An Evaluation of the Effectiveness of Flexible and Non-flexible Road Safety Barriers in Western Australia

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Title

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Abstract

Loss-of-control and run-off-road crashes constitute around a third of all serious casualty crashes in WA, and contribute to around 1,000 deaths and serious injuries in the state annually. Barriers of both flexible and non-flexible designs are continued to be used increasingly as a counter measure to reduce the severity of such crashes, with extended lengths being introduced across installation programs.

Besides studies conducted in America and Europe, there are very few studies on the effectiveness of the road safety barriers on Australian roads. The aim of this project is to evaluate the effectiveness of three types of road safety barriers that are in active and continuous use on WA roads, namely Flexible Wire-rope Barriers, Concrete Barriers, and Beams.

Results from the analysis will provide road authorities with more objective information to guide barrier investment choices.

Keywords

Road safety barriers, flexible wire-rope, concrete barriers, beams

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EXECUTIVE SUMMARY

Loss-of-control and run-off-road crashes constitute around a third of all serious casualty crashes in WA, and contribute to around 1,000 deaths and serious injuries in the state annually. Road safety barriers of both flexible and non-flexible designs are continued to be used increasingly as a counter measure to reduce the severity of such crashes, with extended lengths of barriers being introduced across installation programs.

Besides studies conducted in America and Europe, there are very few studies on the effectiveness of road safety barriers on Australian roads. The aim of this project is to evaluate the effectiveness of three types of road safety barriers that are in active and continuous use on WA roads, namely *Flexible Wire-rope Barriers*, *Concrete Barriers*, and *Beams*.

This study examined the effectiveness of the three types of road safety barriers in reducing (1) Run-off Road Crashes (all severities), and (2) Run-off Road KSI Crashes, in the period after installation of road safety barriers, compared to the frequencies and crash severities in the period before installation.

Overall results from this study found that road safety barriers were successful in reducing Run-off Road KSI Crashes when all sites (metropolitan and rural) were considered together. Overall, the 114 metropolitan and rural sites together reported a significant 76.7% reduction in Run-off Road KSI Crashes per million vehicles during the study period (p-value < 0.001). *Flexible Wire-rope Barriers* and *Beams* were highly successful in reducing Run-off Road KSI Crashes. *Concrete Barriers* were relatively less successful in reducing Run-off Road KSI Crashes.

The 83.4% reduction in Run-off Road KSI Crashes per million vehicles at sites treated with *Flexible Wire-rope Barriers* only, when compared to the 64.4% reduction in all Run-off Road Crashes (all severities) per million vehicles experienced by the same 41 sites, indicated that the *Flexible Wire-rope Barriers* were highly successful in reducing risk of crashes and crash severity in Run-off Road Crashes when all sites were considered, with crash severity being reduced at a higher rate than crash frequency.

The 16.9% reduction in Run-off Road KSI Crashes per million vehicles at all 8 sites treated with *Concrete Barriers* only, when compared to the 24.8% reduction in all Run-off Road Crashes (all severities) per million vehicles experienced by the same sites, indicated that the

Concrete Barriers were reducing crash severity at a lower rate than their reduction in frequency of crashes in Run-off Road Crashes.

The 74.5% reduction in Run-off Road KSI Crashes per million vehicles at all sites with *Beams* only, when compared to the 81.6% reduction in all Run-off Road Crashes (all severities) per million vehicles experienced by the same sites, indicated that the *Beams* were highly successful in reducing crash frequency in Run-off Road Crashes when all sites were considered, though the reduction in crash severity was at a slightly lower rate.

Reductions in Frequency and Severity in Run-off Road Crashes at Sites Treated with Road Safety Barriers in Western Australia

	No. of Usable Sites in Final Sample (n)	Estimate (Beta)	IRR	Std. Err. (IRR)	Probability 0 < p < 1	95% C.I. of IRR - Lower Bound	95% C.I. of IRR - Upper Bound	Reduction (%)
Run-off Road Crashes (all severities) per million vehicles								
Sites with Barriers of Interest Only	114	-1.122	0.325	0.004	< 0.001	0.317	0.334	67.5%
Sites with Flexible Wire-rope Barriers Only	41	-1.032	0.356	0.007	< 0.001	0.343	0.370	64.4%
Sites with Concrete Barriers Only	8	-0.285	0.752	0.012	< 0.001	0.728	0.777	24.8%
Sites with Beams Only	57	-1.693	0.184	0.005	< 0.001	0.174	0.195	81.6%
Run-off Road KSI Crashes per million vehicles								
Sites with Barriers of Interest Only	114	-1.456	0.233	0.008	< 0.001	0.218	0.249	76.7%
Sites with Flexible Wire-rope Barriers Only	41	-1.798	0.166	0.009	< 0.001	0.150	0.183	83.4%
Sites with Concrete Barriers Only	8	-0.185	0.831	0.006	< 0.001	0.818	0.843	16.9%
Sites with Beams Only	57	-1.365	0.255	0.015	< 0.001	0.228	0.286	74.5%

* *Increase/reduction in crashes per million vehicles is not statistically significant (p-value > 0.05).*
\+ *Negative reduction indicates an increase.*

It is recommended that the choice of future installations of barriers be given to *Flexible Wire-rope Barriers* or *Beams*, especially at locations likely to experience a higher risk of Run-off Road Crashes. The use of *Concrete Barriers* should only be reserved for special locations/functions such as bridges, or the separation of vehicle traffic from railway tracks, where a collision between a vehicle and a train would be so devastated that the absolute avoidance of such a collision would be a higher priority than any reduction in impact to the run-off vehicle and its occupants.

Limitations of the study included:

- A high number of sites that had barrier installation year(s) missing had to be excluded from the study as the correct “before” and “after” periods could not be meaningfully determined.
- Another limitation was the lack of availability of information regarding the operational dates of the road sections where the road safety barriers were situated. Since information on which of the sites having no meaningful “before” period (i.e. “greenfield” site that needed to be excluded from the study) was not readily available, the WAPOL crash data was utilised to “estimate” a list of such sites, which might not have been accurate.

Recommendations include:

- Maintaining accurate and timely recording of details of barrier treatments, including location, barrier types, barrier positioning, costs, start and completion dates and any other details relevant to future evaluations.

It is recommended that this evaluation be repeated should the installation dates of more sites become available.

ACKNOWLEDGEMENTS

This report was funded by Main Roads, WA. The authors would like to acknowledge the contributions of David Moyses and Tony Radalj, and to thank Bruce Snook, Syeda Sultana, Fritha Argus and Stuart Newstead for their time, support and feedback with various aspects of the data management and analysis related to this project.

1 BACKGROUND

In Western Australia (WA), approximately one-fifth of metropolitan, over one-third of regional, and nearly two-thirds of remote road deaths and serious injuries occur when a driver loses control of their vehicle and it leaves the road. These crashes constitute around a third of all serious casualty crashes which equates to approximately 1,000 deaths and serious injuries in the state annually (Office of Road Safety 2009).

Drivers can potentially drive their vehicle off road due to a variety of reasons, which can include inappropriate speed, poor perception, inadequate control, poor driving conditions, distraction or fatigue (Szwed 2011). When a driver loses control of a vehicle and it runs off the road, he has the potential to hit a roadside hazard and the vehicle may roll over. Vehicles are not designed to withstand the impact forces associated with a roll-over, thus leaving occupants unprotected (Szwed 2011). Collisions with roadside objects often involve fatal and serious trauma and are a great burden on society.

