An Evaluation of the Effectiveness and Cost-Effectiveness of Sealed Shoulders and Audible Edgelines on Albany Highway, 2000-2004

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Title

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Abstract

This report presents the results of an evaluation of Black Spot sites on Albany Highway that were treated with sealed shoulders and audible edgelines during 2000 to 2004 in Western Australia. The purpose of this report is to evaluate the effectiveness of the treatments in terms of reduction in crash frequency (presented for all-reported crashes including property damage only (PDO) and casualty crashes) for all crash types and non-collision crashes only and the net economic worth of these treatments.

Fourteen sites were treated with either sealed shoulders, audible edgelines or a combination of both treatments, but one site was removed due to no crashes recorded at the site. Treatment costs, after removal of this site, were $1.3 million. The average length of follow up exposure crash data post treatment for all treated sites was 58.9 months (SD=2.576) with a minimum of 53 months and a maximum of 60 months.

The results showed the sealed shoulders and audible edgelines have been effective overall, reducing all-reported crash frequencies for all crash types by 58% and casualty crash frequencies by 79%. The estimated crash cost savings over the expected life of the treated sites were $51.9 million for all reported crashes, of which $51.4 million were attributable to the reduction in casualty crashes. This will result in an overall net cost savings to the community of $50.6 million after subtracting the capital costs of providing treatments. The benefit cost ratio (BCR) across all treatment sites was 40.3.

The results provide Main Roads Western Australia and other road safety organisations with reliable, objective information about the potential role of shoulder sealing and audible edgelines in contributing towards reducing road trauma in Western Australia.

Keywords

Black spot treatment, evaluation, cost-effectiveness, cost-benefit analysis

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EXECUTIVE SUMMARY

This report presents the results of an evaluation of the effectiveness and cost-effectiveness of sealed shoulders and audible edgelines on Albany Highway which were treated as part of the National and State Black Spot Program during 2000 to 2004 in Western Australia. The effectiveness of the treatments in terms of reduction in crash frequency (presented for all-reported crashes including property damage only (PDO) and casualty crashes) for all crash types and specifically for non-collision type crashes and the net economic worth of the treatments was evaluated. It is anticipated that these results will provide Main Roads, WA and other road safety organisations with reliable, objective information for enhancing strategies for future road safety investment.

The study adopted a quasi-experimental "*before*" and "*after*" design incorporating the use of comparison sites to determine the change in casualty crash and all-reported crash frequencies (include fatal, hospitalisation and PDO crashes) for all crash types and specifically for non-collision crashes at sites treated on Albany Highway for the years 2000 to 2004. This study design estimated treatment effect by comparing all-reported crash and casualty crash frequency at each treated site with those at an appropriately matched comparison site. The use of a comparison group provided an adequate measure of the reductions in crash frequency due to factors other than these treatments over the study period. South Western Highway was chosen as an appropriate location as it shared similar characteristics as Albany Highway in terms of traffic volume, speed limits, road design and vehicular use of the highway. Also the fact that large sections of the South Western Highway had not had audible edgelines installed was of paramount consideration. While it was not possible to match on all road characteristics the speed limit at the treated site, traffic volume and length of road were each matched to a unique comparison site on the South Western Highway in WA. Crash data for both treated and untreated sites was obtained from the Integrated Road Information System (IRIS) using police reported data which is maintained by Main Roads Western Australia. Each comparison site's crash data was based on the same *before* and *after* period for its uniquely matched treated site. A site inspection for each untreated site on the South Western Highway was also undertaken.

The major findings from the evaluation are summarised below.

Overall

There were a total of 14 sites treated with either audible edgelines or audible edgelines and sealed shoulders on Albany Highway. One site was removed as there were no crashes reported prior to treatment. The average length of follow up exposure crash data post treatment for all treated sites was 58.9 months (SD=2.576) months with a minimum of 53 months and a maximum of 60 months.

The results showed that the road engineering treatments have been effective overall, reducing all-reported crash frequencies by 58% and casualty crash frequencies by 79% for all crash types. There was very strong evidence of a 71% reduction ($p<0.001$) in all-reported crashes for all crash types for sites treated with both sealed shoulders and audible edgelines. The 88% decrease in casualty crashes was also significant ($p<0.001$).

It was not possible to determine the reduction for audible edgelines as the number of crashes at treated sites was too small.

