An Evaluation of the Effectiveness and Cost-effectiveness of a Rural Run-off-road Crash Program in Western Australia

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Abstract

Single vehicle loss-of-control run-off-road crashes are especially problematic in regional and remote Western Australia, where they accounted for almost 60% of all road deaths and serious injuries from 2008 to 2012.

Approximately 984 kilometres of rural WA roads were treated with run-off-road treatments under the rural Run-off-road Crash Program funded by the Road Trauma Trust Account in the 2012/13, 2013/14 and 2014/15 budgets. The aim of this study is to evaluate the effectiveness and cost-effectiveness of the program implemented to reduce the number of people killed or seriously injured. Specific treatments examined included: "*shoulder widening and/or sealing*", and "*audible edgelines*".

Overall, 57 rural sites that met the inclusion criteria of the study reported a significant 35.5% reduction in Run-off-road Crashes (all severities) during the study period. The sites also reported a significant 18.4% reduction in Run-off-road casualty crashes, as well as a significant 25.6% reduction in Run-off-road Killed or Seriously Injured Crashes.

The Run-off-road Crash Program also performed well in economic terms. In relation to the net economic worth of the program, the Net Present Value and the Benefit-cost Ratio across all treatment sites were estimated to be $100.2 million and 2.1 respectively.

Keywords

Rural run-off-road crashes, shoulder widening and/or sealing, audible edge lines, crash frequency, crash severity

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EXECUTIVE SUMMARY

In Western Australia (WA), single vehicle, loss-of-control, run-off-road 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). Approximately one-fifth of metropolitan road deaths and serious injuries occur when a driver loses control of their vehicle and it leaves the road. Such crashes are especially problematic in regional and remote WA, where they accounted for almost 60% of all road deaths and serious injuries from 2008 to 2012 (Bramwell et al. 2014).

Approximately 984 kilometres of rural WA roads were treated with run-off-road treatments under the rural Run-off-road Crash Program funded by the Road Trauma Trust Account (RTTA) in the 2012/13, 2013/14 and 2014/15 budgets (as at 31st March 2016). The aim of this study is to evaluate the effectiveness in terms of reducing crashes and the cost-effectiveness of the rural Run-off-road Crash Program in WA, and specific treatments implemented to reduce the number of people killed or seriously injured, namely:

(1) *Shoulder Widening and/or Sealing* (as the only treatment),
(2) *Audible Edgelines or White Lines* (as the only treatment), and
(3) *Shoulder Widening and/or Sealing, with Audible Edgelines*.

As these treatments are intended to reduce the number of single vehicle, run-off-road crashes, this study adopted a quasi-experimental "before" and "after" comparison of (a) Run-off-road Crashes (all severities), (b) Run-off-road Casualty Crashes, and (c) Run-off-road Killed or Seriously Injured (KSI) Crashes, at sites treated under the WA rural Run-off-road Crash Program between 2012 and 2015.

Overall, 57 rural sites that met the inclusion criteria of the study reported a significant 35.5% reduction in Run-off-road Crashes (all severities) during the study period (p-value < 0.001). The sites also reported a significant 18.4% reduction in Run-off-road Casualty Crashes (p-value = 0.021), as well as a significant 25.6% reduction in Run-off-road KSI Crashes (p-value = 0.031).

Reductions in Run-off-road Crashes at Sites Treated under the Run-off-road Crash Program in WA

	Treatment	No. of Rural Sites in Sample	Incidence Rate Ratio (IRR)	Std. Err. of IRR	p-value (Probability 0 < p < 1)	Crash Reduction (%)
Run-off-road Crashes (Severity 1 + 2 + 3 + 4 + 5)	**All Run-off-road Crash Treatments**	**57**	0.645	0.040	< 0.001	35.5%
	Shoulder Widening and/or Sealing (only)	12	0.401	0.085	< 0.001	59.9%
	Audible Edgelines (AEL) or White Lines (only)	15	0.783	0.042	< 0.001	21.7%
	Shoulder Widening and/or Sealing, with AEL	27	0.596	0.131	0.018	40.4%
	Other Treatment or Combinations	3	0.515	0.323	0.290	48.5% *
Run-off-road Casualty Crashes (Severity 1 + 2 + 3)	**All Run-off-road Crash Treatments**	**57**	0.816	0.072	0.021	18.4%
	Shoulder Widening and/or Sealing (only)	12	0.481	0.141	0.012	51.9%
	Audible Edgelines (AEL) or White Lines (only)	15	1.024	0.088	0.784	-2.4% *+
	Shoulder Widening and/or Sealing, with AEL	27	0.545	0.174	0.057	45.5% *
	Other Treatment or Combinations	3	0.604	0.380	0.423	39.6% *
Run-off-road Killed or Seriously Injured (KSI) Crashes (Severity 1 + 2)	**All Run-off-road Crash Treatments**	**57**	0.744	0.102	0.031	25.6%
	Shoulder Widening and/or Sealing (only)	12	0.360	0.185	0.047	64.0%
	Audible Edgelines (AEL) or White Lines (only)	15	0.901	0.134	0.483	9.9% *
	Shoulder Widening and/or Sealing, with AEL	27	0.543	0.213	0.120	45.7% *
	Other Treatment or Combinations	3	0.943	0.587	0.925	5.7% *

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

The treatment "*shoulder widening and/or sealing*" was found to be highly successful in reducing both the frequency and severity of run-off-road crashes. "*Audible edgelines or white lines*" was also successful in reducing the frequency of such crashes, but appeared to be less successful in reducing the more severe of such crashes when implemented as the only treatment.

Such reductions, at a first glance, appeared to be diminished when the above two treatments were applied together at 27 sites in the study. This is, however, not surprising given the relatively short "after" exposure available for these sites, even after adjusting for exposure, as these were still much less than the recommended three to five years of crash data needed for this type of analysis (Nicholson 1986). Should longer "after" exposure be available then the real effects (either increases or reductions) could become more apparent.

The Run-off-road Crash Program also performed well in economic terms. In relation to the net economic worth of the program, the NPV and the BCR across all treatment sites were estimated to be $100.2 million and 2.1 respectively. Sites treated with "*audible edgelines or white lines*" had a better rate of return than other sites, with a BCR of 3.4, possibly due to the relatively low costs of such treatment. Sites treated with both "*shoulder widening and/or*

sealing" and "*audible edgelines*" together had a lower rate of return (BCR = 1.6) than sites treated with only one of the two treatments, again possibly due to the relatively short "after" exposure observed for these sites.

Economic Evaluation of the Run-off-road Crash Program in Relation to Run-off-road Crash Reductions in WA

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
All Run-off-road Crash Treatments	5%	15	92,819,693	192,998,346	100,178,653	2.1
Shoulder Widening and/or Sealing (only)	5%	15	29,030,594	88,686,994	59,656,400	3.1
Audible Edgelines (AEL) or White Lines (only)	5%	15	6,701,071	22,778,123	16,077,052	3.4
Shoulder Widening and/or Sealing, with AEL	5%	15	49,651,053	81,311,499	31,660,446	1.6
Other Treatment or Combinations	5%	15	7,436,976	221,730	-7,215,246	0.0

It is recommended that the Run-off-road Crash Program be continued as both its overall effectiveness and cost-effectiveness are apparent. Considering that the positive outcomes from this study were obtained from conservative assumptions and adjustments, the real effects from the program could be better than reported.

It is also recommended that the analysis be repeated after observation of longer "after" exposure for the treated sites, particularly for the 27 sites treated with both "*shoulder widening and/or sealing*" and "*audible edgelines*".

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1 BACKGROUND

In Western Australia (WA), single vehicle, loss-of-control, run-off-road 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). Approximately one-fifth of metropolitan road deaths and serious injuries occur when a driver loses control of their vehicle and it leaves the road. Such crashes are especially problematic in regional and remote WA, where they accounted for almost 60% of all road deaths and serious injuries from 2008 to 2012 (Bramwell et al. 2014).

Drivers can potentially lose control of their vehicle for 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 causing the vehicle to 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.

In rural areas especially, the unsealed shoulders of sealed roads pose a major hazard to drivers. When running off the bitumen, the left wheel(s) of a vehicle may come into contact with the soft-edge of the road such as gravel or dirt shoulder. Drivers often make a sharp overcorrection to the right to bring the vehicle back onto the road, leading to the vehicle leaving the road or colliding with another vehicle (Meuleners & Hendrie 2009).

Towards Zero, the State's road safety strategy for 2008-2020 has identified rural run-off-road crashes as a priority area due to the large contribution this particular crash type has on the number of people killed or seriously injured. In 2013, increased funding from the Road Trauma Trust Account (RTTA) meant the Regional Run-off-road Program was the largest funded program at the time with $37 million allocated to its further development and implementation (http://apps.mainroads.wa.gov.au/ar-2013/online/officeofroadsafety-cs1.html).

1.1 The use of run-off-road crash treatments in rural Western Australia

According to information provided by Main Roads Western Australia (MRWA), approximately 984 kilometres of rural WA roads were treated with run-off-road treatments under the rural Run-off-road Crash Program funded by the Road Trauma Trust Account

(RTTA) in the 2012/13, 2013/14 and 2014/15 budgets (as at 31st March 2016). Of these, approximately 204 km of road were treated with "*shoulder widening and/or sealing*" (as the only treatment), 350 km with "*audible edgelines or white lines*" (as the only treatment), 387 km with "*shoulder widening and/or sealing*" as well as "*audible edgelines*", and 43 km with some variations of the above treatments.

Both "*audible edgelines*" and "*shoulder widening and/or sealing*" are countermeasures that aim to prevent vehicles from running off the road. An "*audible edgeline*" is a narrow band of raised or grooved material placed on the road surface at the edge of the road. When the tyres of a moving vehicle come into contact with the "*edgeline*", it creates noise and vibration that can be heard and felt inside the vehicle. The idea behind these "*audible edgelines*" is to warn or alert distracted or fatigued drivers that they have crossed an "*edgeline*", allowing the driver time to react and correct the vehicle and avoid running into roadside objects (Woolley & McLean 2006; Meuleners & Hendrie 2009).

The primary effect of "*shoulder widening and/or sealing*" on rural roads is to provide drivers greater manoeuvring space and opportunity to recover safely before their vehicle hits the soft edge of the road or roadside objects. It also reduces the potential for vehicles which stray from the sealed pavement to lose control in loose shoulder material (Meuleners & Hendrie 2009).

1.2 Effectiveness of run-off-road crash treatments in reducing the frequency and severity of such crashes

"*Audible edgelines*" were shown to have an alerting effect on drivers in a driving simulator study (Anund et al. 2008), and had led to significant but varying reductions in run-off-road crashes on major interstate roads in the United States (Federal Highway Administration, 2001).

