct 07
Calder Highway	2003 – 2005	Jan 95 – Dec 02	Jan 06 – Oct 07
Hume Highway	2001 – 2005	Jan 95 – Dec 00	Jan 06 – Oct 07
Midland Highway	2005	Jan 95 – Dec 04	Jan 06 – Oct 07
Goulburn Valley Highway	2003	Jan 95 – Dec 02	Jan 04 – Oct 07
Eastern Freeway	Dec 00 – May 01	Jan 95 – Nov 00	Jun 01 – Oct 07
Metropolitan Ring Road/Western Ring Road	Jun 01 – May 02	Jan 95 – May 01	Jun 02 – 19 Dec 05*

* *Crashes from the 20th of December, 2005 were not included in the analysis due to the opening of the Craigieburn bypass.*

Crash severity levels and DCA codes were used to extract crash counts into the following analysis categories:

- Casualty Crashes;
- Casualty Crashes – Off-Road/Head-on;
- Fatal and Serious Injury (Serious Casualty) Crashes; and,
- Fatal and Serious Injury (Serious Casualty) Crashes – Off-Road /Head-on.

Statistical Analysis Methods

Count data assembled for analysis in a quasi-experimental before and after-treatment/control design define a two by two contingency table. The aim of the statistical analysis is to estimate the percentage change in casualty crash frequency from before treatment to after treatment at the treated sites relative to that at the control sites. 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 show 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 (Breslow and Day, 1987). 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 (1986a, 1986b).

The log-linear Poisson regression approach to analysing quasi-experimental road safety evaluation designs was originally proposed by Brühning and Ernst (1985). Modifications of the method have been successfully applied by Newstead and Corben (2001) in their evaluation of the TAC-funded Accident Blackspot programme implemented in Victoria during 1992 to 1996, and more recently in the evaluation of crash effects of strip shopping centre treatments in Victoria (Scully, J., Newstead, S. and Corben, B., 2008).

The analysis method demonstrated by Brühning and Ernst (1985) 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 2.

Table 2 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.

$$\ln(n_{ijk}) = \beta_0 + \beta_i + \beta_{ij} + \beta_{ik} + \beta_{ijk} \qquad (1)$$

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.

$$\Delta_i = 100 \times (1 - \exp(\beta_{ijk}))\% \qquad (2)$$

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 (1985) and were used to estimate the overall programme effect of the analysed sections of road treated with flexible barrier.

Regression-to-the-Mean

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. If the treatment effect at the site is evaluated using the same inadequate casualty crash data from which the site was selected for treatment, the results of the evaluation will be spurious. Put in lay terms, wire rope barrier installation at sites has generally been installed on a crash history basis; that is at sites that have already been identified as having a crash problem. The regression-to-the-mean concept in this context states that if a site has already a poor crash history, by pure chance, irrelevant of any treatment, there is potential for its crash history to improve, or for the crash numbers at this site to 'regress to the mean' number of crashes. It is important then to allow for this tendency when associating any reductions in crash numbers simply with the treatment.

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, attempts were made to minimise any overlap 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.

4. RESULTS

This section presents the results of evaluations of the effectiveness of flexible barrier use in Victoria.

A total of 101,670 metres were included in the analysis along ten routes, namely, Monash Freeway, Princes Highway, Western Highway/Freeway, Calder Highway, Hume Highway, Midland Highway, Goulburn Valley Highway (GVH), Eastern Freeway, Metropolitan Ring Road (MRR) and Western Ring Road (WRR). The Hume Highway had the longest total length of barrier, (19.9 km) followed by the Western Ring Road (19.0 km). The shortest total length was 235 m on the Midland Highway, (see Table 3). Continuous lengths of barrier varied from around 20 m (Metropolitan Ring Road) to over 3 km (Western Ring Road).

Table 3 – Lengths of flexible barrier included in the analysis, by route

Routes	Metres
Monash Freeway	17685
Princes Highway	3343
Western Highway/Freeway	16167
Calder Highway	9031
Hume Highway	19923
Midland Highway	235
Gouburn Valley Highway	3815
Eastern Freeway	7106
Metropolitan Ring Road	5394
Western Ring Road	18972
Total	**101670**

Barrier installation generally appeared to be confined to either the right or left side of the carriageway, or along the median (Table 4). The distribution of barrier location between left, median and right sides of the road was overall, fairly even, with around 31 km installed on the left side of the road, 40 km along the median, and 30 km on the right roadside. Some adjustments were made to account for location data recorded with respect to forward and reverse chainage.