	Crash Reduction	**BCR**
All sites - All crash types (n=13)		
❑ All reported crashes	58% (p<0.001)	
❑ Casualty Crashes	79% (p<0.001)	
All sites Non-Collision Crashes (n=13)		
❑ All reported crashes	59% (p=0.007)	
❑ Casualty Crashes	80% ((p=0.002)	
Sealed shoulders/audible edgelines All crash types (n=7)		
❑ All reported crashes	71% (p<0.001)	
❑ Casualty Crashes	88% (p<0.001)	

This reduction in the number of reported crashes was estimated to reduce crash costs by $51.9 million over the lifetime of the treated sites, with $51.4 million of this reduction attributable to a reduction in casualty crashes. After accounting for treatment costs of $1.3 million, the net cost savings to the community were estimated at $50.6 million. Expressed as a benefit cost ratio (BCR), the net economic worth of both sealed shoulders and audible edgelines was 40.3.

Summary of the Results of the Economic Evaluation of the State Black Spot Program in Relation to Total Crash Reduction in Western Australia

Area	Present Value of Treatment Costs and Operating/ Maintenance Costs ($)	Present Value of Crash Cost Savings	Net Present Value	Benefit Cost Ratio
Whole program	1 288 200	51 903 224	50 615 024	40.3
Sealed shoulder constructed and audible edgelines installed	1 080 000	41 242 998	40 162 998	38.2

Discussion

This analysis confirmed that the engineering road treatments of sealed shoulders and/or audible edge lines were highly effective in reducing all-severity crashes, casualty crashes, types of crashes and cost of crashes at treated sites on Albany Highway in WA. By including crashes of all severities, all possible beneficial and detrimental effects of the treatments were taken into consideration (Newstead and Corben, 2001). The use of long follow-up post treatment data of at least 53 months has also provided reliable conclusions concerning treatment effectiveness.

All sites treated with sealed shoulders were also treated with audible edge lines, which demonstrated significant reductions in all-severity crashes, casualty crashes, all crash types and non-collision crasheas. Previous research similarly found that the sealing of shoulders in combination with edge lining and incorporating audible markers to be effective in reducing single vehicle crashes (Newstead and Corben, 2001).

A limitation of this study was the lack of data to examine possible effects of “crash migration”, where crashes prevented by road engineering treatments on one road section may occur further along another untreated road section. Furthermore, while every effort was made to match treatment and control sites on as many variables as possible, we have not accounted for other possible confounding factors such as weather condition and road lighting.

Recommendations and Conclusion

In conclusion, this project highlighted the potential role for good road engineering and road design to contribute towards reducing road trauma in Western Australia. It is also in line with the Safe System approach, which is designed to make roads more forgiving by improving the road infrastructure to make crashes less likely to occur or less serious if they do.

Recommendations include:

- ❑ Identification of road sections where similar treatments would be effective in reducing single vehicle crashes in rural areas.
- ❑ Further monitoring of both sealed shoulders and audible edgelines and the benefits of these treatments.

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1. INTRODUCTION

Single vehicle crashes are a major focus of the State Road Safety Strategy – Towards Zero – due to the large contribution this particular crash type has on the number of people killed and seriously injured on rural roads. In Western Australia approximately 57% of fatal crashes occurred in rural areas in 2008, with 87% of rural fatal crashes being single vehicle crashes (Office of Road Safety 2009). Single vehicle crashes are defined as a crash which involves only one moving vehicle and involves collisions with pedestrians, animals, fixed objects such as trees, poles, a bridge or a parked vehicle and non-collisions such as a roll-over (Legge et al. 2005).

Given the focus on single vehicle crashes, this project aims to establish the effectiveness of two of Main Roads Western Australia major treatments, sealing of shoulders and installation of audible edgelines, which aim to reduce the number of people killed or seriously injured on WA roads. As a result of the work undertaken by Wheatbelt South (WBS) over the past nine years to fully seal the shoulders and install audible edgelines along the length of Albany Highway within WBS, this section of road has been identified as an excellent case study into the effectiveness of these treatments.

A common cause of single vehicle crashes on rural roads is running off the bitumen onto the soft-edge of the road. Both audible edgelines and sealed shoulders countermeasures 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 avoiding running into roadside objects (Woolley & McLean 2006). These audible edgelines have shown to have an alerting effect on drivers in a driving simulator study (Anund et al. 2008), and have led to significant reductions in run off road crashes on major interstate roads in the United States including New York (72%), California (49%), Pennsylvania (60-65%), Massachusetts (42%), Washington (18%), Kansas (34%) and New Jersey (34%) (Federal Highway Administration, 2001).

In rural areas, the unsealed shoulders of sealed roads pose a major hazard to drivers. When the left wheel(s) of a vehicle come into contact with the 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 roadway or colliding with another vehicle. The primary effect of sealed shoulders 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 if the vehicle leaves the lane it is travelling in. It also reduces the potential for vehicles which stray from the sealed pavement to lose control in loose shoulder material. Previous research has found unsealed shoulders to be a contributing factor in over 50% of fatal run off road crashes in New South Wales (Catchpole, 1990). This is consistent with current research that has highlighted the safety benefits and cost-effectiveness of sealed shoulders.