In Australia, early research found unsealed shoulders to be a contributing factor in over 50% of fatal run-off-road crashes in New South Wales (Catchpole, 1990). This was consistent with later research that highlighted the safety benefits and cost-effectiveness of sealed shoulders (Meuleners & Hendrie 2009).

Meuleners & Hendrie (2009) considered a sample of 13 sites on Albany Highway, WA that were treated with "*shoulder sealing*" and/or "*audible edgelines*" as part of the WA State Black Spot Program during 2000 to 2004. Their results showed the "*shoulder sealing*"

and/or "*audible edgelines*" treatments that were applied to the 13 sites to have been effective overall, reducing the frequencies of all reported crashes by 58% and casualty crashes by 79%. The 13 sites with the mix of treatment(s) also observed reductions in the targeted run-off-road crashes by 59% and run-off-road casualty crashes by 80%. However, the relatively small sample of sites (thus observations) that were available did not enable the effects due to individual treatments to be identified separately.

Zhang et al. (2014), Meuleners et al. (2014) and Chow et al. (2015) also found sites treated with "*shoulder sealing*" or "*edgelines*" in the more recent 2007/08, 2009/10 and 2011/12 WA State Black Spot Programs to have varying degrees of success in reducing all reported crashes and casualty crashes. "*Shoulder sealing*" was found to have significantly reduced all reported crashes by 44.4% (n = 17), 39.0% (n = 10) and 50.1% (n = 7) in the 2007/08, 2009/10 and 2011/12 programs respectively, and casualty crashes by 42.9% at sites treated in 2007/08. Of these more recent State Black Spot Programs only the 2007/08 program had sites treated with "*edgelines*" and Chow et al. (2015) found the treatment to have reduced all reported crashes by 43.9% (n = 4). The studies also did not specifically target run-off-road crashes nor rural run-off-road crashes.

1.3 Aim

The aim of this study is to evaluate the effectiveness in terms of reducing crashes and the cost-effectiveness of the rural Run-off-road Crash Program in WA, and specific treatments implemented to reduce the number of people killed or seriously injured, namely:

(1) *Shoulder Widening and/or Sealing* (as the only treatment),
(2) *Audible Edgelines or White Lines* (as the only treatment), and
(3) *Shoulder Widening and/or Sealing, with Audible Edgelines*.

As these treatments are intended to reduce the number of single vehicle, run-off-road crashes, an evaluation of their effectiveness specifically in reducing such crashes was undertaken using the following data:

(a) Run-off-road Crashes (all severities),
(b) Run-off-road Casualty Crashes, and
(c) Run-off-road Killed or Seriously Injured (KSI) Crashes.

1.4 Significance

The results from this study will provide WA road authorities with more objective information to guide treatment investment choices. It is anticipated that these results will also serve to highlight the significance of road trauma on rural roads, and the role that good traffic engineering and road design can contribute towards a reduction of injuries and deaths on WA roads.

2 METHODS

This study examined the effectiveness of the WA rural Run-off-road Crash Program and specific treatments such as "*shoulder widening and/or sealing*" and "*audible edgelines*" in reducing the frequency and severity of such cashes.

2.1 Study design

This study adopted a quasi-experimental "before" and "after" comparison of (1) Run-off-road Crashes (all severities), (2) Run-off-road Casualty Crashes, and (3) Run-off-road Killed or Seriously Injured (KSI) Crashes, at sites treated under the WA rural Run-off-road Crash Program between 2012 and 2015.

2.2 Integrated Road Information System (IRIS)

Crash data were obtained from the Integrated Road Information System (IRIS) which is maintained by MRWA. It was used to identify crashes at sites treated (before and after the treatment) which occurred in Western Australia during the period 25th February, 2007 (5 years before the first such treatment) to 31st December, 2015 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, 2015.

The Road Use Movement (RUM) Code was used to identify run-off-road crashes. For the purpose of this report, a single vehicle run-off-road crash was defined as a crash with RUM Code 71, 72, 73, 74, 81, 82, 83 or 84 that did not occur at an intersection.

Critical data retrieved for use in the study were:

- crash date;
- crash severity; and
- specific crash location.

The study adopted an approach that utilised five years of pre-treatment crash data as well as up to five years (if available) of post-treatment crash data which excluded the construction period. Crash data which was used in the analysis included all fatal, hospitalisation, medical

treatment and PDO run-off-road crashes. This was consistent with MRWA's intention to ensure application of funds to a wider range of projects at hazardous situations using different thresholds such as run-off-road crashes (all severities) or run-off-road casualty crashes rather than run-off-road KSI crashes only. Separate analyses by run-off-road casualty crashes only and by run-off-road KSI crashes only were also undertaken.

2.2.1 Operational definitions

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 and does not include collisions that occur due to a medical condition, deliberate acts (e.g. suicide attempts) or police chases*".

The severity of a crash is derived from "*the most serious injury in a crash*". A fatal crash is "*a road crash in which at least one person was killed immediately or died within 30 days of the crash, as a result of the crash*". A hospitalisation crash is a road crash that involved at least one admission to hospital but "*no fatalities within 30 days of the crash*". A medical treatment crash (or medical attention crash) is "*a road crash in which the most serious injury resulted in a person requiring medical treatment, but without being admitted to hospital*". A property damage only (PDO) crash involved no/unknown injuries only.

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*".

KSI crashes include all fatal crashes, and hospitalisation crashes. Casualty crashes include all fatal crashes, hospitalisation crashes, and medical treatment crashes. All reported crashes include all fatal crashes, hospitalisation crashes, medical treatment crashes, as well as PDO crashes.

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.

2.3 Treatment site data

A list of rural WA sites treated under the Run-off-road Crash Program funded by the RTTA was provided by MRWA. The list includes information on each site (as an individual project) such as "road name", "road number", "project description" (i.e. treatment implemented), "start SLK", "end SLK", "start date" and "end date" of the construction period of treatment, as well as the initial cost (capital outlay) in treating the site.

Approximately 984 kilometres of rural WA roads were treated in the 2012/13, 2013/14 and 2014/15 budgets (as at 31st March 2016). Of these, approximately 204 km was treated with "*shoulder widening and/or sealing*" (as the only treatment), 350 km with "*audible edgelines (AEL) or white lines*" (as the only treatment), 387 km with "*shoulder widening and/or sealing, with AEL*", and 43 km with some variations of the above treatments.

2.4 Criteria for exclusion of non-usable sites

Not all sites provided by MRWA 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 an "after" exposure period of less than six months.
- Sites with no run-off-road crashes reported in the "before" exposure period, prior to implementation of the treatment.

Nine out of a list of 66 sites were excluded. A final sample of 57 sites was utilised for the study, consisting of approximately 944 km of rural roads. Of these, 12 sites (187 km) were treated with "*shoulder widening and/or sealing*" (as the only treatment), 15 sites (350 km) were treated with "*audible edgelines (AEL) or white lines*" (as the only treatment), 27 sites (365 km) were treated with "*shoulder widening and/or sealing, with AEL*", and 3 sites (43 km) were with other treatments.

2.5 Traffic volume and length of each treated site

For the purpose of this analysis it was assumed that before and after traffic volumes remained constant for the treated sites during the study period. The annual average daily traffic (AADT) figures held by MRWA have, on average, an approximate growth rate of 2.17% per annum across the WA road network. Therefore, the assumption of constant traffic volumes means that results from this study would likely be conservative.

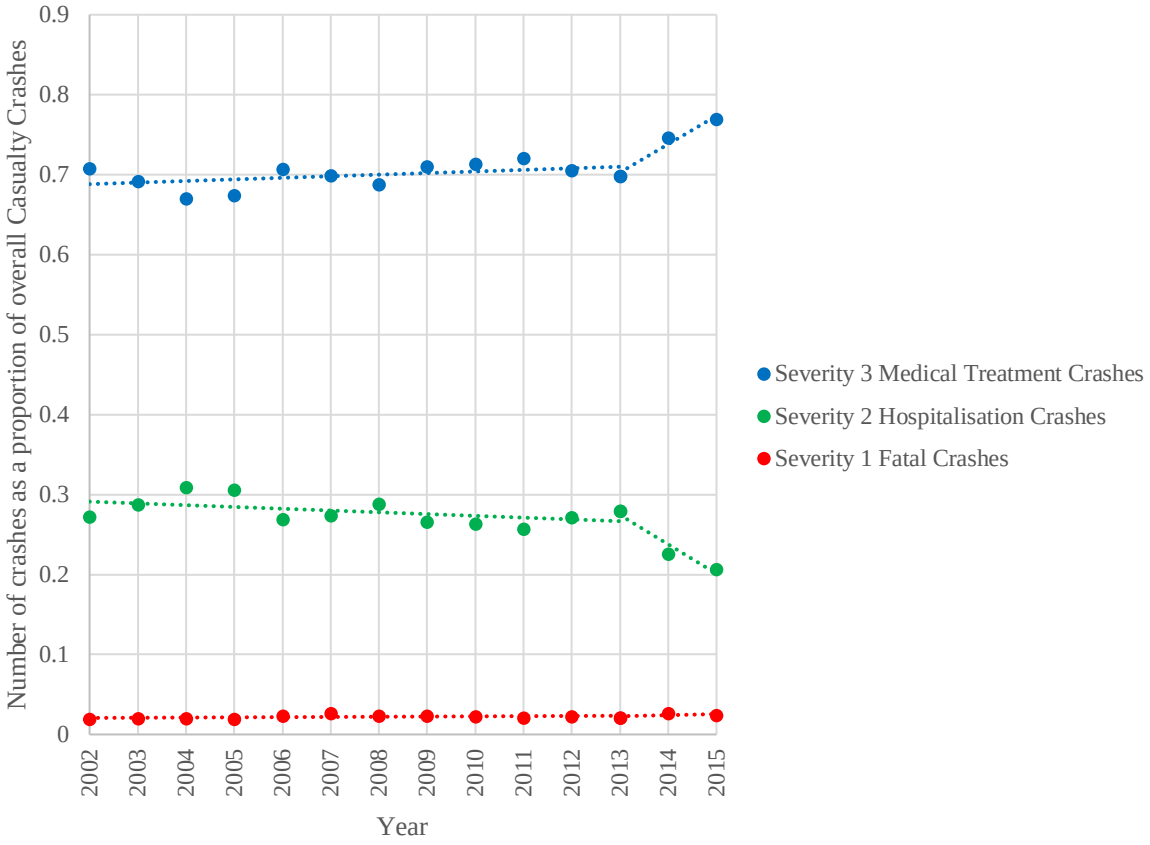
Effects due to the length of each treated site (road section) were not considered for the study, as the length remained unchanged across the "before" and "after" periods, for each treated site.