Table 4 – Location of barrier within specified route section

Barrier Location	Metres
Total left	31441
Total median	40364
Total right	29863

The evaluation findings are presented in terms of relative risk: the risk, for example, of a casualty crash occurring at an existing site with no treatment being "one" and the modified risk after treatment introduction being described relative to this.

Table 5 provides estimated relative risks for all casualty crashes associated with barrier introduction and Table 6 provides estimates for the fatal and serious injury crash subset. Table 7 and 8 provide estimated relative risks for casualty crashes, and fatal and serious injury crashes respectively for the "off-road/head-on" crash subset. Expected reduction when considering all the sites included in the study for each of these categories are also included. In addition to the estimated relative risks associated with the flexible barrier installations, are 95% confidence limits as well as the statistical significance for each case. Low statistical significance values indicate the crash effect is unlikely to have arisen through chance variation in the data. Results that were considered to be statistically significant (at the 5% level) have been highlighted within each table.

Table 5 shows that the barriers were associated with a very strong statistically significant 29% reduction in casualty crashes overall compared to the control sites. For the individual road sections, the Hume Highway and Eastern Freeway produced statistically significant results. In particular, relative risk in total casualty crashes of 0.23 (p=0.005) and 0.25 (p<0.0001) were seen for the treated sections of the Hume Highway and Eastern Freeway respectively. That is, relative to its original condition, the risk of a casualty crash occurring along the treated section of the Hume Highway was estimated to have reduced by 77% as a result of the introduction of flexible barrier; likewise an estimated reduction in relative risk of 75% in total casualty crashes along the Eastern Freeway was seen as a result of the flexible barrier treatment.

Table 5 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

When considering only fatal and serious injury crashes, the overall reductions appear to be more substantial, Table 6 indicating a statistically significant reduction in relative risk of 42% in all fatal and serious injury crashes when considering all treated routes. Again, Hume Highway and Eastern Freeway both produced statistically significant reductions, and the reductions were very similar to those for casualty crashes only; 77% (p=0.0165) and 76% (p=0.0003) respectively.

Table 6 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

Many crashes that occur along these routes are not necessarily targetted by barrier treatment and so impact was also analysed with respect to targetted crashes only, namely "off-road" and "head-on" crashes. Table 7 indicates that when these crashes are singled out, the same patterns of statistical significance were produced, however the estimated reductions were more pronounced. Overall across all sites, for casualty crashes in the 'target crash' category, reductions were shown to be around 44% (p=0.0013). On individual routes that produced statistical findings, the barriers were found to be highly effective, barriers along the Hume Highway estimated to reduce casualty off-road and head-on crashes by 79% (p=0.0322); and on the Eastern Freeway, by 86% (p<0.0001).

Table 7 Results for Casualty Crashes – Targetted 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

Flexible barriers have the predominant aim of reducing targetted crashes that have serious or fatal injury consequences, Table 8 thus presents analysis findings that are of most relevance when establishing flexible barrier effectiveness. Table 8 indicates that when considering all the routes within the study highly significant reductions of 56% (0.0023) were estimated as a result of the barrier installations. The Hume Highway and Eastern Freeway again produced statistically significant results, with estimated reductions in fatal and serious casualty crashes of the target types of 87% (p=0.0484) and 83% (p=0.0023) respectively. Table 9 provides a summary of the statistically significant findings.

Table 8 Results for Fatal and Serious Injury Crashes – Targetted 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 9 Crash Reduction Summary (Statistically Significant Findings)

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

These estimated reductions can provide inferred casualty and serious casualty crashes saved as a result of flexible barrier installation. Table 10 focusses on the savings for only the routes that produced statistically significant findings, and presents the number of crash savings implicit from the above reduction factors.

Table 10 Implicit Number of Casualty and Serious Casualty Crashes Potentially Saved over the Treatment Periods, (All Crash Types and Targetted Crashes)

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

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

When considering all treated sites, flexible barriers are estimated to have effected around 200 casualty crash savings during the combined after-periods, nearly 120 serious casualty crashes of all types, over 75 targetted-casualty crash savings, and 55 targetted-serious casualty crash savings over the combined after-periods.