From an engineering perspective, a range of road and roadside safety treatments such as road safety barriers can be used to reduce the likelihood of a vehicle running off the road from a lapse in concentration or an error of judgement of the driver. Road safety barriers are designed to absorb energy that is released in a collision and prevent a more serious collision with roadside hazards. All systems of barriers can generally be divided into three broad types comprising rigid, semi-rigid, and flexible barriers (Szwed 2011), and are used increasingly as a counter measure to reduce the severity of loss-of-control or run-off-road crashes according to data from Main Roads Western Australia (MRWA).

1.1 The use of road safety barriers in Western Australia

There are approximately 368 km of single, left or right carriageways in WA that have been treated with some type of road safety barriers in WA according to data from MRWA.

Rigid safety barriers in general comprise of a reinforced concrete wall constructed to a profile and height that is designed to contain and redirect errant vehicles. Traditionally they have been used where there were significant truck volumes and containment was important. Rigid concrete barriers that have been installed in WA include *Type F Shape Concrete Barriers* and *Constant Slope Shape Concrete Barriers*.

Semi-rigid safety barriers in general include systems that have a steel beam attached to wooden or steel posts. These barriers deform permanently under impact and complete sections have to be replaced when hit. Semi-rigid barriers that have been installed in WA include *W Beams* and *Thrie Beams*. In particular, although *Tric Bloc Concrete Barriers* are made of concrete, unlike other concrete barriers they are not permanently fixed to the ground and can be moved if the impact is large enough in a collision. Therefore, these can also be considered a type of semi-rigid barriers.

Compared to rigid and semi rigid barriers, relatively large deflections can occur in *flexible barriers* such as wire-ropes during vehicle impact. Wire-rope barriers normally comprise wire ropes (generally 3 or 4 cables) supported on weak posts. Designs in general enable the cables to readily strip from the frangible posts during impact, thereby minimising snagging and ensuring that the vehicle is smoothly redirected. Upon impact the posts separate from the wire rope and the kinetic energy of the vehicle is largely dissipated through the deflection of the wire rope. In theory, when compared to more rigid barriers, flexible barriers manage the exchange of energy in a more controlled way for a vehicle that has encroached onto the roadside. Flexible wire-rope barriers that have been installed in WA include *Brifen* and *Flexfence*.

In more recent years, rigid barriers are generally only used where there is insufficient space to accommodate the deflections of semi-rigid or flexible barriers. However as experience with flexible barriers has grown, flexible barriers are being considered where only rigid barriers may have been considered in the past.

1.2 Effectiveness of road safety barriers in reducing crash severity

There have been a number of global studies that have examined the effectiveness of road safety barriers in reducing crash severity, either by analysing crash statistics (Kurucz 1984; Elvik 1995; Hu & Donnell 2010; Chitturi et al. 2011; Wang et al. 2011; Martin et al. 2013) or by way of computational simulations (Ren & Vesenjak 2005; Borovinsek et al. 2007; Itoh et al. 2007; Antonson et al. 2013). However, there have been very few Australian studies undertaken assessing the effectiveness of road safety barriers. One study completed by Monash University Accident Research Centre (MUARC) in 2009 examined the effectiveness of flexible wire-rope barriers in Victoria and found reductions of up to 89% in loss-of-control crashes (Candappa et al. 2009). There have been no studies undertaken in WA.

1.3 Aim

The overall aim of this study is to evaluate the effectiveness of three types of road safety barriers used on WA roads in reducing:

(1) Run-off Road Crashes (all severities), and
(2) Run-off Road KSI Crashes,

after installation of road safety barriers. The results will also be stratified by metropolitan and rural locations. The three barrier types of interest in this study are:

(1) Flexible Wire-rope Barriers (such as *Brifen* or *Flexfence*)
(2) Concrete Barriers (such as *Type F Shape Concrete Barrier* or *Constant Slope Shape Concrete Barrier*)
(3) Beams (such as *W Beams* or *Thrie Beams*)

In particular, *Tric Bloc Concrete Barriers* are Concrete Barriers but behave more similar to Beams if the impact is large enough in a collision. Out of all WA sites with such barriers installed, the necessary crash information required for analysis was available for three of these sites only. Given the relatively small sample size and the more ambiguous classification of such barriers, a decision was made to omit these from the study.

1.4 Significance

The results from the study will provide Western Australian road authorities with more objective information to guide barrier investment choices.

2 METHODS

2.1 Study design

This study examined the effectiveness of the three types of road safety barriers and adopted a quasi-experimental "before" and "after" comparison of (1) Run-off Road Crashes (all severities), and (2) Run-off Road KSI Crashes, at sites treated with three different road safety barriers that were implemented between 2000 and 2013.

2.2 Study data

Information on each treated site was obtained from the Road Safety Section at MRWA. Crash data were obtained from the Integrated Road Information System (IRIS) which is maintained by Main Roads WA. It was used to identify crashes involving road safety barriers which occurred in Western Australia during the period 1st January, 1995 to 31st December, 2014 hereinafter referred to as the study period.

The IRIS database contains detailed information on the characteristics of the vehicles involved in road crashes, crash circumstances, Police reported injury and road information related to the crash location. Crash data for the evaluation was obtained up to and including 31st December, 2014.

The definition of a crash used throughout this report is the definition used by the Road Safety Council in its annual publication "Reported Road Crashes in Western Australia 2013" (Office of Road Safety 2014). That is, a crash is "*any unpremeditated incident where in the course of the use of any vehicle on a road that was not temporarily closed off to the public, a person is injured or property is damaged. The crash must involve vehicle movement. Does not include collisions that occur due to a medical condition, deliberate acts (e.g. suicide attempts) or police chases*".

For the purpose of this report, a killed or seriously injured (KSI) crash was defined as a road crash that resulted in at least one person who was either "*killed immediately or died within 30 days of the day of the road crash as a result of the crash*" or "*admitted to hospital as a result of the road crash and who does not die from injuries sustained in the crash within 30 days of the crash*".

In WA, it is mandatory for the driver of a vehicle to report a traffic crash when the incident occurred on a road or any place commonly used by the public, e.g. carparks; and

- the incident resulted in bodily harm to any person; or
- the total value of property damaged to all involved parties exceeds $3000; or
- the owner or representative of any damaged property is not present.

Critical data retrieved for use in the study were:

- crash date;
- crash severity;
- local government area of crash; and
- specific crash location.

2.3 Sites

A list of road safety barriers installed on WA roads was provided by MRWA. The list was arranged such that each length of road with continuous configuration (placement/positioning) of consistent barrier types was recorded as an individual road section, with information on "road number.", "SLK from", "SLK to", "carriageway type", as well as "barrier type" and "year installed" for the left and/or right side of the carriageway. There exists 2,775 of such road sections on 239 roads or ramps with a unique "road number." in the MRWA list, comprising of approximately 368 km of either single, left, or right carriageways.