2.6 Drop-offs in WA killed or seriously injured (KSI) crashes between 2014 and 2015

The years 2014 and 2015 observed unusual drop-offs in the number of KSI crashes reported/recorded in WA compared to the years before. It was suspected that such drop-offs could have been due to administrative changes in the reporting and/or recording of crashes from 2014. A number of 2014 and 2015 crashes that would have been classified as Hospitalisation Crashes (Severity 2) had they been reported in 2013 or before, were now classified as Medical Treatment Crashes (Severity 3). In order to utilise 2014 and 2015 crashes in the study, some adjustment were required so they could be comparable to crashes before 2014.

Although there was a migration between hospitalisation crashes (Severity 2) and medical treatment crashes (Severity 3) from 2014, it is expected that the total count of casualty crashes (Severity 1 + 2 + 3) would remain the same irrespective to the degree of migration between hospitalisation crashes (Severity 2) and medical treatment crashes (Severity 3). Therefore, the 2014 and 2015 casualty crashes (Severity 1 + 2 + 3) could be assumed to be reliable and comparable to the casualty crashes before 2014. Figure 2.1 demonstrates that fatal crashes (Severity 1) (as a proportion of overall casualty crashes) remained stable and followed a consistent trend from 2002 to 2015. Hospitalisation crashes (Severity 2) (as a proportion of overall casualty crashes) also remained stable and followed another consistent trend from 2002 to 2013, until an obvious drop-off from 2014. Similarly, medical treatment crashes (Severity 3) (as a proportion of overall casualty crashes) remained stable and followed its own consistent trend from 2002 to 2013, before an obvious increase from 2014.

Figure 2.1 Fatal Crashes, Hospitalisation Crashes, and Medical Treatment Crashes as proportions of overall Casualty Crashes (Severity 1 + 2 + 3) in WA, 2002-2015



For all run-off-road crashes in this study, an “additive” approach then was taken to adjust for the migration of hospitalisation crashes (Severity 2) into medical treatment crashes (Severity 3). Had the stable trend in hospitalisation crashes (Severity 2) (as a proportion of overall casualty crashes) from 2002 to 2013 continued into 2014 and 2015, there would have been an additional 0.17 hospitalisation crash (Severity 2) for every 2014 casualty crash (Severity 1, 2 or 3) reported/recorded, and an additional 0.27 hospitalisation crash (Severity 2) for every 2015 casualty crash reported/recorded. Thus an adjustment method which followed that of Table 2.1 was utilised.

Table 2.1 Adjustment applied due to changes in KSI crashes reported/recorded

	Before Adjustment	After Adjustment
Crashes Before 2014	Each Severity 1 Crash	1 × Severity 1 Crash
	Each Severity 2 Crash	1 × Severity 2 Crash
	Each Severity 3 Crash	1 × Severity 3 Crash (No Adjustment)
	Each Severity 4 Crash	1 × Severity 4 Crash
	Each Severity 5 Crash	1 × Severity 5 Crash
Crashes in 2014	Each Severity 1 Crash	1 × Severity 1 Crash + 0.17 × Severity 2 Crash
	Each Severity 2 Crash	1 × Severity 2 Crash + 0.17 × Severity 2 Crash = 1.17 × Severity 2 Crash
	Each Severity 3 Crash	1 × Severity 3 Crash + 0.17 × Severity 2 Crash
	Each Severity 4 Crash	1 × Severity 4 Crash (No Adjustment)
	Each Severity 5 Crash	1 × Severity 5 Crash (No Adjustment)
Crashes in 2015	Each Severity 1 Crash	1 × Severity 1 Crash + 0.27 × Severity 2 Crash
	Each Severity 2 Crash	1 × Severity 2 Crash + 0.27 × Severity 2 Crash = 1.27 × Severity 2 Crash
	Each Severity 3 Crash	1 × Severity 3 Crash + 0.27 × Severity 2 Crash
	Each Severity 4 Crash	1 × Severity 4 Crash (No Adjustment)
	Each Severity 5 Crash	1 × Severity 5 Crash (No Adjustment)

Note that this additive adjustment method did not detract from any of the "extra" medical treatment crashes (Severity 3). This ensured that (1) the final number of run-off-road KSI crashes (after adjustment) would be reliable and realistic in both the "before" and "after" periods of the study; while (2) the final number of run-off-road casualty crashes (after adjustment) could only be worse than it really was in the "after" period; and similarly (3) the final number of run-off-road crashes (all severities) (after adjustment) in the "after" period could also only be worse. This approach was the more conservative of the options available.

2.7 Regression to the mean

The high crash rates observed at some sites may possibly be due to chance or a combination of both chance and the hazardousness of the site. Even if no treatment is to be carried out, some of these sites will likely have fewer crashes in the subsequent period 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), at least three and preferably five years of data is the preferred before and after time period to smooth out any random fluctuations as well as to provide sufficient evidence of any trend or change in an established pattern of crashes. Five years of pre-treatment crash data and at least six months of post-treatment crash data were used for all sites evaluated in the study. The statistical methodology used in this report also recognised the level and distribution of random variation in the data and provided appropriate confidence intervals and significance levels.

2.8 Cost data

Two types of cost data were used in the evaluation of the economic worth of the Run-off-road Crash Program: the costs of implementing the program and the cost savings from a reduction in the number of road crashes as a result of the program being implemented.

The costs of treating the sites include both the initial capital outlay as well as operating and maintenance costs. As discussed previously (section 2.3), MRWA provided the initial capital outlay for each site included in the study. The initial capital outlay was obtained from recorded expenditure, and operating and maintenance costs and expected treatment life were estimated by treatment type.

The operating and maintenance cost for shoulder widening and/or sealing is on average approximately $500 per km per annum across the WA road network; while audible edgelines as a treatment is in general re-applied approximately every 4 years at an average cost of $3000 per km (i.e. effectively an operating and maintenance cost of $750 per km per annum). However, such costs might be higher for a particular site depending on its condition and traffic volume experienced. This study took a very conservative approach in ensuring that the operating and maintenance costs were not under-estimated. For the 350 km of rural roads treated with audible edgelines or white lines (as the only treatment) under the Run-off-road Crash Program, the initial capital outlay was on average $5327.99 per km. Taking this $5327.99 also as the operating and maintenance cost for such sites every 4 years (instead of $3000), the annual operating and maintenance cost was thus over-estimated to be $1332.00 per km per annum. As other sites under the same rural Run-off-road Crash Program were expected to experience similar conditions and traffic volumes, a multiplication factor ($5327.99 ÷ $3000 = 1.78) was applied as a "site condition adjustment" such that 1.78 × $500 = $888.00 was used as an over-estimate for the cost per km per annum for operating and maintaining the shoulder widening and/or sealing treatment at the rural sites. The operating and maintenance cost for shoulder widening and/or sealing together with AEL was then estimated to be $888.00 + $1332.00 = $2220.00 per km per annum. For the 3 sites in sample with other treatments, the cost of the most similar treatment from above was used as an estimate for each site. All final costs used were likely to be over-estimates and this would ensure the cost savings from any economic analysis to be conservative.

The cost savings from fewer road crashes at treated sites were calculated using the road crash severity costs for WA as provided by MRWA, based on the Willingness to Pay (WTP) approach of estimating crash severity costs. These costs include the human costs of treating injuries plus any associated productivity losses and loss of functioning, vehicle repair and related costs, and general crash costs. Excluded are road user costs such as vehicle operating costs and travel time. Applying certain treatments may change the travel time on particular routes as well as vehicle operating costs and maintenance costs. However, to include this type of analysis in calculating the benefits and costs of treated sites requires extensive data and for this reason studies evaluating the cost-effectiveness of road safety treatments such as black spot programs tend to exclude these costs (Bureau of Transport Economics, 2001). The unit of costing used in calculating the economic worth of the Run-off road Crash Program

was the road crash, with unit road crash costs (using averages from rural WA crashes in 2011-2015) expressed in 2015 Australian dollars shown below.

Crash Severity	$
Severity 1 - Fatal	8,302,821
Severity 2 - Hospitalisation	484,526
Severity 3 - Medical Treatment	102,185
Severity 4 or 5 - Property Damage Only	12,062

2.9 Statistical analysis – effectiveness of the treatment

The frequencies of crashes between "before" and "after" treatment periods were compared in the analysis. The study used a generalised estimating equation (GEE) Poisson regression model to evaluate the sites treated under the Run-off-road Crash Program. The number of run-off-road crashes in one year is a discrete "count" variable and assumed to follow a Poisson distribution. However, the application of standard Poisson regression analysis was inappropriate due to the longitudinal nature of the observations, while the GEE was one of the more appropriate methods that could accommodate the inherent correlation of the longitudinal data. The decision to use the GEE Poisson model took into account the correlated nature of the repeated measures taken before and after each run-off-road crash treatment.

The correct effect of each treatment could also be estimated by the GEE Poisson regression model, 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).

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

2.10 Economic analysis – cost-effectiveness of the treatment

Two indicators of the economic worth of the program were calculated: the net present value (NPV) and the benefit-cost ratio (BCR).

NPV is the difference between the present value of the time stream of cost savings from a reduction in road crashes and the present value of the time stream of costs incurred to achieve these savings. In the case of the Run-off-Road Crash Program, the latter include the capital costs of installing the treatments and maintenance and operating costs. NPV is expressed in monetary terms, with a NPV significantly greater than zero indicating a project is

worthwhile. If the economic worth of two or more projects is being compared then the project with the highest NPV is the most worthwhile.

The BCR is the ratio of the present value of the time stream of cost savings from a reduction in road crashes to the present value of the time stream of costs incurred to achieve these savings. It has no units, since it is a ratio of monetary values. A BCR significantly greater than one indicates a project is worthwhile, or if the economic worth of two or more projects are being compared then the project with the highest BCR is the most worthwhile.