Eastern Freeway saw savings ranging from 270 casualty crash savings of all crash types in an after-period of approximately six years and four months, down to 44 targetted-serious casualty savings over the same after-period. Hume Highway crash savings were estimated to range from 14 casualty crashes to seven targetted-serious casualty crashes over a 21-month period.

5. DISCUSSION

Flexible barrier lengths across Victoria were evaluated to determine how effectively they reduced the incidence of crashes at installed sites. Over 100 km of barrier across ten major routes were included in the analysis, with similar lengths of barriers on the left, right and centre of the road.

Results were presented in terms of overall and individual route effects on all crash types and targetted-crash types, with respect to both casualty and serious casualty crash outcomes.

Results suggest that where findings were statistically significant, substantial reductions in crash numbers can be expected.

When considering the individual routes that produced statistically significant findings, namely the Hume Highway and the Eastern Freeway, the effects are more pronounced, the barriers estimated to reduce by three quarters, the incidence of both casualty and serious casualty crashes. In terms of crash savings, an implied 270 casualty crashes are estimated to be saved on the Eastern Freeway alone over around a six and a half-year period, and 98 serious casualty crashes; along the Hume Highway, an indicative 14 casualty crashes and ten serious casualty crashes can be expected to be saved over a 21-month period. As symptomatic 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 are 15 and six for the Eastern Freeway and the Hume Highway respectively.

In reality, flexible barriers are intended to target off-road crashes and head-on crashes; so as might be expected, when only these targetted crashes are taken into account, evaluation findings suggest further reductions in both casualty and serious casualty crashes. Between 83% and 87% of serious casualty crashes are estimated to be prevented along one route through the use of these barriers; implicitly, this indicates savings of around 44 and 7 targetted serious casualty crashes on the Eastern Freeway and the Hume Highway respectively. Indicative annual crash saving rates for targetted casualty and serious casualty crashes for the Eastern Freeway and Hume Highway respectively, are 17 and four for casualty crashes; and seven and one for serious casualty crashes.

When considering total effects over all the sites included in the analysis, expected reductions in all types of casualty crashes are around a third, over the accumulated after-periods. Implicitly, around 200 casualty crashes were estimated to be saved during the total after-periods considered within the study as a result of the use of flexible barrier.

When overall effects on serious casualty crashes of all crash types alone were considered, the reduction effect increases to over 40%, or implies nearly 120 serious casualty crashes can be saved over the combined after-periods included in the study.

Results are provided with respect to individual routes and then additional analysis undertaken to give an overall indication of effectiveness across all sites included in the analysis. The overall findings are based on substantially greater quantities of data than estimates for individual routes and 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 no basis for assuming a difference in the performance of barriers along the individual routes and those forming the overall sample evaluated.

Considering around 100 km of barrier were included in the analysis, and around an estimated 200 casualty crashes can be saved, an estimate of two casualty crash savings per kilometre of barrier installed can be suggested as an indicative rate of effectiveness for flexible barrier usage. Similarly, for the individual routes, suggestive casualty crash saving rates range from 38 casualty crash savings per kilometre of barrier (Eastern Freeway) to one casualty crash per 1.5 kilometres of barrier (Hume Highway). Alternatively, for each km of barrier installed, annually, at least six casualty crashes are estimated to be saved on the Eastern Freeway, and one every three years on the Hume Freeway.

Of the effectiveness parameters provided in this report, changes to the relative risk present one of the clearest means of establishing effect. As can be seen, on both the Eastern Freeway and the Hume Highway, the relative risk is very similar after treatment for both routes, indicating barriers were equally effective in reducing crash frequencies and severity along both routes. When the relative risk is extended to take the form of implied crashes saved, differences that emerge could misleadingly suggest barriers are effective on one route more so than on another. These differences generally are likely to be related to the initial road and roadside conditions, existing roadside hazards, and hazard proximity to travel lane. Additionally, with respect to the Eastern Freeway and the Hume Highway, increases in crash numbers at the controls for the Eastern Highway sites accentuates reductions at the treated sites; conversely, reductions in overall crash numbers along the Hume Highway indicate comparatively fewer overall crash reductions specifically due to the barriers.

The following is a general discussion of the results and is provided as a basis for further discussion.