It is anticipated that these results will 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.

1.1 Aim

The aim of this study is to evaluate the effectiveness and cost-effectiveness of the installation of sealed shoulders and audible edgelines on Albany Highway, on non-collision crashes as well as all crash types in terms of the net reduction in crash frequency and crash costs.

1.2 Significance

The results of this analysis will provide Main Roads Western Australia and other responsible agencies with reliable and objective information for future investments in developing road safety strategies. The economic analysis should also enable road authorities to manage future resources so that funding is allocated in such a way as to minimise injury from road trauma.

METHODS

2.1 Study Design

The study adopted a quasi-experimental "*before*" and "*after*" design. This study design incorporates the use of comparison sites to determine the change in crash frequencies at sites treated with sealed shoulders and audible edgelines on Albany Highway under the National and State Black Spot Program for the years 2000 to 2004. Analyses were undertaken for all-reported crash frequencies (including fatal, hospitalisation and PDO crashes) and casualty crash frequencies (including fatal and hospitalisation crashes) and also for all crash types and non-collision crashes specifically. It estimated treatment effect by comparing all-reported crash and casualty crash frequency at each treated site to those at an appropriately matched comparison site. The use of a comparison group provided an adequate measure of the reductions in crash frequency due to factors other than these treatments over the study period. The analysis also included the estimation of the net economic worth of the Program.

2.2 Selection of Sites for Funding

Black spots are locations noted for a high incidence of crashes involving death and injury (Australian National Audit Office, 2007). The national and State Black Spot Programs continue to provide funding for road safety related works on State and Local Government roads. All road classifications were eligible for funding. The overall program targeted existing black spots, black lengths and also potentially hazardous locations. Black spots could be at an intersection, mid block or a short section of road. For the purpose of this research audible edgelines and sealed shoulders were targeted for this evaluation. Sixty percent of the projects were funded by the National Black Spot Program and 40% by the State Black Spot Program. For a more detailed list of the criteria used for the selection of sites see Appendix A.

2.3 Data Collection

Information on each treated site on Albany Highway was obtained from the Road Safety Section at Main Roads Western Australia. Only BCR applications (and not road safety audits) were included in the evaluation and only the specific treatments of sealed shoulders and audible edgelines were included in the analysis. Crash data from January 1, 1995 to December 31, 2008 was obtained from the Integrated Road Information System (IRIS) using police reported data which is maintained by Main Roads Western Australia.

2.3.1 Integrated Road Information System (IRIS)

The Integrated Information System (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 December 31, 2008.

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" (Legge et al. 2006). A crash is "*any apparently unpremeditated collision reported to the police which resulted from the movement of at least one road vehicle on a road open to and used by the public and involving death or injury to any person, or property damages*". In WA during the study period, it was mandatory to report a crash to the police if a person is injured or if property damage exceeds $1,000.

A casualty crash is defined as "*a road crash which resulted in a person being killed, or hospitalised or received medical treatment*".

A hospitalisation crash is defined as "*a road crash in which the most serious injury resulted in a person being hospitalised*".

A fatal crash is "*a road crash in which a person was fatally injured*".

A Property Damage Only (Major) crash is "*a road crash with property damage exceeding $1000*".

A Property Damage Only (Minor) crash is "*a road crash with property damage not exceeding $1000*". There is no legislative requirement to report crashes of this nature; however they can be reported to Police for insurance purposes.

Critical data retrieved for use in the study were:

- Crash date;
- Crash severity;
- Local government area of crash;
- Crash type and event (identified by road user movement (RUM) codes 70-77 and 81-85 to identify non-collision crashes) ;
- Specific crash location.

The approach adopted in this study was to use five years pre crash data and at least six months post treatment crash data with a maximum of five year, excluding the construction period. Crash data which was used in the analysis included all crash types and crash severities (fatality, hospitalisation and property damage only (PDO) crashes). This was consistent with Main Roads' intention to ensure application of funds to a wider range of projects at hazardous situations using different thresholds such as all-reported crashes rather than casualty crashes only. A separate analysis for all-reported crashes and casualty crashes was also undertaken.

As sealed shoulders and audible edgelines are intended to reduce the number of non-collision type crashes, an evaluation of its effectiveness specifically for non-collision crashes was also undertaken using all-reported crash and casualty crash data. Figure 2.1 shows a typical section of Albany Highway treated with audible edge lines and 1.5m sealed shoulders added to the 1m unsealed shoulders. Figure 2.2 further shows the detail of the painted audible edge line.