The formulas for calculating the NPV and BCR are as follows –

$$NPV = \sum_{i=0}^{n} \left(B_i / (1+r)^i \right) - \sum_{i=0}^{n} \left(C_i / (1+r)^i \right)$$

$$BCR = \left[\sum_{i=0}^{n} \left(B_i / (1+r)^i \right) \right] \Big/ \left[\sum_{i=0}^{n} \left(C_i / (1+r)^i \right) \right]$$

where B_i = benefits in year resulting from savings in road crash costs
C_i = costs of installing run-off-road crash treatments in year 0 and the operating and maintenance costs in subsequent years
r = discount rate (5% used in the base case analysis)
n = the expected life of the project (15 years assumed for all treatments)

NPVs and BCRs were calculated using the following sources of data: (i) the capital costs of initial treatment of the sites, (ii) the maintenance and operating costs of treatments, (iii) the expected treatment life, (iv) the effectiveness of treatments in reducing the number of road crashes, and (v) the unit road crash cost data. The treatment life of projects varied between 10 and 20 years, with an average treatment life of 15 years. This latter was varied to 10 years and 20 years in the sensitivity analysis. Maintenance and operating costs were estimated on an annual basis and assumed to remain constant throughout the expected life of the treatment. Likewise savings from a reduction in road crash costs achieved since installing the treatments were assumed to be maintained over the entire expected life of the treatments. Future costs and cost savings were discounted using a 5% discount rate in the base case, with 3% and 8% used in the sensitivity analysis. Again 5% was the discount rate suggested by MRWA. NPVs and BCRs were calculated for the whole Run-off-road Crash Program and separately for individual treatment types.

3 RESULTS

3.1 All Sites Treated under the rural Run-off-Road Crash Program

There was a total of 57 rural sites that met the inclusion criteria. The exposure time for the "before" period was 1826 days for all sites. The mean exposure time for the "after" period was 695.1 days with a standard deviation of 303.6 days.

Table 3.1 details the reductions in Run-off-road Crashes (all severities), Run-off-road Casualty Crashes, and Run-off-road Killed or Seriously Injured (KSI) Crashes, observed at all sites in the study. Overall, the 57 rural sites reported a significant 35.5% reduction in Run-off-road Crashes during the study period (p-value < 0.001). The sites also reported a significant 18.4% reduction in Run-off-road Casualty Crashes (p-value = 0.021), as well as a significant 25.6% reduction in Run-off-road KSI Crashes (p-value = 0.031).

Table 3.1 Reductions in Crashes at Sites Treated under the Rural Run-off-road Crash Program in WA

	Treatment	No. of Rural Sites in Sample	Exposure (days) - Before Treatment	Number of Crashes - Before Treatment		Mean Exposure (days) - After Treatment	Number of Crashes - After Treatment		Incidence Rate Ratio (IRR)	Std. Err. of IRR	p-value (Probability 0 < p < 1)	95% C.I. of IRR - Lower Bound	95% C.I. of IRR - Upper Bound	Crash Reduction (%)	
				Raw Count	Adjusted		Raw Count	Adjusted							
Run-off-road Crashes (Severity 1 + 2 + 3 + 4 + 5)	**All Run-off-road Crash Treatments**	**57**	1826	441	441.17	695.1	134	141.93	0.645	0.040	< 0.001	0.571	0.728	35.5%	
	Shoulder Widening and/or Sealing (only)	12	1826	72	72	728.1	11	11.98	0.401	0.085	< 0.001	0.265	0.608	59.9%	
	Audible Edgelines (AEL) or White Lines (only)	15	1826	237	237	975.8	101	106.09	0.783	0.042	< 0.001	0.704	0.871	21.7%	
	Shoulder Widening and/or Sealing, with AEL	27	1826	123	123.17	545.3	21	22.59	0.596	0.131	0.018	0.388	0.916	40.4%	
	Other Treatment or Combinations	3	1826	9	9	507.7	1	1.27	0.515	0.323	0.290	0.151	1.758	48.5% *	
Run-off-road Casualty Crashes (Severity 1 + 2 + 3)	**All Run-off-road Crash Treatments**	**57**	1826	192	192.17	695.1	59	66.93	0.816	0.072	0.021	0.687	0.970	18.4%	
	Shoulder Widening and/or Sealing (only)	12	1826	36	36	728.1	6	6.98	0.481	0.141	0.012	0.271	0.853	51.9%	
	Audible Edgelines (AEL) or White Lines (only)	15	1826	85	85	975.8	43	48.09	1.024	0.088	0.784	0.865	1.211	-2.4% *+	
	Shoulder Widening and/or Sealing, with AEL	27	1826	63	63.17	545.3	9	10.59	0.545	0.174	0.057	0.292	1.018	45.5% *	
	Other Treatment or Combinations	3	1826	8	8	507.7	1	1.27	0.604	0.380	0.423	0.176	2.072	39.6% *	
Run-off-road Killed or Seriously Injured (KSI) Crashes (Severity 1 + 2)	**All Run-off-road Crash Treatments**	**57**	1826	115	115.17	695.1	28	35.93	0.744	0.102	0.031	0.569	0.973	25.6%	
	Shoulder Widening and/or Sealing (only)	12	1826	21	21	728.1	2	2.98	0.360	0.185	0.047	0.131	0.987	64.0%	
	Audible Edgelines (AEL) or White Lines (only)	15	1826	50	50	975.8	20	25.09	0.901	0.134	0.483	0.673	1.206	9.9% *	
	Shoulder Widening and/or Sealing, with AEL	27	1826	39	39.17	545.3	5	6.59	0.543	0.213	0.120	0.252	1.172	45.7% *	
	Other Treatment or Combinations	3	1826	5	5	507.7	1	1.27	0.943	0.587	0.925	0.279	3.192	5.7% *	

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

3.1.1 Sites with Shoulder Widening and/or Sealing as the only treatment

For the 12 sites with "*Shoulder Widening and/or Sealing*" as the only treatment, the exposure time for the "before" period was also 1826 days for all sites. The mean exposure time for the "after" period was 728.1 days with a standard deviation of 223.7 days.

The 12 sites reported a significant 59.9% reduction in Run-off-road Crashes (p-value < 0.001). The sites also reported a significant 51.9% reduction in Run-off-road Casualty Crashes (p-value = 0.012), as well as a significant 64.0% reduction in Run-off-road KSI Crashes (p-value = 0.047).

3.1.2 Sites with Audible Edgelines or White Lines as the only treatment

For the 15 sites with "*Audible Edgelines or White Lines*" as the only treatment, the exposure time for the "before" period was also 1826 days for all sites. The mean exposure time for the "after" period was 975.8 days with a standard deviation of 274.2 days.

The 15 sites reported a significant 21.7% reduction in Run-off-road Crashes (p-value < 0.001), but there was no significant change in Run-off-road Casualty Crashes (p-value = 0.784). The 15 sites in sample did observe a 9.9% reduction in Run-off-road KSI Crashes, but the reduction did not carry sufficient statistical significance (p-value = 0.483) to infer a similar reduction for locations outside this study if they were to receive the same treatment under similar conditions.

3.1.3 Sites treated with Shoulder Widening and/or Sealing, as well as Audible Edgelines

For the 27 sites treated with "*Shoulder Widening and/or Sealing, with Audible Edgelines*", the exposure time for the "before" period was also 1826 days for all sites. The mean exposure time for the "after" period was 545.3 days, which was relatively short compared to other sites in the study. The standard deviation of exposure time for the "after" period was 251.2 days.

The 27 sites reported a significant 40.4% reduction in Run-off-road Crashes (p-value = 0.018). The sites in sample did observe a 45.5% reduction in Run-off-road Casualty Crashes and a 45.7% reduction in Run-off-road KSI Crashes, but the reductions did not carry sufficient statistical significance (p-value = 0.057 and p-value = 0.120, respectively) to infer similar reductions for locations outside this study if they were to receive the same treatment

under similar conditions, possibly due to the relatively short "after" exposure available for these sites, even after adjusting for exposure.

3.2 Economic evaluation of the Run-off-road Crash Program

Table 3.2 presents the results of the economic evaluation of the Run-off-road Crash Program in terms of its reduction in run-off-road crashes. The estimated crash cost savings over the expected life of the treatments were $193.0 million for run-off-road crashes of all severities, all of which were attributable to a reduction in run-off-road casualty crashes and run-off-road KSI crashes. This will result in an overall net cost saving to the community over the expected life of the treated sites of $100.2 million after subtracting the capital costs of installing treatments and the maintenance and operating costs. The BCR across all treatment sites was estimated to be 2.1, which indicates benefits in the form of cost savings to the community of $2.10 for each $1 invested in the program. In particular, sites treated with "*audible edgelines or white lines*" (as the only treatment) had a better rate of return than other sites with a BCR of 3.4, possibly due to the relatively low costs of such treatment. Sites treated with both "*shoulder widening and/or sealing*" and "*audible edgelines*" together had a lower rate of return (BCR = 1.6) than sites treated with only one of the two treatments, possibly due to the relatively short "after" exposure observed for these sites, even after adjusting for exposure.

Table 3.3 shows the effect of varying the assumptions relating to the discount rate and treatment life of projects on the estimated rate of return of the Run-off-road Crash Program. The Program was found to be cost-effective across all variations in assumptions, with lower discount rates and longer treatment lives of projects improving rates of return and vice versa. A discount rate of 3% increased the NPV of the Run-off-road Crash Program to $124.3 million and the BCR to 2.3. An expected treatment life of 20 years increased the NPV to $132.4 million and the BCR to 2.4.

Table 3.2 Economic Evaluation of the Run-off-road Crash Program in Relation to Run-off-road Crash Reductions in WA

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
All Run-off-road Crash Treatments	5%	15	92,819,693	192,998,346	100,178,653	2.1
Shoulder Widening and/or Sealing (only)	5%	15	29,030,594	88,686,994	59,656,400	3.1
Audible Edgelines (AEL) or White Lines (only)	5%	15	6,701,071	22,778,123	16,077,052	3.4
Shoulder Widening and/or Sealing, with AEL	5%	15	49,651,053	81,311,499	31,660,446	1.6
Other Treatment or Combinations	5%	15	7,436,976	221,730	-7,215,246	0.0

Table 3.3 Sensitivity Analysis for the Economic Evaluation of the Run-off-road Crash Program in Relation to Run-off-road Crash Reductions in WA

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
All Run-off-road Crash Treatments	3%	15	95,129,529	219,426,635	124,297,106	2.3
	5%	15	92,819,693	192,998,346	100,178,653	2.1
	8%	15	90,121,640	162,128,209	72,006,569	1.8
	5%	10	88,879,852	147,920,123	59,040,271	1.7
	5%	15	92,819,693	192,998,346	100,178,653	2.1
	5%	20	95,906,663	228,318,313	132,411,651	2.4

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
Shoulder Widening and/or Sealing (only)	3%	15	29,283,487	100,831,375	71,547,888	3.4
	5%	15	29,030,594	88,686,994	59,656,400	3.1
	8%	15	28,735,196	74,501,485	45,766,290	2.6
	5%	10	28,599,238	67,972,557	39,373,319	2.4
	5%	15	29,030,594	88,686,994	59,656,400	3.1
	5%	20	29,368,572	104,917,297	75,548,725	3.6