The results of this study tend to be conservative for a number of reasons. Firstly, the number of lengths of barrier within the one site can influence greatly the overall estimated effectiveness of the barriers. Much of the treated sites in this study had only one side of the road treated with barrier. That is, on divided roads, out of four possible treatment locations – left roadside of carriageway, left side of median, right side of median and right roadside of carriageway – treatment effects presented here are generally based on barriers only along one side of the road. However all crashes in the vicinity were included in the analysis, suggesting that should the treatment site be comprehensively treated with barriers on all sides, the effects are likely to be even larger.

Secondly, due to limited data the actual location of barrier length on the carriageway (e.g., left roadside) was not taken into account in this study when identifying target crash types relevant to the site; rather all target crash types in the vicinity of the barrier length were considered for before and after comparisons. So, for a site that had barrier installed on its left roadside, a prevalent off-road crash issue to the right would not be expected to be addressed by a barrier on the left-hand side but was still included in the total crash numbers in the analysis. This suggests that actual effectiveness again may be larger.

Finally, modifications to control sites over the study periods may also have impacted on estimated reductions. While care was taken to select control sites that provided a consistent road standard over the study period, it is possible that treatments such as shoulder sealing, or other forms of barrier may have been introduced at the controls, potentially increasing safety at the control site and thus, reducing comparative effectiveness for the treated site.

These not withstanding, the study results are comparable with some of the overseas evaluations undertaken by Sweden and the U.S. Direct comparison has not been made as comparison is difficult due to variations in parameters from one study to another. For serious casualties (both fatal and serious injuries) for *all crash types*, evaluations in Sweden of a 2+1 flexible barrier configuration[1] indicate savings of up to 76% of fatalities on an undivided road, and up to 90% on a freeway (Larsson et. al, 2003). A study in Alberta, Canada, of an 11 km long 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 a recent five-year period prior to barrier installation along the same section of road which produced seven fatal crashes, (MacGregor, Hassan and Lahey, 2008). Another preliminary study on the effect of cable median barrier use on crash numbers in Oklahoma, U.S., found that fatalities reduced from six to one, and injuries reduced from 77 to eight, post flexible barrier installation (FHWA, 2008) – approximate reductions of between 80 and 90%. While this Victorian analysis does not distinguish between fatal and serious injury crashes, the study findings are still comparable in proportions, with over three out of four casualty crashes being reduced as a result of flexible barrier implementation. Should only fatalities be considered, this figure is likely to be greater.

The difference in impact on crash reductions when comparing specific types of crashes with all crashes, on the other hand, does not appear to be that great. Results indicate that barrier installation on individual routes can reduce targetted crash types by up to 87%; interestingly, estimated reductions in all crash types are nearly as high, at about 75%. While not specifically analysed as part of this project, it is expected that other crash types such as cross-traffic crashes, right-turn crashes and rear-end crashes would also be included in the total crash numbers at the treated site. Therefore, it would be expected that where all crash types are included, estimated reductions would be considerably less than reductions estimated for targetted crash analyses. The counterintuitive result is possibly explained by exploring the locations from which crashes were extracted. While analyses that rely on real-world crash data have some inherent limitations (which are discussed later), in general crashes occurring in the vicinity of the existing barriers were included in the before and after analysis. As barriers are generally terminated on approach to intersections, it is likely that only a limited number of intersection crashes would have been included in the analysis. The crash types within the "all-crash" category therefore and the "targetted-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.

Barriers, however, can also be seen as a continuous roadside object, suggesting that barrier installation per se is unlikely to reduce greatly *overall* crash numbers; rather, that injury levels are more likely to be mitigated (NCHRP, 2003; State of North Carolina, 2007). As mentioned via introduction, flexible barriers function by deflecting upon vehicle contact thereby absorbing much of the impact energy, the residual energy is less likely to produce highly severe injury outcomes. One likely explanation for the similarities in reductive effects on targetted serious casualty and all casualty crashes is that flexible barriers have potentially converted the serious casualty crashes in to less severe outcomes (fatal to serious injury and serious injury to minor), and notably, converted casualty crashes in to

[1] The 2+1 barrier system involves a road geometry that has one continuous lane in each direction and one centre lane alternating the permitted direction of travel at intervals of 1.5-2.5 km; flexible barrier is placed on the road pavement itself and physically separates the two directions of travel.

property damage crashes, which are not included in the analysis. That is, for a given speed, the injury outcomes are likely to be less severe with flexible barrier but the proportion of serious casualties and casualties may remain similar due to these injury outcome conversions. It is worth remembering also that a crash is classified a serious injury if it involves a hospital visit; so the injury severity can range from life threatening levels to say a broken collarbone and still be classified as a serious injury. Further crash detail would be required to explore this.