According to MRWA data, approximately 143 km of carriageways have *Flexible Wire-Rope Barriers* installed on at least one side of the carriageway; 59 km of carriageways have at least one type of *Concrete Barriers* installed; 118 km of carriageways have *Beams* as parts of their installations. There also exist carriageways treated with other older road safety barrier types such as *Lip Channels* (Single or Double Sided), and *Rail Barriers* (Two, Three or Four Rails), but such barrier types have been superseded and phased out in all new installation programs and were not included in the analysis.

2.4 Criteria for exclusion of non-usable sites

Not all 2,775 sites could be utilised for the study, only those sites with the necessary information remained in the final sample. There was a strict set of criteria, discussed with MRWA. Exclusion criteria included:

- Sites with missing installation year for the barriers on one or both sides of the carriageway.
- Sites with different installation years of barriers on the two sides of carriageway.

- Sites with an “after” exposure period of less than six months.
- Sites with no crashes reported in the “before” exposure period, prior to implementation of the road safety barriers.

There were 133 sites (87 metro and 46 rural) that contained one or a mixture of the three barrier types only and reported at least one crash in the “before” period. These sites formed the final sample for Phase One of the study.

Further, while most sites (n = 114) were assumed to have no other barrier type(s) installed prior to their current treatment, 19 of the Concrete Barrier sites along Kwinana Freeway were identified to have Beams installed as a prior treatment. These 19 sites had their Beams replaced by Concrete Barriers in 2006 as a more targeted separation of vehicle traffic from the then newly installed Perth to Mandurah railway tracks which began operation in 2007. At such sites, a collision between a vehicle and a train would be so devastated that the absolute avoidance of such a collision would be a higher priority than any reduction in impact to the run-off vehicle and its occupants. These 19 sites are analysed separately from the 114 sites to study changes in the frequencies of crashes in switching from Beams to Concrete Barriers.

2.5 Traffic volume

As traffic volume was known to grow from year to year, it was necessary to adjust for traffic volume associated with each site during the study period. MRWA provided the 2014 figures of annual average daily traffic (AADT) for all treatment sites utilised in the study. With an approximate growth rate of 2.17% per annum for the years before 2014, the AADT at a particular site during a different crash year (say Year i) could be calculated using the 2014 figure with the following formulation:

$$AADT_{Year\ i} = AADT_{Year\ j} \times (1 + 0.0217)^{i-j}$$

where Year j = 2014. A crash that happened in Year i at the site could then be adjusted by dividing it over the $AADT_{Year\ i}$ calculated.

Thus *crashes per million vehicles*, were aggregated for each treatment site for the “before” period and “after” period. The adjusted crashes were then meaningfully compared across the “before” and “after” periods, instead of using unadjusted raw counts of crashes. A growth rate of 2.17% per annum was assumed for the calculations of AADT across all treatment sites.

Effects due to the length of each treated site (road section) were not considered for Phase One of the study, as the length remained unchanged across the “before” and “after” periods, for each treated site.

2.6 Regression to the mean

It is possible that high crash rates at some sites may be due to chance or a combination of both chance and a moderately hazardous site. These sites are likely to have fewer crashes in the subsequent period even if no treatment is carried out because the number of crashes will tend to gravitate to the long-term mean. Under these conditions the effect of any treatment is likely to be over-estimated. Failing to allow for the regression to the mean effect can result in statistically significant results for treatments that are in fact ineffective.

On the basis of work reported by Nicholson (1986), five years of data is the preferred before and after time period to smooth out any random fluctuations as well as providing sufficient evidence of any trend or change in an established pattern of crashes. All sites evaluated in Phase One of this study used five-years of pre-treatment crash data and at least six months of post-treatment crash data. The statistical methodology used in Phase One also recognised the level and distribution of random variation in the data and provided appropriate confidence intervals and significance levels.

2.7 Statistical Analysis

A generalised estimating equation (GEE) Poisson regression model was used to evaluate the sites treated with road safety barriers. The number of crashes per million vehicles in one year is a discrete "count" variable and is assumed to follow a Poisson distribution. However, the longitudinal nature of the observations render the application of standard Poisson regression analysis inappropriate, and methods such as the GEE should be used to accommodate the inherent correlation of the longitudinal data. The decision to use the GEE Poisson model was to take account of the correlated nature of the repeated measures taken before and after the installation of barrier(s) at each treatment site.

The GEE Poisson regression model was also capable of estimating the correct effect of each treatment, as robust standard errors were generated to provide valid statistical inferences. Details about the GEE technique can be found in Dupont (2002) and Twisk (2003).

Information on traffic volumes over time at individual treatment sites is useful to determine whether any changes in crash history are due to the installation of barrier(s) at the site or whether changes in traffic flow give rise to the observed discrepancies before and after treatment. The annual average daily traffic (AADT) information provided by MRWA was utilised as the measure of traffic volume for this study.

The model was fitted to the data using the Stata (Version 12) statistical package.

3 RESULTS

3.1 Run-off Road Crashes (all severities)

All Three Types of Barriers

Table 3.1 details the reductions in Run-off Road Crashes (all severities) per million vehicles at the 114 sites treated with all 3 barrier types (and no prior treatments). Overall, the 114 metropolitan and rural sites together reported a significant 67.5% reduction in Run-off Road Crashes per million vehicles during the study period (p-value < 0.001). A significant 23.3% reduction was reported at the 68 metropolitan sites (p-value < 0.001) and an 87.5% reduction was reported at the 46 rural sites (p-value < 0.001).

For each individual barrier type, results for the analysis of metropolitan sites and the analysis of rural sites were presented separately in Table 3.1 for reference but omitted from discussion, due to the low number of Run-off Road Crashes reported at these sites. If a convergence was not achieved for the metropolitan sites on their own, then the results for the rural sites alone (or vice versa) would not have enough statistical power to be reliable and would be omitted.

Flexible Wire-rope Barriers

There was a significant 64.4% reduction in Run-off Road Crashes per million vehicles at the 41 metropolitan and rural sites that were treated with *Flexible Wire-rope Barriers* only (p-value < 0.001).

Concrete Barriers

There was a significant 24.8% reduction in Run-off Road Crashes per million vehicles at all 8 sites treated with *Concrete Barriers* only (all metropolitan sites only) (p-value < 0.001).

Beams

There was a significant 81.6% reduction in Run-off Road Crashes per million vehicles at the 57 metropolitan and rural sites with *Beams* only (p-value < 0.001).

Sites switching from Beams to Concrete Barriers

For the 19 sites that had *Beams* switched to *Concrete Barriers* (all metropolitan), there was a 26.7% reduction in Run-off Road Crashes per million vehicles after the switch (p < 0.001).

This reduction is lower than the 81.6% reduction experienced by sites switching from having no barriers to having *Beams* installed.