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
Audible Edgelines (AEL) or White Lines (only)	3%	15	7,427,298	25,897,253	18,469,955	3.5
	5%	15	6,701,071	22,778,123	16,077,052	3.4
	8%	15	5,852,786	19,134,756	13,281,970	3.3
	5%	10	5,462,360	17,457,884	11,995,524	3.2
	5%	15	6,701,071	22,778,123	16,077,052	3.4
	5%	20	7,671,633	26,946,670	19,275,036	3.5

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
Shoulder Widening and/or Sealing, with AEL	3%	15	50,912,823	92,445,915	41,533,092	1.8
	5%	15	49,651,053	81,311,499	31,660,446	1.6
	8%	15	48,177,215	68,305,703	20,128,488	1.4
	5%	10	47,498,876	62,319,741	14,820,865	1.3
	5%	15	49,651,053	81,311,499	31,660,446	1.6
	5%	20	51,337,340	96,192,038	44,854,699	1.9

4 DISCUSSIONS AND RECOMMENDATIONS

This study presents the results of the evaluation of the rural Run-off-road Crash Program in WA in terms of its effectiveness in reducing the frequency and severity for run-off-road crashes, as well as the associated costs for sites treated under the 2012/13, 2013/14 and 2014/15 budgets (as at 31st March 2016). The analysis found the program to be effective overall in reducing both the frequency and severity of such crashes, with a 35.5% reduction in run-off-road crashes, 18.4% reduction in run-off-road casualty crashes, and a 25.6% reduction in run-off-road KSI crashes, for all sites treated under the program.

A number of decisions were made regarding the analysis. As the treatments under the program were intended to reduce the number of single vehicle run-off-road crashes, the study examined the effects of the treatments on all severity of run-off-road crashes (including PDO), as well as run-off-road casualty crashes only, and run-off-road KSI crashes only.

The evaluation of the program identified "*shoulder widening and/or sealing*" to be highly successful in reducing both the frequency and severity of run-off-road crashes. "*Audible edgelines or white lines*" was also successful in reducing the frequency of such crashes, but appeared to be less successful in reducing the more severe of such crashes when implemented as the only treatment.

Such reductions, at a first glance, appeared to be diminished when the above two treatments were applied together at 27 sites in the study. This is, however, not surprising given the relatively short "after" exposure available for these sites, even after adjusting for exposure, as these were still much less than the recommended three to five years of crash data needed for this type of analysis (Nicholson 1986). Should longer "after" exposure be available then the real effects (either increases or reductions) could become more apparent.

The findings in this study are consistent with previous research. Catchpole (1990) found unsealed shoulders to be a contributing factor in over 50% of fatal run-off-road crashes in New South Wales. Meuleners & Hendrie (2009) found 13 WA sites with a mix of "*shoulder sealing*" and/or "*audible edgelines*" treatments to have observed reductions in run-off-road crashes by 59% and run-off-road casualty crashes by 80%. Zhang et al. (2014), Meuleners et al. (2014) and Chow et al. (2015) also found sites treated with "*shoulder sealing*" or "*edgelines*" in the 2007/08, 2009/10 and 2011/12 WA State Black Spot Programs to have varying degrees of success in reducing all reported crashes and casualty crashes.

The Run-off-road Crash Program also performed well in economic terms. In relation to the net economic worth of the program, the NPV and the BCR across all treatment sites were estimated to be $100.2 million and 2.1 respectively. Sites treated with "*audible edgelines or white lines*" had a better rate of return than other sites, with a BCR of 3.4, possibly due to the relatively low costs of such treatment. Sites treated with both "*shoulder widening and/or sealing*" and "*audible edgelines*" together had a lower rate of return (BCR = 1.6) than sites treated with only one of the two treatments, again possibly due to the relatively short "after" exposure observed for these sites.

It is recommended that the Run-off-road Crash Program be continued as both its overall effectiveness and cost-effectiveness are apparent. Considering that the positive outcomes from this study were obtained from conservative assumptions and adjustments, the real effects from the program could be better than reported.

It is also recommended that the analysis be repeated after observation of longer "after" exposure for the treated sites, particularly for the 27 sites treated with both "*shoulder widening and/or sealing*" and "*audible edgelines*".

REFERENCES

Bramwell J., Hill D.L., Thompson P.E. (2014). Reported Road Crashes in Western Australia 2012, Road Safety Council of Western Australia.

Bureau of Infrastructure, Transport and Regional Economics (BITRE). (2012). Evaluation of the National Black Spot Program Volume 1 BITRE Report 126, Canberra ACT.

Catchpole J. (1990). Road designs and fatal accidents. Proc. 15th Australian Road Research Board Conference 15(7), pp 199-215.

Chow K., Meuleners L., Hendrie D. (2015). A preliminary evaluation of the effectiveness and cost-effectiveness of the state black spot program in Western Australia, 2011-2012, Curtin-Monash Accident Research Centre.

Dupont W.D., (2002). Statistical Modeling for Biomedical Researchers: a Simple Introduction to the Analysis of Complex Data. Cambridge University Press, Cambridge.

Meuleners L., Hendrie D. (2009). An evaluation of the effectiveness and cost-effectiveness of sealed shoulders and audible edgelines on Albany Highway, 2000-2004, Centre for Population Health Research, Curtin Health Innovation Research Institute.

Meuleners L., Zhang M., Hendrie D. (2014). An evaluation of the effectiveness and cost-effectiveness of the state black spot program in Western Australia, 2009-2010, Curtin-Monash Accident Research Centre.

Nicholson A.J. (1986). Estimation of the Underlying True Accident rate: A New Procedure, 13th ARRB-5th REAA Combined Conference, Volume 13, Part 9, Safety, August.

Office of Road Safety (2009). Towards zero – road safety strategy, http://www.ors.wa.gov.au/Documents/Strategies/ors-towards-zero-strategy.aspx

Office of Road Safety (2014). Reported road crashes in Western Australia 2013, http://www.ors.wa.gov.au/Stats/Annual/annual-crash-statistics-2013.aspx

Szwed N. (2011). Flexible road safety barriers (fact sheet no. 8), Curtin-Monash Accident Research Centre.

Twisk J. (2003). Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide. Cambridge University Press: Cambridge.

Wooley J.E., McLean A.J. (2006). Edge delineations. Centre for Automotive Safety Research Report Series, Report No. CARSR025. Centre for Automotive Safety Research, The University of Adelaide; South Australia.

Zhang M., Meuleners L., Hendrie D. (2014). An evaluation of the effectiveness and cost-effectiveness of the state black spot program in Western Australia: 2007-2008, Curtin-Monash Accident Research Centre.

APPENDIX A – All Reported Crashes in WA (Metropolitan and Rural), 2002-2015

Year	Severity 1 Fatal Crashes	Severity 2 Hospitalisation Crashes	Severity 3 Medical Treatment Crashes	Severity 4 + 5 Property Damage Only (Major or Minor) Crashes	Severity 4 PDO (Major) Crashes	Severity 5 PDO (Minor) Crashes	Severity 1 + 2 Killed or Seriously Injured Crashes	Severity 1 + 2 + 3 Casualty Crashes	Severity 1 + 2 + 3 + 4 + 5 All Reported Crashes
2002	159	2208	5739	28261	20522	7739	2367	8106	**36367**
2003	154	2230	5357	28271	20425	7846	2384	7741	**36012**
2004	163	2485	5388	29867	21966	7901	2648	8036	**37903**
2005	151	2385	5251	31194	23821	7373	2536	7787	**38981**
2006	182	2122	5565	31690	24925	6765	2304	7869	**39559**
2007	213	2190	5586	33646	26857	6789	2403	7989	**41635**
2008	185	2280	5433	31412	21728	9684	2465	7898	**39310**
2009	176	2007	5358	29691	18108	11583	2183	7541	**37232**
2010	175	2032	5506	31921	19962	11959	2207	7713	**39634**
2011	167	2006	5618	31675	19836	11839	2173	7791	**39466**
2012	171	2017	5237	31733	19944	11789	2188	7425	**39158**
2013	149	1945	4853	29950	18642	11308	2094	6947	**36897**
2014	174	1465	4831	28246	17986	10260	1639	6470	**34716**
2015	142	1219	4539	26480	17335	9145	1361	5900	**32380**