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 individual routes. The routes considered in the analysis were generally within 100 km/h zones. At this speed, clear zone guidelines require roadside hazards to be around 9 m from the edge of the carriageway (Austroads, 2003). Assuming uniform trajectory and 1.2 second standard reaction time, for typical departure angles, an errant vehicle is expected to collide with the object at 100 km/h as the vehicle will travel over 30 m prior to the driver even activating the brakes. 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 target crash groups, hence both categories producing similar results. Crash data indicate proportions of off-road casualty crashes that had serious casualty outcomes ranging from 20% to 100%. Detailed crash analysis would be required to investigate the extent of this influence.

Many of the routes analysed did not produce statistically significant findings. Statistical reliability is influenced not only by treatment effect, but also by adequate barrier length and crash data quantities as well as adequate after-periods. As barrier installation in Victoria has only gradually increased, long lengths of barrier along one route installed early enough to provide lengthy after-periods are not common. Additionally, barriers may not always have been introduced as a result of crash history, so although a long length of barrier exists, there may have been insufficient crashes before and after to produce any statistically reliable estimates. Similarly, barriers may not always have been placed in long continuous stretches; instead they had often been installed in short, intermittent, stretches. This not only reduces the potential for effective barrier protection, given the degree of randomness associated with loss-of-control crashes, and so the increased likelihood of errant vehicles slipping in between intermittent barrier lengths; but it limits the number of crashes that are appropriate to be included within the analysis.

The current study relied heavily on accurate locations of barrier installations and accurate locations of crash occurrence, as the effect of the barrier was based on correctly matching crash to barrier. Inaccuracies within data can thus affect overall findings and can well affect likelihood of producing statistically reliable findings. For example, barrier and crash location data accuracy are dependent on a number of factors including, how the location data are recorded (GPS coordinates or chainage); the police officer at the scene of the crash (level of care in recording details of the crash, knowledge and experience, follow-up paperwork); transfer of data to VicRoads; and regional record maintenance of new barrier installations. These can all influence the resultant data used in the analysis. The use of control sites addresses these to a large extent as the final effect at the treated sites is relative to the control sites, so data inaccuracies are generally contained in both the control and treated site analysis, and thus are negated in the final results. In addition, some verification of the barrier location details was undertaken 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, modification to the data was made, as in the case of Princes Highway West, and on the Eastern Freeway.

6. RECOMMENDATIONS

This evaluation was commissioned by the Baseline Committee of MUARC with the primary objective of determining how effectively flexible barriers reduce casualty and serious casualty crashes off-road crashes. The resultant analysis has indicated that these barriers can have a significant reductive effect on crashes. On individual routes that produced statistically significant findings, flexible barriers were estimated to reduce all casualty crashes by between 75% and 77%, and serious casualty crashes by between 76% and 77%. Targetted off-road and head-on crash types were reduced by between 79% and 85% (casualty crashes), and 83% and 87% (serious casualty crashes).

Once sufficient time has elapsed, a subsequent study incorporating more data may lead to a greater number of routes with statistically reliable findings. Further evaluation detail can also be obtained, including undertaking an in-depth crash analysis at each site, examining the roadside hazards being protected and distance of these to the roadway, as well as measuring distance of barrier from roadway, and calculating respective effects.

It is recommended therefore that a list of desired information sought through such an analysis be created by VicRoads, and VicRoads' regions be notified, so detailed records of new installations can be kept progressively. A second stage, more detailed analysis of the same routes can then be undertaken. This can assist VicRoads in ascertaining more comprehensively effects of the barriers, which could help direct implementation strategies.

In the interim, as discussed with the PAC, it is recommended that a select number of routes be analysed with respect to:

- detailed barrier location (the actual side of the road on which it is located);
- detailed target crash analysis (which target crashes are relevant to the barrier length);
- and other available detail such as, whether there appears to be significant differences in effect between installation lengths, and if there exists a minimum threshold length for effectiveness; impact of barrier distance from travel lane; relative effectiveness of three-strand versus four-strand barrier type, and effect in relation to vehicle type.

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