Table 3.1 Reductions in Run-off Road Crashes (all severities) per Million Vehicles at Sites Treated with Road Safety Barriers in Western Australia

	No. of Usable Sites in Final Sample (n)	Length of Carriageways Covered by Sample (km)	"Before" Period: Exposure (days)	"Before" Period: No. of Run-off Road Crashes	"After" Period: Mean Exposure (days)	"After" Period: No. of Run-off Road Crashes	Estimate (Beta)	IRR	Std. Err. (IRR)	Probability 0 < p < 1	95% C.I. of IRR - Lower Bound	95% C.I. of IRR - Upper Bound	Reduction (%)
Sites with Barriers of Interest Only													
Metro + Rural Sites	114	34.6	1826	127	1368	62	-1.122	0.325	0.004	< 0.001	0.317	0.334	67.5%
Metro Sites	68	17.98	1826	83	1359	54	-0.265	0.767	0.007	< 0.001	0.754	0.780	23.3%
Rural Sites	46	16.62	1826	44	1381	8	-2.079	0.125	0.003	< 0.001	0.119	0.132	87.5%
Sites with Flexible Wire-rope Barriers Only													
Metro + Rural Sites	41	18.77	1826	49	1158	29	-1.032	0.356	0.007	< 0.001	0.343	0.370	64.4%
Metro Sites	25	10.68	1826	33	964	28				convergence not achieved			
Rural Sites	16	8.09	1826	16	1461	1				omitted**			
Sites with Concrete Barriers Only													
Metro + Rural Sites	8	3.41	1826	29	1689	13	-0.285	0.752	0.012	< 0.001	0.728	0.777	24.8%
Metro Sites	8	3.41	1826	29	1689	13	-0.285	0.752	0.012	< 0.001	0.728	0.777	24.8%
Rural Sites	0									no observations			
Sites with Beams Only													
Metro + Rural Sites	57	11.26	1826	42	1435	11	-1.693	0.184	0.005	< 0.001	0.174	0.195	81.6%
Metro Sites	29	3.37	1826	16	1562	7	-1.257	0.284	0.022	< 0.001	0.245	0.331	71.6%
Rural Sites	28	7.89	1826	26	1304	4	-1.719	0.179	0.006	< 0.001	0.168	0.191	82.1%
Sites with Concrete Barriers Only (with Beams as a prior treatment before Concrete Barriers)													
Metro + Rural Sites	19	15.12	1826	85	1826	78	-0.311	0.733	0.008	< 0.001	0.717	0.749	26.7%
Metro Sites	19	15.12	1826	85	1826	78	-0.311	0.733	0.008	< 0.001	0.717	0.749	26.7%
Rural Sites	0									no observations			

** Increase/reduction in crashes per million vehicles is not statistically significant (p-value > 0.05).*
*** If convergence was not achieved for either the Metropolitan or Rural stratification, then only the results for all sites combined (Metropolitan and Rural) are presented.*
+ Negative reduction indicates an increase.

3.2 Run-off Road KSI Crashes

All Three Types of Barriers

Table 3.2 details the reductions in Run-off Road KSI Crashes per million vehicles at the 114 sites treated with all 3 barrier types (and no prior treatments). Overall, the 114 metropolitan and rural sites together reported a significant 76.7% reduction in Run-off Road KSI Crashes per million vehicles during the study period (p-value < 0.001). The 68 metropolitan sites reported an 8.5% reduction that was not considered statistically significant (p-value = 0.078). There was a significant 87.3% reduction at the 46 rural sites (p-value < 0.001).

For each individual barrier type, if a convergence was not achieved for the metropolitan sites on their own, then the results for the rural sites alone (or vice versa) would not have enough statistical power to be reliable and would be omitted.

Flexible Wire-rope Barriers

There was a significant 83.4% reduction in Run-off Road KSI Crashes per million vehicles at the 41 metropolitan and rural sites that were treated with *Flexible Wire-rope Barriers* only (p-value < 0.001).

Concrete Barriers

There was a significant 16.9% reduction in Run-off Road KSI Crashes per million vehicles at all 8 sites treated with *Concrete Barriers* only (all metropolitan sites only) (p-value < 0.001).

Beams

There was a significant 74.5% reduction in Run-off Road KSI Crashes per million vehicles at the 57 metropolitan and rural sites with *Beams* only (p-value < 0.001).

Sites switching from Beams to Concrete Barriers

For the 19 sites that had *Beams* switched to *Concrete Barriers* (all metropolitan), there was no significant change in Run-off Road KSI Crashes per million vehicles after the switch (p = 0.611), compared to the 74.5% reduction experienced by sites switching from having no barriers to having *Beams* installed.

Table 3.2 Reductions in Run-off Road KSI Crashes per Million Vehicles at Sites Treated with Road Safety Barriers in Western Australia

	No. of Usable Sites in Final Sample (n)	Length of Carriageways Covered by Sample (km)	"Before" Period: Exposure (days)	"Before" Period: No. of Run-off Road KSI Crashes	"After" Period: Mean Exposure (days)	"After" Period: No. of Run-off Road KSI Crashes	Estimate (Beta)	IRR	Std. Err. (IRR)	Probability 0 < p < 1	95% C.I. of IRR - Lower Bound	95% C.I. of IRR - Upper Bound	Reduction (%)
Sites with Barriers of Interest Only													
Metro + Rural Sites	114	34.6	1826	26	1368	8	-1.456	0.233	0.008	< 0.001	0.218	0.249	76.7%
Metro Sites	68	17.98	1826	14	1359	6	-0.089	0.915	0.046	0.079	0.828	1.010	8.5% *
Rural Sites	46	16.62	1826	12	1381	2	-2.063	0.127	0.006	< 0.001	0.116	0.139	87.3%
Sites with Flexible Wire-rope Barriers Only													
Metro + Rural Sites	41	18.77	1826	11	1158	3	-1.798	0.166	0.009	< 0.001	0.150	0.183	83.4%
Metro Sites	25	10.68	1826	4	964	3				omitted**			
Rural Sites	16	8.09	1826	7	1461	0				convergence not achieved			
Sites with Concrete Barriers Only													
Metro + Rural Sites	8	3.41	1826	5	1689	2	-0.185	0.831	0.006	< 0.001	0.818	0.843	16.9%
Metro Sites	8	3.41	1826	5	1689	2	-0.185	0.831	0.006	< 0.001	0.818	0.843	16.9%
Rural Sites	0									no observations			
Sites with Beams Only													
Metro + Rural Sites	57	11.26	1826	7	1435	1	-1.365	0.255	0.015	< 0.001	0.228	0.286	74.5%
Metro Sites	29	3.37	1826	2	1562	0				convergence not achieved			
Rural Sites	28	7.89	1826	5	1304	1				omitted**			
Sites with Concrete Barriers Only (with Beams as a prior treatment before Concrete Barriers)													
Metro + Rural Sites	19	15.12	1826	9	1826	11	-0.029	0.972	0.055	0.611	0.870	1.086	2.8% *
Metro Sites	19	15.12	1826	9	1826	11	-0.029	0.972	0.055	0.611	0.870	1.086	2.8% *
Rural Sites	0									no observations			

** Increase/reduction in crashes per million vehicles is not statistically significant (p-value > 0.05).*
*** If convergence was not achieved for either the Metropolitan or Rural stratification, then only the results for all sites combined (Metropolitan and Rural) are presented.*
+ Negative reduction indicates an increase.

4 DISCUSSIONS AND CONCLUSIONS

The overall results from this study found that road safety barriers, in general, were successful in reducing the frequency of Run-off Road KSI Crashes when all sites (metropolitan and rural) were considered together, possibly more effective in rural areas than in the metropolitan area.

The reductions in Run-off Road KSI Crashes per million vehicles at the sites treated with all 3 barrier types (76.7% for all sites, 8.5% for metro sites, 87.3% for rural sites), when compared to the reductions in all Run-off Road Crashes (all severities) per million vehicles (67.5% for all sites, 23.3% for metro sites, 87.5% for rural sites), indicated that all 3 barriers in general were successful in reducing crash severity in Run-off Road Crashes when all sites (metropolitan and rural) were considered together.