APPENDIX B – List of Treatment Sites Used in the Study

																					Run-off-road Crashes - Before Treatment (Raw Count)					Run-off-road Crashes - After Treatment (Raw Count)					Run-off-road Crashes - Before Treatment (Adjusted for Drop-offs in 2014 and 2015 Killed or Seriously Injured (KSI) Crashes)					Run-off-road Crashes - After Treatment (Adjusted for Drop-offs in 2014 and 2015 Killed or Seriously Injured (KSI) Crashes)					
Site	Road Name	Road Number	Treatment Description	With Shoulder Widening and/or Sealing?	With Audible Edgelines (AEL) or White Lines?	With Other Treat-ment(s)?	Start SLK	End SLK	Length of Road Section (km)	Start SLK used for crash matching to account for precision errors	End SLK used for crash matching to account for precision errors	Construction Start Date	Construction End Date	Funding Year	Project Number	Initial Capital Outlay ($)	Notes on Initial Capital Outlay	Initial Capital Outlay per km ($)	Exposure Before Treatment (days)	Exposure After Treatment (days)	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	Included in Final Sample for Analysis?
S01	Albany Hwy	H001	shoulder widening and/or sealing, with AEL	Y	Y		250.8	252.65	1.85	250.805	252.645	1/08/2012	1/05/2013	2012	21108311	1,505,383.00		813,720.54	1826	974	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	Y
S51	Brand Hwy	H004	shoulder widening and/or sealing, with AEL	Y	Y		86	118.2	32.2	86.050	118.150	1/01/2013	30/06/2013	2012	21108324	6,017,541.00		186,880.16	1826	914	0	8	4	12	1	0	1	0	0	0	0	8	4	12	1	0	1.17	0	0	0	Y
S31	Great Northern Hwy	H006	shoulder widening and/or sealing, with AEL	Y	Y		353.57	406.1	52.53	353.575	406.095	18/11/2013	30/03/2014	2013	21108442	4,254,883.00		80,999.11	1826	641	0	0	1	2	0	0	0	1	1	0	0	0	1	2	0	0	0.27	1	1	0	Y
S53	Great Northern Hwy	H006	shoulder widening and/or sealing, with AEL	Y	Y		1149.7	1168.35	18.65	1149.705	1168.345	23/11/2013	26/06/2014	2013	21109335	1,524,378.00		81,736.09	1826	553	1	1	3	2	1	0	0	0	1	0	1	1	3	2	1	0	0	0	1	0	Y
S54	Great Northern Hwy	H006	shoulder widening and/or sealing, with AEL	Y	Y		1399.34	1442.97	43.63	1399.345	1442.965	13/02/2015	2/04/2015	2014	21110638	1,984,172.00		45,477.24	1826	273	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	Y
S55	Great Northern Hwy	H006	shoulder widening and/or sealing	Y			1559.34	1599.96	40.62	1559.345	1599.955	11/02/2013	3/04/2013			1,202,954.00		29,614.82	1826	1002	0	1	1	2	0	0	0	0	1	0	0	1	1	2	0	0	0	0	1	0	Y
S41	Great Northern Hwy	H006	shoulder widening and/or sealing, with AEL	Y	Y		2291.8	2299.97	8.17	2291.805	2299.965	12/05/2014	30/11/2014	2013	21109366	1,487,085.00		182,017.75	1826	396	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N
S33	North West Costal Hwy	H007	audible edgelines (AEL) or white lines		Y		18.5	29.6	11.1	18.550	29.550	16/08/2014	16/08/2014	2013	21109466	48,890.00		4,404.50	1826	502	0	0	0	4	0	0	1	0	1	0	0	0	0	4	0	0	1.17	0	1	0	Y
S32	North West Costal Hwy	H007	shoulder widening and/or sealing, with AEL	Y	Y		66.2	83.5	17.3	66.250	83.450	29/04/2014	16/06/2014	2013	21109465	1,417,059.00		81,910.92	1826	563	0	4	0	3	0	0	0	0	0	0	0	4	0	3	0	0	0	0	0	0	Y
S34	North West Costal Hwy	H007	shoulder widening and/or sealing, with AEL	Y	Y		83.5	92	8.5	83.550	91.950	23/03/2015	26/05/2015	2014	21110618	1,601,117.00		188,366.71	1826	219	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	Y
S35	North West Costal Hwy	H007	audible edgelines (AEL) or white lines		Y		103.1	107.9	4.8	103.150	107.850	16/08/2014	16/08/2014	2013	21109467	20,195.00		4,207.29	1826	502	0	0	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	Y
S30	North West Costal Hwy	H007	audible edgelines (AEL) or white lines		Y		456.65	473.37	16.72	456.655	473.365	15/04/2012	19/04/2012	2012	21108440	70,000.00		4,186.60	1826	1351	0	1	0	2	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	Y
S29	North West Costal Hwy	H007	audible edgelines (AEL) or white lines		Y		529.3	611.85	82.55	529.305	611.845	20/04/2012	25/04/2012	2012	21108439	334,906.00		4,057.01	1826	1345	0	2	0	2	1	1	1	2	1	0	0	2	0	2	1	1	1.44	2	1	0	Y
S56a	North West Costal Hwy	H007	shoulder widening and/or sealing, with AEL	Y	Y		1098.85	1108.42	9.57	1098.855	1108.415	23/11/2013	30/06/2014	2013	21109336	654,388.44		68,379.15	1826	549	0	0	1	2	0	0	1	1	0	0	0	0	1	2	0	0	1.44	1	0	0	Y
S57	North West Costal Hwy	H007	shoulder widening and/or sealing, with AEL	Y	Y		1163.7	1177.27	13.57	1163.705	1177.265	22/05/2015	22/06/2015	2014	21111220	1,042,080.00		76,792.93	1826	192	0	3	1	0	1	0	0	0	0	0	0	3	1	0	1	0	0	0	0	0	Y
S56b	North West Costal Hwy	H007	shoulder widening and/or sealing, with AEL	Y	Y		1219	1230	11	1219.500	1229.500	23/11/2013	30/06/2014	2013	21109336	752,170.62		68,379.15	1826	549	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	Y
S56c	North West Costal Hwy	H007	shoulder widening and/or sealing, with AEL	Y	Y		1230.42	1235	4.58	1230.425	1234.995	23/11/2013	30/06/2014	2013	21109336	313,176.50		68,379.15	1826	549	0	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	Y
S56d	North West Costal Hwy	H007	shoulder widening and/or sealing, with AEL	Y	Y		1264.5	1267.5	3	1264.550	1267.450	23/11/2013	30/06/2014	2013	21109336	205,137.44		68,379.15	1826	549	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N
S37	South Coast Hwy	H008	shoulder widening and/or sealing, with AEL	Y	Y		442	455.5	13.5	442.050	455.450	11/03/2013	17/07/2013	2012	21108309	3,273,659.00		242,493.26	1826	897	0	1	1	1	0	0	1	0	0	0	0	1	1	1	0	0	1	0	0	0	Y
S03	South Western Hwy	H009	audible edgelines (AEL) or white lines		Y		84.8	149.73	64.93	84.805	149.725	1/02/2013	31/03/2013	2012	21108288	190,815.00		2,938.78	1826	1005	3	12	9	20	7	2	5	4	10	0	3	12	9	20	7	2	6.85	4	10	0	Y
S04	South Western Hwy	H009	shoulder widening and/or sealing	Y			173.52	177.55	4.03	173.525	177.545	27/05/2014	30/06/2014	2013	21109981	910,271.00		225,873.70	1826	549	0	2	1	4	0	0	0	0	0	0	0	2	1	4	0	0	0	0	0	0	Y
S05	South Western Hwy	H009	shoulder widening and/or sealing	Y			177.56	181.7	4.14	177.565	181.695	27/05/2014	30/06/2014	2014	21109981	568,297.00		137,269.81	1826	549	2	2	3	4	0	0	0	2	0	0	2	2	3	4	0	0	0.54	2	0	0	Y
S06	South Western Hwy	H009	audible edgelines (AEL) or white lines		Y		187.81	240.96	53.15	187.815	240.955	1/02/2013	31/03/2013	2012	21108289	32,751.00		616.20	1826	1005	0	7	7	7	8	0	1	4	8	1	0	7	7	7	8	0	1.71	4	8	1	Y
S07	South Western Hwy	H009	audible edgelines (AEL) or white lines		Y		245	255	10	245.500	254.500	1/02/2013	31/03/2013	2012	21108423	45,263.00		4,526.30	1826	1005	0	2	2	1	2	0	0	0	3	0	0	2	2	1	2	0	0	0	3	0	Y
S11a	South Western Hwy	H009	shoulder widening and/or sealing	Y			255.7	255.87	0.17	255.705	255.865	24/03/2013	19/04/2013	2012	21108427	9,122.20		53,660.03	1826	986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N
S11b / S12a	South Western Hwy	H009	shoulder widening and/or sealing, with AEL	Y	Y		255.87	263.23	7.36	255.875	263.225	24/03/2013	1/05/2014	2012 / 2013	21108427	416,245.05		56,555.03	1826	609	1	1	1	2	0	1	0	0	0	1	1	1	1	2	0	1	0.27	0	0	1	Y
S12b / S08a	South Western Hwy	H009	audible edgelines (AEL) or white lines		Y		263.23	263.28	0.05	263.235	263.275	1/02/2013	1/07/2014	2012 / 2013	21108424 / 21108427	757.18	Note: $612.43 from Proj. 21108424 and $144.75 from Proj. 21108427	15,143.64	1826	548	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N
S08b	South Western Hwy	H009	audible edgelines (AEL) or white lines		Y		263.28	268.7	5.42	263.285	268.695	1/02/2013	1/07/2014	2012	21108424	66,387.57		12,248.63	1826	548	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	Y
S09	South Western Hwy	H009	audible edgelines (AEL) or white lines		Y		269.9	277.5	7.6	269.950	277.450	1/02/2013	31/03/2013	2012	21108425	35,300.00		4,644.74	1826	1005	0	3	0	1	1	0	0	0	0	0	0	3	0	1	1	0	0	0	0	0	Y
S10	South Western Hwy	H009	audible edgelines (AEL) or white lines		Y		288.2	294.2	6	288.250	294.150	1/02/2013	31/03/2013	2012	21108426	23,642.00		3,940.33	1826	1005	0	0	2	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	1	0	Y
S38	Coolgardie Esperance Hwy	H010	shoulder widening and/or sealing, with AEL	Y	Y		101.4	104.3	2.9	101.450	104.250	12/01/2015	9/02/2015			685,131.00		236,252.07	1826	325	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	Y
S39	Coolgardie Esperance Hwy	H010	shoulder widening and/or sealing, with AEL	Y	Y		104.3	113.64	9.34	104.305	113.635	1/05/2015	30/06/2015			2,827,544.00		302,734.90	1826	184	1	0	1	1	0	0	0	0	1	0	1	0.17	1	1	0	0	0	0	1	0	Y
S40	Coolgardie Esperance Hwy	H010	shoulder widening and/or sealing, with AEL	Y	Y		155.68	164.23	8.55	155.685	164.225	28/01/2013	8/04/2014	2013	21109348	2,473,205.00		289,263.74	1826	632	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	Y
S42	Victoria Hwy	H011	shoulder widening and/or sealing, with AEL	Y	Y		25	36	11	25.500	35.500	1/05/2015	30/06/2016	2014	21111218	519,547.00		47,231.55	1826	N/A	1	1	1	1	0						1	1	1	1	0						N
S43	Victoria Hwy	H011	shoulder widening and/or sealing, with AEL	Y	Y		52	72	20	52.500	71.500	5/05/2014	25/07/2014	2013	21109354	820,465.00		41,023.25	1826	524	0	1	2	2	0	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	Y
S44a	Broome Hwy	H042	shoulder widening and/or sealing, with AEL	Y	Y		0	24.27	24.27	0.050	24.265	10/05/2013	29/07/2013	2012	21108319	3,517,749.73		144,942.30	1826	885	0	1	0	3	0	0	0	1	0	0	0	1	0	3	0	0	0.27	1	0	0	Y
S44b / S45a	Broome Hwy	H042	shoulder widening and/or sealing, with AEL	Y	Y		24.27	24.3	0.03	24.275	24.250	10/05/2013	29/07/2013	2012 / 2013	21108319 / 21109373	10,338.29	Note: $4348.27 from Proj. 21108319 and $5990.02 from Proj. 21109373	344,609.53	1826	885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N
S45b	Broome Hwy	H042	shoulder widening and/or sealing	Y			24.3	30.28	5.98	24.350	30.275	27/05/2013	29/07/2013	2013	21109373	1,194,009.98		199,667.22	1826	885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N
S14a	Bussell Hwy	H043	shoulder widening and/or sealing, with AEL	Y	Y		5.37	8.63	3.26	5.375	8.625	7/04/2014	12/05/2014	2013	21109722	226,859.71		69,588.87	1826	598	0	0	0	4	1	0	0	0	1	0	0	0	0	4	1	0	0	0	1	0	Y
S14b / S15	Bussell Hwy	H043	shoulder widening and/or sealing, with AEL	Y	Y		8.63	15.5	6.87	8.635	15.495	1/02/2013	12/05/2014	2012 / 2013	21108428 / 21109722	531,318.52	Note: $53243.00 from Proj. 21108428 and $478075.52 from Proj. 21109722	77,338.94	1826	598	0	3	2	12	0	0	0	1	2	0	0	3	2	12	0	0	0.17	1	2	0	Y
S14c	Bussell Hwy	H043	shoulder widening and/or sealing, with AEL	Y	Y		15.5	15.7	0.2	15.505	15.695	7/04/2014	12/05/2014	2013	21109722	13,917.77		69,588.87	1826	598	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	Y
S16	Bussell Hwy	H043	audible edgelines (AEL) or white lines		Y		26.8	46.62	19.82	26.805	46.615	1/02/2013	31/03/2013	2012	21108429	51,860.00		2,616.55	1826	1005	0	2	5	11	4	0	5	4	3	2	0	2	5	11	4	0	6.04	4	3	2	Y
S13	Bussell Hwy	H043	audible edgelines (AEL) or white lines		Y		72.4	96	23.6	72.450	95.950	1/02/2013	31/03/2013	2012	21108290	74,179.00		3,143.18	1826	1005	1	4	2	9	2	0	1	2	2	2	1	4	2	9	2	0	1.44	2	2	2	Y
S17	Bussell Hwy	H043	shoulder widening and/or sealing, with AEL	Y	Y		98.7	111.53	12.83	98.705	111.525	6/05/2013	14/06/2013	2012	21108431	1,208,563.00		94,198.21	1826	930	1	2	2	2	0	0	1	0	1	0	1	2	2	2	0	0	1	0	1	0	Y
S18	Bussell Hwy	H043	shoulder widening and/or sealing, with AEL	Y	Y		111.53	128.5	16.97	111.535	128.495	23/09/2013	30/06/2014	2013	21109308	2,024,737.00		119,312.73	1826	549	0	0	1	2	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	Y
S19	Coalfields Hwy	H045	audible edgelines (AEL) or white lines		Y		4	10	6	4.500	9.500	1/02/2013	31/03/2013	2012	21108430	12,910.00		2,151.67	1826	1005	0	1	0	2	0	0	0	1	1	0	0	1	0	2	0	0	0	1	1	0	Y
S20	Coalfields Hwy	H045	shoulder widening and/or sealing, with AEL	Y	Y		10	16	6	10.500	15.500	16/09/2013	17/10/2013	2013	21109312	383,530.00		63,921.67	1826	805	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	Y
S46	Williams Narrogin Hwy	H053	audible edgelines (AEL) or white lines		Y		3.165	28.699	25.534	3.166	28.699	25/02/2012	26/04/2012	2012	21108421	718,379.00		28,134.21	1826	1344	1	3	0	11	1	0	2	1	3	0	1	3	0	11	1	0	2.17	1	3	0	Y
S21	Forrest Hwy	H057	audible edgelines (AEL) or white lines		Y		76.85	89.51	12.66	76.855	89.505	1/02/2013	31/03/2013	2012	21108291	138,210.00		10,917.06	1826	1005	0	7	6	43	12	0	1	5	17	3	0	7	6	43	12	0	1.27	5	17	3	Y
S22	Vasse Hwy	M008	shoulder widening and/or sealing, with AEL	Y	Y		32.57	43.65	11.08	32.575	43.645	1/10/2014	1/05/2015	2014	21109983	973,212.00		87,835.02	1826	244	1	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	2	0	Y