4.1 Effects of Flexible Wire-rope Barriers

When *Flexible Wire-rope Barriers* were considered on their own, they were found to be successful in reducing the number of Run-off Road KSI Crashes when all metropolitan and rural sites were considered together.

The 83.4% reduction in Run-off Road KSI Crashes per million vehicles at sites treated with *Flexible Wire-rope Barriers* only, when compared to the 64.4% reduction in all Run-off Road Crashes (all severities) per million vehicles experienced by the same 41 sites, indicated that the *Flexible Wire-rope Barriers* were highly successful in reducing risk of crashes and crash severity in Run-off Road Crashes when all sites were considered, with crash severity being reduced at a higher rate than crash frequency.

4.2 Effects of Concrete Barriers

Concrete Barriers were found to have very little success in reducing the number of Run-off Road KSI Crashes.

The 16.9% reduction in Run-off Road KSI Crashes per million vehicles at the 8 sites in sample treated with *Concrete Barriers* only (all metropolitan sites), when compared to the 24.8% reduction in all Run-off Road Crashes (all severities) per million vehicles experienced by the same sites, indicated that the *Concrete Barriers* were reducing crash severity at a lower rate than their reduction in frequency of crashes in Run-off Road Crashes.

4.3 Effects of Beams

Beams were found to be successful in reducing the number of Run-off Road KSI Crashes when all metropolitan and rural sites were considered together.

The 74.5% reduction in Run-off Road KSI Crashes per million vehicles at all sites with *Beams* only, when compared to the 81.6% reduction in all Run-off Road Crashes (all severities) per million vehicles experienced by the same sites, indicated that the *Beams* were highly successful in reducing crash frequency in Run-off Road Crashes when all sites were considered, though the reduction in crash severity was at a slightly lower rate.

4.4 Recommendations

It is recommended that the choice of future installations of barriers be given to *Flexible Wire-rope Barriers* or *Beams*, especially at locations likely to experience a higher risk of Run-off Road Crashes. The use of *Concrete Barriers* should only be reserved for special locations/functions such as the separation of vehicle traffic from railway tracks, where a collision between a vehicle and a train would be so devastated that the absolute avoidance of such a collision would be a higher priority than any reduction in impact to the run-off vehicle and its occupants.

It is also recommended that the analyses be repeated should more sites with more complete information such as installation date become available.

Obtaining accurate information related to the start and dates of the barrier installations at the sites need to be properly documented for any future evaluation to ensure the validity of the results. It is also crucial that neither the before treatment period nor the after treatment period overlaps the installation period, in which case estimates of the treatment effect could result in bias towards the lesser or greater magnitude compared to the true value.

The lack of availability of information regarding the operational dates of the road sections where the road safety barriers were situated, meant that information on which of the sites having no meaningful “before” period (thus needed to be exclude from the study) was not readily available. The WAPOL crash data was utilised to “estimate” a list of such sites, which might not have been accurate.

Given some of the difficulties experienced in the current study, it is recommended that a comprehensive and systematic method of data collection be implemented to facilitate future evaluations of road safety barriers.

Recommendations include:

- Maintaining accurate and timely recording of details of barrier treatments, including location, barrier types, barrier positioning, costs, start and completion dates and any other details relevant to future evaluations.

It is recommended that this evaluation be repeated should the installation dates of more sites become available.

Limitations of the study included:

- A high number of sites that had barrier installation year(s) missing had to be excluded from the study as the correct "before" and "after" periods could not be meaningfully determined.
- Another limitation was the lack of availability of information regarding the operational dates of the road sections where the road safety barriers were situated. Since information on which of the sites having no meaningful "before" period (i.e. "greenfield" sites that needed to be excluded from the study) was not readily available, the WAPOL crash data was utilised to "estimate" a list of such sites, which might not have been accurate.

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APPENDIX A – List of treatment sites used for the study