APPENDIX B – List of Treatment Sites Used in the Study (cont'd)

Site	Road Name	Road Number	Treatment Description	With Shoulder Widening and/or Sealing?	With Audible Edgelines (AEL) or White Lines?	With Other Treat-ment(s)?	Start SLK	End SLK	Length of Road Section (km)	Start SLK used for crash matching to account for precision errors	End SLK used for crash matching to account for precision errors	Construction Start Date	Construction End Date	Funding Year	Project Number	Initial Capital Outlay ($)	Notes on Initial Capital Outlay	Initial Capital Outlay per km ($)	Exposure Before Treatment (days)	Exposure After Treatment (days)
S23a	Donnybrook Kojonup	M013	shoulder widening and/or sealing, with AEL	Y	Y		1.26	4.15	2.89	1.265	4.145	1/04/2015	30/06/2015	2014	21111015	282,306.30		97,683.84	1826	184
S23b	Donnybrook Kojonup	M013	shoulder widening and/or sealing, with AEL	Y	Y		5.5	10.84	5.34	5.505	10.835	1/04/2015	30/06/2015	2014	21111015	521,631.70		97,683.84	1826	184
S24a	Donnybrook Kojonup	M013	shoulder widening and/or sealing	Y			14.1	18.56	4.46	14.105	18.555	1/04/2015	30/06/2016	2014	21109982	610,438.66		136,869.65	1826	N/A
S24b	Donnybrook Kojonup	M013	shoulder widening and/or sealing	Y			19.12	25.93	6.81	19.125	25.925	1/04/2015	30/06/2016	2014	21109982	932,082.34		136,869.65	1826	N/A
S47	Northam-Cranbrook Rd	M031	shoulder widening and/or sealing	Y			98.22	166.6	68.38	98.225	166.595	15/10/2012	28/05/2013	2012	21108302	10,256,114.00		149,987.04	1826	947
S48	Northam-Cranbrook Rd	M031	shoulder widening and/or sealing	Y			172.42	183.46	11.04	172.425	183.455	6/12/2012	15/05/2013	2012	21108422	5,114,613.00		463,280.16	1826	960
S49	Northam-Cranbrook Rd	M031	shoulder widening and/or sealing	Y			183.46	204.31	20.85	183.465	204.305	10/02/2014	30/06/2014	2013	21109346	2,288,859.00		109,777.41	1826	549
S02	Northam Cranbrook Rd	M031	shoulder widening and/or sealing	Y			336	340.8	4.8	336.050	340.750	1/07/2013	24/10/2014	2013	21109355	1,618,348.00		337,155.83	1826	433
S50	Collie Lake King Rd	M037	shoulder widening and/or sealing	Y			157.21	172	14.79	157.215	171.995	25/02/2014	30/06/2014	2013	21109347	2,168,075.00		146,590.60	1826	549
S36	Wubin-Mullewa	M039	other treatment or combinations			Y	85.82	123.82	38	85.825	123.815	1/07/2014	1/11/2014	2014	21109340	4,400,000.00		115,789.47	1826	425
S52a	York-Merredin Rd	M041	other treatment or combinations	Y	Y	Y	17	17.5	0.5	17.050	17.450	1/07/2013	30/06/2014	2013	21109350	272,487.63		544,975.26	1826	549
S52b	York-Merredin Rd	M041	other treatment or combinations	Y	Y	Y	59.27	63.5	4.23	59.275	63.495	1/07/2013	30/06/2014	2013	21109350	2,305,245.37		544,975.26	1826	549
S25	Caves Rd	M043	shoulder widening and/or sealing	Y			4.78	8	3.22	4.785	7.995	6/05/2013	24/05/2013	2012	21108433	518,576.00		161,048.45	1826	951
S26	Caves Rd	M043	shoulder widening and/or sealing	Y			8	15.58	7.58	8.005	15.575	9/01/2014	21/03/2014	2013	21109309	1,132,023.00		149,343.40	1826	650
S27	Caves Rd	M043	shoulder widening and/or sealing	Y			17.09	20.4	3.31	17.095	20.395	24/03/2014	26/05/2014	2013	21109311	1,567,943.00		473,698.79	1826	584
S28	Collie Mumballup	M046	shoulder widening and/or sealing	Y			3.81	7.62	3.81	3.815	7.615	26/02/2013	22/03/2013	2012	21108432	383,592.00		100,680.31	1826	1014

Site	Run-off-road Crashes - Before Treatment (Raw Count)					Run-off-road Crashes - After Treatment (Raw Count)					Run-off-road Crashes - Before Treatment (Adjusted for Drop-offs in 2014 and 2015 Killed or Seriously Injured (KSI) Crashes)					Run-off-road Crashes - After Treatment (Adjusted for Drop-offs in 2014 and 2015 Killed or Seriously Injured (KSI) Crashes)					Included in Final Sample for Analysis?
	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	Severity 1 Fatal	Severity 2 Hospitalisation	Severity 3 Medical Treatment	Severity 4 Propoerty Damage Only (PDO) (Major)	Severity 5 Propoerty Damage Only (PDO) (Minor)	
S23a	0	0	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	Y
S23b	0	1	0	2	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	Y
S24a	0	0	0	0	0						0	0	0	0	0						N
S24b	0	2	0	0	0						0	2	0	0	0						N
S47	1	7	3	10	2	0	1	1	2	1	1	7	3	10	2	0	1.27	1	2	1	Y
S48	0	0	2	1	1	0	1	0	0	0	0	0	2	1	1	0	1.17	0	0	0	Y
S49	0	4	1	1	1	0	0	0	0	0	0	4	1	1	1	0	0	0	0	0	Y
S02	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	Y
S50	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	Y
S36	0	3	2	0	0	0	1	0	0	0	0	3	2	0	0	0	1.27	0	0	0	Y
S52a	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	Y
S52b	0	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	Y
S25	0	0	1	1	1	0	0	1	0	0	0	0	1	1	1	0	0	1	0	0	Y
S26	0	0	1	2	1	0	0	0	0	1	0	0	1	2	1	0	0	0	0	1	Y
S27	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	Y
S28	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	Y

APPENDIX C – Reductions in Run-off-road Crashes using Raw Crash Count – Unadjusted for Drop-offs in 2014 and 2015 KSI Crashes