Treatment Sites Usable for Study	Road No.	SLK (from)	SLK (to)	Carriage -way	Barrier Type(s)	Installation Year	Region	Annual Average Daily Traffic (AADT) - 2014, assuming growth rate = 2.17% p.a.	Before Installation of Road Safety Barrier(s)				After Installation of Road Safety Barrier(s)				Existence of Other Barrier Type(s) Prior to Current Treatment?	Utilisation in the Study
									Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes	Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes		
1	H001	16.88	16.91	L	Beams Only	2003	Metro	11895	1826	8807	0	0	1826	10018	0	0	Assumed None	Yes
2	H002	29.25	30.64	L	Concrete Barriers Only	2007	Metro	14359	1826	11585	6	2	1826	13177	8	2	Assumed None	Yes
3	H002	30.64	32.64	L	Flexible Wire-rope Barriers Only	2007	Metro	14359	1826	11585	8	1	1826	13177	10	0	Assumed None	Yes
4	H002	34.39	37.9	L	Flexible Wire-rope Barriers Only	2007	Metro	6433	1826	5190	8	0	1826	5904	10	2	Assumed None	Yes
5	H002	42.6	44.41	L	Flexible Wire-rope Barriers Only	2007	Metro	18436	1826	14874	3	0	1826	16919	5	1	Assumed None	Yes
6	H002	45	45.09	L	Beams Only	2004	Metro	18436	1826	13946	1	0	1826	15864	0	0	Assumed None	Yes
7	H002	54.84	54.87	L	Beams Only	2006	Rural	10558	1826	8337	0	0	1826	9483	0	0	Assumed None	Yes
8	H002	44.98	45.24	R	Flexible Wire-rope Barriers Only	2004	Metro	19208	1826	14530	1	0	1826	16528	1	0	Assumed None	Yes
9	H002	55.22	55.73	R	Beams Only	2007	Rural	11867	1826	9574	1	0	1826	10890	0	0	Assumed None	Yes
10	H005	6.22	6.24	L	Beams Only	2013	Metro	27684	1826	25406	0	0	365	28899	0	0	Assumed None	Yes
11	H005	12.4	12.45	L	Beams Only	2006	Metro	13260	1826	10471	1	0	1826	11910	0	0	Assumed None	Yes
12	H005	12.45	12.51	L	Beams Only	2006	Metro	13260	1826	10471	3	0	1826	11910	0	0	Assumed None	Yes
13	H005	12.4	12.5	R	Beams Only	2006	Metro	13728	1826	10840	0	0	1826	12330	0	0	Assumed None	Yes
14	H005	243.8	243.84	S	Beams Only	2007	Rural	1740	1826	1404	0	0	1826	1596	0	0	Assumed None	Yes
15	H005	271.98	272.78	S	Flexible Wire-rope Barriers Only	2007	Rural	1125	1826	908	3	1	1826	1032	0	0	Assumed None	Yes
16	H006	3.34	3.53	S	Beams Only	2010	Metro	14866	1826	12792	0	0	1461	14550	1	0	Assumed None	Yes
17	H006	11.13	11.23	S	Beams Only	2009	Metro	14866	1826	12520	0	0	1826	14241	0	0	Assumed None	Yes
18	H006	36.65	36.67	S	Beams Only	2009	Rural	6389	1826	5381	0	0	1826	6120	0	0	Assumed None	Yes
19	H006	36.67	36.86	S	Beams Only	2009	Rural	6389	1826	5381	0	0	1826	6120	0	0	Assumed None	Yes
20	H006	54.75	54.91	S	Beams Only	2009	Rural	4163	1826	3506	1	0	1826	3988	0	0	Assumed None	Yes
21	H006	70.04	70.22	S	Flexible Wire-rope Barriers Only	2003	Rural	1587	1826	1175	0	0	1826	1337	0	0	Assumed None	Yes
22	H006	71.33	71.36	S	Flexible Wire-rope Barriers Only	2006	Rural	1587	1826	1253	1	0	1826	1425	0	0	Assumed None	Yes
23	H007	1133.27	1134.06	S	Beams Only	2013	Rural	2389	1826	2192	0	0	365	2494	0	0	Assumed None	Yes
24	H009	113.18	113.24	S	Beams Only	2010	Rural	3505	1826	3016	1	0	1461	3431	0	0	Assumed None	Yes
25	H009	146.32	146.36	S	Beams Only	2002	Rural	5777	1826	4187	1	0	1826	4762	0	0	Assumed None	Yes
26	H009	175.45	175.75	S	Beams Only	2013	Rural	6105	1826	5603	2	1	365	6373	0	0	Assumed None	Yes
27	H009	176.07	176.44	S	Beams Only	2013	Rural	6105	1826	5603	1	0	365	6373	0	0	Assumed None	Yes
28	H009	177.52	178.39	S	Beams Only	2013	Rural	6105	1826	5603	5	0	365	6373	0	0	Assumed None	Yes
29	H009	218.03	218.55	S	Beams Only	2009	Rural	2841	1826	2393	0	0	1826	2722	1	1	Assumed None	Yes
30	H009	288.2	288.55	S	Flexible Wire-rope Barriers Only	2010	Rural	1461	1826	1257	1	1	1461	1430	0	0	Assumed None	Yes
31	H012	11.22	11.26	L	Beams Only	2010	Metro	18942	1826	16299	0	0	1461	18540	0	0	Assumed None	Yes
32	H012	9.63	9.97	R	Beams Only	2003	Metro	26323	1826	19490	0	0	1826	22169	1	0	Assumed None	Yes
33	H015	0.96	1.08	L	Flexible Wire-rope Barriers Only	2006	Metro	89287	1826	70507	3	1	1826	80199	1	0	Assumed None	Yes
34	H015	1.42	1.5	L	Concrete Barriers Only	2006	Metro	79251	1826	62582	0	0	1826	71185	1	0	Beams	Yes
35	H015	2.2	2.25	L	Concrete Barriers Only	2006	Metro	79251	1826	62582	0	0	1826	71185	0	0	Beams	Yes
36	H015	2.91	3.15	L	Concrete Barriers Only	2006	Metro	74130	1826	58538	1	0	1826	66585	5	0	Beams	Yes
37	H015	5.62	5.75	L	Concrete Barriers Only	2006	Metro	53513	1826	42258	2	0	1826	48067	1	0	Beams	Yes
38	H015	6.01	6.37	L	Concrete Barriers Only	2006	Metro	53513	1826	42258	3	0	1826	48067	1	0	Beams	Yes
39	H015	6.42	8	L	Concrete Barriers Only	2006	Metro	68606	1826	54176	11	0	1826	61623	11	2	Beams	Yes
40	H015	8.74	8.78	L	Concrete Barriers Only	2006	Metro	68606	1826	54176	0	0	1826	61623	0	0	Beams	Yes

Treatment Sites Usable for Study	Road No.	SLK (from)	SLK (to)	Carriage -way	Barrier Type(s)	Installation Year	Region	Annual Average Daily Traffic (AADT) - 2014, assuming growth rate = 2.17% p.a.	Before Installation of Road Safety Barrier(s)				After Installation of Road Safety Barrier(s)				Existence of Other Barrier Type(s) Prior to Current Treatment?	Utilisation in the Study
									Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes	Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes		
41	H015	8.86	10.92	L	Concrete Barriers Only	2006	Metro	52651	1826	41577	14	1	1826	47293	13	0	Beams	Yes
42	H015	11.04	13.26	L	Concrete Barriers Only	2006	Metro	47275	1826	37331	13	0	1826	42463	10	2	Beams	Yes
43	H015	13.45	14.15	L	Concrete Barriers Only	2006	Metro	37101	1826	29297	1	0	1826	33325	1	0	Beams	Yes
44	H015	0.52	0.7	R	Concrete Barriers Only	2006	Metro	94490	1826	74615	2	0	1826	84873	5	1	Beams	Yes
45	H015	0.93	1.02	R	Mixture of two of three types	2006	Metro	94490	1826	74615	0	0	1826	84873	0	0	Assumed None	Yes
46	H015	1.08	1.2	R	Concrete Barriers Only	2006	Metro	75404	1826	59544	0	0	1826	67729	1	0	Beams	Yes
47	H015	1.58	1.68	R	Concrete Barriers Only	2006	Metro	75404	1826	59544	0	0	1826	67729	3	1	Beams	Yes
48	H015	6.05	6.88	R	Concrete Barriers Only	2006	Metro	64618	1826	51027	3	2	1826	58041	2	0	Beams	Yes
49	H015	6.93	7	R	Concrete Barriers Only	2006	Metro	64618	1826	51027	0	0	1826	58041	1	0	Beams	Yes
50	H015	7.02	7.66	R	Concrete Barriers Only	2006	Metro	64618	1826	51027	0	0	1826	58041	2	0	Beams	Yes
51	H015	8.91	11.86	R	Concrete Barriers Only	2006	Metro	41796	1826	33005	17	2	1826	37542	11	3	Beams	Yes
52	H015	12.23	14.84	R	Concrete Barriers Only	2006	Metro	41031	1826	32401	17	4	1826	36855	10	2	Beams	Yes
53	H015	15.02	15.18	R	Concrete Barriers Only	2006	Metro	51892	1826	40977	1	0	1826	46610	0	0	Beams	Yes
54	H016	0.05	0.26	L	Concrete Barriers Only	2007	Metro	56725	1826	45766	3	0	1826	52057	1	0	Assumed None	Yes
55	H016	0.4	0.44	L	Beams Only	2001	Metro	56725	1826	40234	0	0	1826	45766	0	0	Assumed None	Yes
56	H016	0.44	0.89	L	Beams Only	2001	Metro	56725	1826	40234	2	1	1826	45766	3	0	Assumed None	Yes
57	H016	0.89	0.94	L	Beams Only	2001	Metro	62202	1826	44120	2	0	1826	50185	0	0	Assumed None	Yes
58	H016	0.94	1.04	L	Concrete Barriers Only	2001	Metro	62202	1826	44120	6	0	1826	50185	0	0	Assumed None	Yes
59	H016	1.13	1.6	L	Concrete Barriers Only	2001	Metro	62202	1826	44120	6	0	1826	50185	3	0	Assumed None	Yes
60	H016	24.87	25.04	L	Beams Only	2008	Metro	38156	1826	31452	2	0	1826	35776	0	0	Assumed None	Yes
61	H016	25.04	25.12	L	Mixture of two of three types	2008	Metro	38156	1826	31452	2	0	1826	35776	0	0	Assumed None	Yes
62	H016	0.89	0.98	R	Beams Only	2001	Metro	86984	1826	61697	2	0	1826	70179	0	0	Assumed None	Yes
63	H016	0.98	1.11	R	Mixture of two of three types	2001	Metro	86984	1826	61697	1	1	1826	70179	5	1	Assumed None	Yes
64	H016	1.11	1.14	R	Beams Only	2001	Metro	86984	1826	61697	0	0	1826	70179	1	0	Assumed None	Yes
65	H016	1.14	1.21	R	Mixture of two of three types	2001	Metro	86984	1826	61697	0	0	1826	70179	0	0	Assumed None	Yes
66	H016	1.21	1.3	R	Concrete Barriers Only	2001	Metro	78324	1826	55555	2	1	1826	63192	0	0	Assumed None	Yes
67	H016	1.33	1.64	R	Concrete Barriers Only	2001	Metro	78324	1826	55555	1	0	1826	63192	1	0	Assumed None	Yes
68	H016	1.64	1.75	R	Concrete Barriers Only	2001	Metro	68703	1826	48731	1	0	1826	55430	0	0	Assumed None	Yes
69	H016	1.87	1.95	R	Beams Only	2001	Metro	38722	1826	27465	0	0	1826	31241	1	0	Assumed None	Yes
70	H016	4.61	5.34	R	Concrete Barriers Only	2012	Metro	96538	1826	86712	4	2	731	98633	0	0	Assumed None	Yes
71	H018	44.35	44.6	L	Beams Only	2010	Metro	14467	1826	12449	0	0	1461	14160	0	0	Assumed None	Yes
72	H020	4.31	4.5	L	Flexible Wire-rope Barriers Only	2013	Metro	42100	1826	38636	0	0	365	43947	0	0	Assumed None	Yes
73	H020	4.61	4.74	L	Flexible Wire-rope Barriers Only	2013	Metro	42100	1826	38636	1	0	365	43947	0	0	Assumed None	Yes
74	H020	4.84	5.22	L	Flexible Wire-rope Barriers Only	2013	Metro	42100	1826	38636	0	0	365	43947	1	0	Assumed None	Yes
75	H020	5.61	5.68	L	Flexible Wire-rope Barriers Only	2013	Metro	43065	1826	39521	1	1	365	44954	0	0	Assumed None	Yes
76	H020	5.68	5.75	L	Flexible Wire-rope Barriers Only	2013	Metro	43065	1826	39521	0	0	365	44954	0	0	Assumed None	Yes
77	H020	5.79	5.87	L	Flexible Wire-rope Barriers Only	2013	Metro	43065	1826	39521	0	0	365	44954	0	0	Assumed None	Yes
78	H020	5.87	5.96	L	Mixture of two of three types	2013	Metro	43065	1826	39521	1	1	365	44954	0	0	Assumed None	Yes
79	H020	6.41	6.53	L	Flexible Wire-rope Barriers Only	2013	Metro	35266	1826	32364	0	0	365	36813	0	0	Assumed None	Yes
80	H020	6.56	6.76	L	Flexible Wire-rope Barriers Only	2013	Metro	32139	1826	29494	1	0	365	33549	0	0	Assumed None	Yes

Treatment Sites Usable for Study	Road No.	SLK (from)	SLK (to)	Carriage -way	Barrier Type(s)	Installation Year	Region	Annual Average Daily Traffic (AADT) - 2014, assuming growth rate = 2.17% p.a.	Before Installation of Road Safety Barrier(s)				After Installation of Road Safety Barrier(s)				Existence of Other Barrier Type(s) Prior to Current Treatment?	Utilisation in the Study
									Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes	Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes		
81	H020	4.6	4.68	R	Flexible Wire-rope Barriers Only	2013	Metro	42331	1826	38848	0	0	365	44188	0	0	Assumed None	Yes
82	H020	4.81	4.87	R	Flexible Wire-rope Barriers Only	2013	Metro	42331	1826	38848	0	0	365	44188	0	0	Assumed None	Yes
83	H020	6.31	6.37	R	Flexible Wire-rope Barriers Only	2013	Metro	32865	1826	30161	1	0	365	34307	0	0	Assumed None	Yes
84	H020	6.56	6.71	R	Flexible Wire-rope Barriers Only	2013	Metro	30352	1826	27854	0	0	365	31683	0	0	Assumed None	Yes
85	H021	5.22	5.3	L	Flexible Wire-rope Barriers Only	2005	Metro	18578	1826	14359	0	0	1826	16333	0	0	Assumed None	Yes
86	H021	7.73	7.79	L	Mixture of two of three types	2005	Metro	23794	1826	18390	1	1	1826	20919	1	0	Assumed None	Yes
87	H023	14.7	14.78	L	Beams Only	2009	Metro	18919	1826	15933	0	0	1826	18124	0	0	Assumed None	Yes
88	H023	6.01	6.1	R	Flexible Wire-rope Barriers Only	2005	Metro	7825	1826	6048	0	0	1826	6879	0	0	Assumed None	Yes
89	H023	6.17	6.23	R	Flexible Wire-rope Barriers Only	2005	Metro	7422	1826	5736	2	1	1826	6525	0	0	Assumed None	Yes
90	H023	12.98	13.11	S	Beams Only	2012	Metro	20990	1826	18853	0	0	731	21445	0	0	Assumed None	Yes
91	H023	13.11	13.3	S	Flexible Wire-rope Barriers Only	2012	Metro	20990	1826	18853	1	0	731	21445	0	0	Assumed None	Yes
92	H023	14.65	14.7	S	Beams Only	2009	Metro	20990	1826	17678	1	0	1826	20108	0	0	Assumed None	Yes
93	H032	11.52	11.57	L	Beams Only	2010	Metro	27043	1826	23270	0	0	1461	26469	0	0	Assumed None	Yes
94	H033	7.04	7.09	S	Beams Only	2006	Metro	7647	1826	6039	1	1	1826	6869	0	0	Assumed None	Yes
95	H035	12.76	12.82	L	Beams Only	2001	Metro	17017	1826	12070	0	0	1826	13729	0	0	Assumed None	Yes
96	H035	33.36	33.45	R	Beams Only	2001	Metro	6928	1826	4914	0	0	1826	5590	0	0	Assumed None	Yes
97	H038	5.4	5.76	L	Beams Only	2007	Metro	11002	1826	8876	0	0	1826	10096	0	0	Assumed None	Yes
98	H038	15.3	15.4	S	Beams Only	2012	Metro	14334	1826	12875	1	0	731	14646	0	0	Assumed None	Yes
99	H040	2.36	2.61	S	Beams Only	2008	Rural	7590	1826	6256	1	0	1826	7117	0	0	Assumed None	Yes
100	H040	2.89	3	S	Beams Only	2008	Rural	7590	1826	6256	1	0	1826	7117	0	0	Assumed None	Yes
101	H040	3.15	3.2	S	Beams Only	2008	Rural	7590	1826	6256	0	0	1826	7117	0	0	Assumed None	Yes
102	H043	7.93	8.07	R	Flexible Wire-rope Barriers Only	2012	Rural	7284	1826	6543	1	1	731	7442	0	0	Assumed None	Yes
103	H043	92.68	93.56	S	Beams Only	2013	Rural	5571	1826	5113	8	3	365	5815	1	0	Assumed None	Yes
104	H043	93.75	94.25	S	Beams Only	2010	Rural	5571	1826	4794	1	0	1461	5453	2	0	Assumed None	Yes
105	H043	116.66	116.82	S	Beams Only	2013	Rural	2545	1826	2336	0	0	365	2657	0	0	Assumed None	Yes
106	H045	3.29	3.64	S	Beams Only	2012	Rural	4734	1826	4252	0	0	731	4837	0	0	Assumed None	Yes
107	H045	4.87	5.17	S	Beams Only	2013	Rural	4734	1826	4344	0	0	365	4942	0	0	Assumed None	Yes
108	H046	10.27	10.5	L	Flexible Wire-rope Barriers Only	2013	Rural	8828	1826	8102	0	0	365	9215	0	0	Assumed None	Yes
109	H046	10.5	11.14	L	Flexible Wire-rope Barriers Only	2013	Rural	8828	1826	8102	0	0	365	9215	0	0	Assumed None	Yes
110	H046	10.78	11.18	R	Flexible Wire-rope Barriers Only	2013	Rural	8828	1826	8102	0	0	365	9215	0	0	Assumed None	Yes
111	H053	8.83	8.95	S	Flexible Wire-rope Barriers Only	2004	Rural	1102	1826	834	1	1	1826	948	0	0	Assumed None	Yes
112	H057	46.39	47.39	L	Flexible Wire-rope Barriers Only	2009	Rural	7099	1826	5979	2	0	1826	6801	1	0	Assumed None	Yes
113	H057	47.56	48.22	L	Flexible Wire-rope Barriers Only	2009	Rural	7099	1826	5979	0	0	1826	6801	0	0	Assumed None	Yes
114	H057	48.27	49.41	L	Flexible Wire-rope Barriers Only	2009	Rural	7099	1826	5979	1	1	1826	6801	0	0	Assumed None	Yes
115	H057	61.29	62.05	L	Flexible Wire-rope Barriers Only	2009	Rural	7099	1826	5979	2	0	1826	6801	0	0	Assumed None	Yes
116	H057	62.97	63.44	L	Flexible Wire-rope Barriers Only	2009	Rural	7099	1826	5979	1	1	1826	6801	0	0	Assumed None	Yes
117	H057	75.02	75.35	L	Mixture of two of three types	2009	Rural	7431	1826	6258	1	0	1826	7119	1	0	Assumed None	Yes
118	H057	50.83	51.2	R	Flexible Wire-rope Barriers Only	2009	Rural	7093	1826	5974	1	0	1826	6795	0	0	Assumed None	Yes
119	H057	74.25	75.05	R	Flexible Wire-rope Barriers Only	2009	Rural	7480	1826	6300	2	1	1826	7166	0	0	Assumed None	Yes
120	H057	75.05	75.36	R	Mixture of two of three types	2009	Rural	7480	1826	6300	1	0	1826	7166	2	1	Assumed None	Yes