	Treatment	No. of Rural Sites in Sample	Road Length Covered by Sample (km)	Exposure (days) - Before Treatment	Number of Crashes - Before Treatment Raw Count	Exposure (days) - After Treatment Min	Max	Mean	S.D.	Number of Crashes - After Treatment Raw Count	Estimate (β)	Incidence Rate Ratio (IRR)	Std. Err. of IRR	z	p-value (Probability 0 < p < 1)	95% C.I. of IRR - Lower Bound	95% C.I. of IRR - Upper Bound	Crash Reduction (%)	
Run-off-road Crashes	**All Run-off-road Crash Treatments**	**57**	**943.9**	1826	441	184	1351	695.1	303.6	134	-0.510	0.601	0.039	-7.84	< 0.001	0.529	0.682	39.9%	
(Severity	Shoulder Widening and/or Sealing (only)	12	186.6	1826	72	433	1014	728.1	223.7	11	-0.995	0.370	0.083	-4.42	< 0.001	0.238	0.575	63.0%	
1 + 2 + 3 + 4 + 5)	Audible Edgelines (AEL) or White Lines (only)	15	349.9	1826	237	502	1351	975.8	274.2	101	-0.296	0.743	0.042	-5.24	< 0.001	0.665	0.831	25.7%	
	Shoulder Widening and/or Sealing, with AEL	27	364.7	1826	123	184	974	545.3	251.2	21	-0.587	0.556	0.126	-2.59	0.010	0.356	0.868	44.4%	
	Other Treatment or Combinations	3	42.7	1826	9	425	549	507.7	71.6	1	-0.883	0.414	0.298	-1.23	0.220	0.101	1.696	58.6%	*
Run-off-road	**All Run-off-road Crash Treatments**	**57**	**943.9**	1826	192	184	1351	695.1	303.6	59	-0.335	0.716	0.069	-3.46	0.001	0.592	0.865	28.4%	
Casualty Crashes	Shoulder Widening and/or Sealing (only)	12	186.6	1826	36	433	1014	728.1	223.7	6	-0.882	0.414	0.134	-2.72	0.007	0.219	0.782	58.6%	
(Severity 1 + 2 + 3)	Audible Edgelines (AEL) or White Lines (only)	15	349.9	1826	85	502	1351	975.8	274.2	43	-0.089	0.914	0.088	-0.93	0.351	0.758	1.103	8.6%	*
	Shoulder Widening and/or Sealing, with AEL	27	364.7	1826	63	184	974	545.3	251.2	9	-0.771	0.463	0.158	-2.25	0.024	0.237	0.904	53.7%	
	Other Treatment or Combinations	3	42.7	1826	8	425	549	507.7	71.6	1	-0.730	0.482	0.355	-0.99	0.321	0.114	2.041	51.8%	*
Run-off-road	**All Run-off-road Crash Treatments**	**57**	**943.9**	1826	115	184	1351	695.1	303.6	28	-0.552	0.576	0.093	-3.42	0.001	0.420	0.790	42.4%	
Killed or Seriously Injured	Shoulder Widening and/or Sealing (only)	12	186.6	1826	21	433	1014	728.1	223.7	2	-1.424	0.241	0.159	-2.15	0.031	0.066	0.880	75.9%	
(KSI) Crashes	Audible Edgelines (AEL) or White Lines (only)	15	349.9	1826	50	502	1351	975.8	274.2	20	-0.335	0.716	0.125	-1.91	0.056	0.508	1.009	28.4%	*
(Severity 1 + 2)	Shoulder Widening and/or Sealing, with AEL	27	364.7	1826	39	184	974	545.3	251.2	5	-0.895	0.409	0.181	-2.02	0.043	0.172	0.973	59.1%	
	Other Treatment or Combinations	3	42.7	1826	5	425	549	507.7	71.6	1	-0.292	0.747	0.535	-0.41	0.684	0.183	3.045	25.3%	*

APPENDIX D – Reductions in Run-off-road Crashes – Adjusted for Drop-offs in 2014 and 2015 KSI Crashes

	Treatment	No. of Rural Sites in Sample	Road Length Covered by Sample (km)	Exposure (days) - Before Treatment	Number of Crashes - Before Treatment Raw Count	Adjusted	Exposure (days) - After Treatment Min	Max	Mean	S.D.	Number of Crashes - After Treatment Raw Count	Adjusted	Estimate (β)	Incidence Rate Ratio (IRR)	Std. Err. of IRR	z	p-value (Probability 0 < p < 1)	95% C.I. of IRR - Lower Bound	95% C.I. of IRR - Upper Bound	Crash Reduction (%)	
Run-off-road Crashes	**All Run-off-road Crash Treatments**	**57**	**943.9**	1826	441	441.17	184	1351	695.1	303.6	134	141.93	-0.439	0.645	0.040	-7.10	< 0.001	0.571	0.728	35.5%	
(Severity	Shoulder Widening and/or Sealing (only)	12	186.6	1826	72	72	433	1014	728.1	223.7	11	11.98	-0.913	0.401	0.085	-4.30	< 0.001	0.265	0.608	59.9%	
1 + 2 + 3 + 4 + 5)	Audible Edgelines (AEL) or White Lines (only)	15	349.9	1826	237	237	502	1351	975.8	274.2	101	106.09	-0.244	0.783	0.042	-4.51	< 0.001	0.704	0.871	21.7%	
	Shoulder Widening and/or Sealing, with AEL	27	364.7	1826	123	123.17	184	974	545.3	251.2	21	22.59	-0.517	0.596	0.131	-2.36	0.018	0.388	0.916	40.4%	
	Other Treatment or Combinations	3	42.7	1826	9	9	425	549	507.7	71.6	1	1.27	-0.663	0.515	0.323	-1.06	0.290	0.151	1.758	48.5%	*
Run-off-road	**All Run-off-road Crash Treatments**	**57**	**943.9**	1826	192	192.17	184	1351	695.1	303.6	59	66.93	-0.203	0.816	0.072	-2.31	0.021	0.687	0.970	18.4%	
Casualty Crashes	Shoulder Widening and/or Sealing (only)	12	186.6	1826	36	36	433	1014	728.1	223.7	6	6.98	-0.733	0.481	0.141	-2.51	0.012	0.271	0.853	51.9%	
(Severity 1 + 2 + 3)	Audible Edgelines (AEL) or White Lines (only)	15	349.9	1826	85	85	502	1351	975.8	274.2	43	48.09	0.024	1.024	0.088	0.27	0.784	0.865	1.211	-2.4%	*+
	Shoulder Widening and/or Sealing, with AEL	27	364.7	1826	63	63.17	184	974	545.3	251.2	9	10.59	-0.606	0.545	0.174	-1.91	0.057	0.292	1.018	45.5%	*
	Other Treatment or Combinations	3	42.7	1826	8	8	425	549	507.7	71.6	1	1.27	-0.504	0.604	0.380	-0.80	0.423	0.176	2.072	39.6%	*
Run-off-road	**All Run-off-road Crash Treatments**	**57**	**943.9**	1826	115	115.17	184	1351	695.1	303.6	28	35.93	-0.296	0.744	0.102	-2.16	0.031	0.569	0.973	25.6%	
Killed or Seriously Injured	Shoulder Widening and/or Sealing (only)	12	186.6	1826	21	21	433	1014	728.1	223.7	2	2.98	-1.022	0.360	0.185	-1.99	0.047	0.131	0.987	64.0%	
(KSI) Crashes	Audible Edgelines (AEL) or White Lines (only)	15	349.9	1826	50	50	502	1351	975.8	274.2	20	25.09	-0.104	0.901	0.134	-0.70	0.483	0.673	1.206	9.9%	*
(Severity 1 + 2)	Shoulder Widening and/or Sealing, with AEL	27	364.7	1826	39	39.17	184	974	545.3	251.2	5	6.59	-0.611	0.543	0.213	-1.56	0.120	0.252	1.172	45.7%	*
	Other Treatment or Combinations	3	42.7	1826	5	5	425	549	507.7	71.6	1	1.27	-0.059	0.943	0.587	-0.09	0.925	0.279	3.192	5.7%	*

APPENDIX E – Economic Evaluation of the Run-off-road Crash Program in Relation to Run-off-road Crash Reductions in WA, using Raw Crash Count – Unadjusted for Drop-offs in 2014 and 2015 KSI Crashes

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
All Run-off-road Crash Treatments	5%	15	92,819,693	212,188,334	119,368,640	2.3
Shoulder Widening and/or Sealing (only)	5%	15	29,030,594	91,598,283	62,567,689	3.2
Audible Edgelines (AEL) or White Lines (only)	5%	15	6,701,071	33,049,036	26,347,965	4.9
Shoulder Widening and/or Sealing, with AEL	5%	15	49,651,053	86,040,046	36,388,993	1.7
Other Treatment or Combinations	5%	20	7,529,117	1,775,656	-5,753,462	0.2

APPENDIX F – Sensitivity Analysis for the Economic Evaluation of the Run-off-road Crash Program in Relation to Run-off-road Crash Reductions in WA, using Raw Crash Count – Unadjusted for Drop-offs in 2014 and 2015 KSI Crashes

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
All Run-off-road Crash Treatments	3%	15	95,129,529	241,244,410	146,114,881	2.5
	5%	15	92,819,693	212,188,334	119,368,640	2.3
	8%	15	90,121,640	178,248,753	88,127,113	2.0
	5%	10	88,879,852	162,627,945	73,748,093	1.8
	5%	15	92,819,693	212,188,334	119,368,640	2.3
	5%	20	95,906,663	251,020,195	155,113,532	2.6

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
Shoulder Widening and/or Sealing (only)	3%	15	29,283,487	104,141,322	74,857,835	3.6
	5%	15	29,030,594	91,598,283	62,567,689	3.2
	8%	15	28,735,196	76,947,113	48,211,917	2.7
	5%	10	28,599,238	70,203,862	41,604,624	2.5
	5%	15	29,030,594	91,598,283	62,567,689	3.2
	5%	20	29,368,572	108,361,371	78,992,799	3.7

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
Audible Edgelines (AEL) or White Lines (only)	3%	15	7,427,298	37,574,616	30,147,319	5.1
	5%	15	6,701,071	33,049,036	26,347,965	4.9
	8%	15	5,852,786	27,762,834	21,910,048	4.7
	5%	10	5,462,360	25,329,841	19,867,481	4.6
	5%	15	6,701,071	33,049,036	26,347,965	4.9
	5%	20	7,671,633	39,097,227	31,425,594	5.1

	Discount Rate	Treatment Life (years)	Present Value (PV) of Total Costs ($)	Present Value (PV) of Crash Cost Savings ($)	Net Present Value (NPV) ($)	Benefit-cost Ratio (BCR)
Shoulder Widening and/or Sealing, with AEL	3%	15	50,912,823	97,821,967	46,909,144	1.9
	5%	15	49,651,053	86,040,046	36,388,993	1.7
	8%	15	48,177,215	72,277,918	24,100,703	1.5
	5%	10	47,498,876	65,943,851	18,444,975	1.4
	5%	15	49,651,053	86,040,046	36,388,993	1.7
	5%	20	51,337,340	101,785,941	50,448,601	2.0