Treatment Sites Usable for Study	Road No.	SLK (from)	SLK (to)	Carriage -way	Barrier Type(s)	Installation Year	Region	Annual Average Daily Traffic (AADT) - 2014, assuming growth rate = 2.17% p.a.	Before Installation of Road Safety Barrier(s)				After Installation of Road Safety Barrier(s)				Existence of Other Barrier Type(s) Prior to Current Treatment?	Utilisation in the Study
									Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes	Exposure (days)	AADT utilised	Run-off Road Crashes (all severities)	Run-off Road KSI Crashes		
121	H057	94.16	94.26	R	Beams Only	2011	Rural	14901	1826	13101	0	0	1096	14901	0	0	Assumed None	Yes
122	H604	0.01	0.34	S	Flexible Wire-rope Barriers Only	2013	Metro	4581	1826	4204	0	0	365	4782	0	0	Assumed None	Yes
123	H626	0	0.07	S	Beams Only	2012	Metro	7528	1826	6762	0	0	731	7692	0	0	Assumed None	Yes
124	H653	0	0.15	S	Beams Only	2013	Metro	17088	1826	15682	0	0	365	17838	0	0	Assumed None	Yes
125	H658	0.5	0.71	S	Flexible Wire-rope Barriers Only	2008	Metro	10793	1826	8897	3	0	1826	10120	0	0	Assumed None	Yes
126	H851	0.12	0.26	S	Flexible Wire-rope Barriers Only	2011	Metro	6286	1826	5526	0	0	1096	6286	0	0	Assumed None	Yes
127	M043	18.96	19.23	S	Beams Only	2013	Rural	4995	1826	4584	0	0	365	5214	0	0	Assumed None	Yes
128	M045	8.8	9.09	S	Flexible Wire-rope Barriers Only	2011	Metro	5115	1826	4497	0	0	1096	5115	0	0	Assumed None	Yes
129	M045	38.44	38.62	S	Beams Only	2008	Rural	2622	1826	2161	0	0	1826	2458	0	0	Assumed None	Yes
130	M053	64.9	64.96	S	Beams Only	2010	Rural	966	1826	831	1	0	1461	945	0	0	Assumed None	Yes
131	M074	30.27	30.51	S	Beams Only	2005	Rural	1498	1826	1158	0	0	1826	1317	0	0	Assumed None	Yes
132	M074	32.72	32.96	S	Beams Only	2005	Rural	1498	1826	1158	2	1	1826	1317	0	0	Assumed None	Yes
133	M074	38.36	38.66	S	Beams Only	2005	Rural	1498	1826	1158	0	0	1826	1317	0	0	Assumed None	Yes

APPENDIX B – Exposure used for the study

Sites with Non-existence of Other Barrier Type(s) Assumed Prior to Current Treatment at Site		No. of Usable Sites in Final Sample (n)	"Before" Period	"After" Period			
			Exposure (days)	Min Exposure (days)	Max Exposure (days)	Mean Exposure (days)	Std. Dev. of Exposure (days)
Sites with Flexible Wire-rope Barriers Only	Metro + Rural Sites	41	1826	365	1826	1157.9	697.3
	Metro Sites	25	1826	365	1826	964.1	690.4
	Rural Sites	16	1826	365	1826	1460.8	611.1
Sites with Concrete Barriers Only	Metro + Rural Sites	8	1826	731	1826	1689.1	387.1
	Metro Sites	8	1826	731	1826	1689.1	387.1
	Rural Sites	0					
Sites with Beams Only	Metro + Rural Sites	57	1826	365	1826	1435.2	581.0
	Metro Sites	29	1826	365	1826	1561.6	477.0
	Rural Sites	28	1826	365	1826	1304.3	655.1

All Sites with Barrier(s) of Interest (Can be Mixture)	Metro + Rural Sites	114	1826	365	1826	1367.9	629.4
	Metro Sites	68	1826	365	1826	1358.8	633.7
	Rural Sites	46	1826	365	1826	1381.4	629.8

Sites with Existence of Beams Assumed Prior to Current Treatment at Site		No. of Usable Sites in Final Sample (n)	"Before" Period	"After" Period			
			Exposure (days)	Min Exposure (days)	Max Exposure (days)	Mean Exposure (days)	Std. Dev. of Exposure (days)
Sites with Concrete Barriers Only	Metro + Rural Sites	19	1826	1826	1826	1826.0	
	Metro Sites	19	1826	1826	1826	1826.0	
	Rural Sites	0					