Figure 2.1 A typical treatment site with audible edge line and 1.5m sealed shoulder installed next to the 1m unsealed shoulder

Figure 2.2 A painted audible edge line.

2.3.2 Treatment Site Data

Main Roads, WA provided details about each treatment site. This included information related to location and municipality, road straight line kilometres (SLK) numbers, treatment description, and precise treatment start and finish dates (to within one week). See Appendix B for a list of projects on Albany Highway and SLK numbers.

Information provided included:

- treatment number;
- Black Spot location and LG;
- Road SLK numbers;
- treatment description;
- treatment start and finish dates;
- treatment cost;
- estimated treatment life.

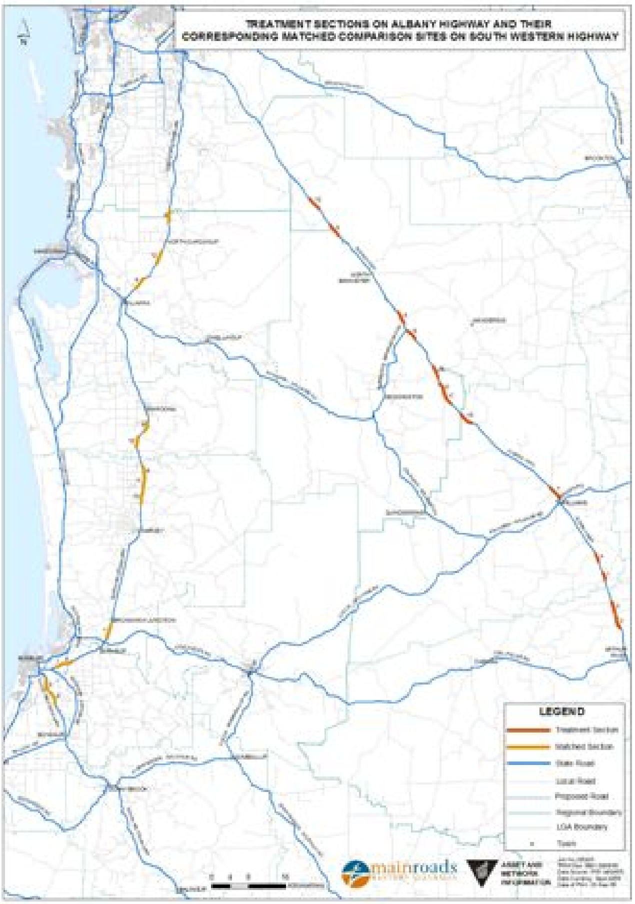
2.3.3 Selection of Comparison Sites

The best method to test the effectiveness of treated sites is to have each treated site matched with a comparison site having identical characteristics. However the selection of comparisons in a quasi-experimental study design is a balance between matching of specific site characteristics in order to control for confounding influences on crash trends. The basic assumption is that if the characteristics of matched sites are identical, then their crash frequencies should be too. The comparison sites are used to indicate what would have happened at the treated sites if no treatment was applied. While it was not possible to match on all road characteristics the speed limit at the treated site, traffic volume and length of road were each matched to a unique comparison site on the South Western Highway in WA. Main Roads Western Australia provided a list of road treatments such as seal shoulders and audible edgelines which had been undertaken on the South Western Highway which were excluded from site selection (see Appendix C)

South Western Highway was chosen as an appropriate location as it shared similar characteristics to Albany Highway in terms of traffic volume, speed limits, road design and vehicular use of the highway. Also the fact that large sections of the South Western Highway had not had audible edgelines installed was of paramount consideration.

A separate database of crash data for the comparison sites was obtained from the Integrated Road Information System (IRIS) at Main Roads Western Australia. Crash data was retrieved for each comparison site based on the same *before* and *after* period for its uniquely matched treated site. The comparison site was matched to traffic volume (what was available), speed limit of the road, and same length of road based on SLKs as the treated site. If the speed limit or traffic volume of the comparisons site (based on SLK) did not match the treated site then the next section of the road was used. Once the matching criteria were satisfied the crash data was extracted form the IRIS database. Figure 2.3 shows the location of the 13 treated sites on Albany Highway and their corresponding matched control sites on South Western Highway.

Figure 2.3 Location of the 13 treated sites on Albany Highway and their corresponding matched control sites on South Western Highway in Western Australia



A site inspection for each comparison site was also undertaken. See Appendix D for road specifications and a picture of each site. Appendix E contain information related to the seal width along Albany Highway and South Western Highway.

2.4 Factors that may affect the State Black Spot Evaluation

All known factors that have the potential to affect the evaluation should be accounted for when estimating the treatment effect. However, as found by Elvik (1997) the more factors that are accounted for, the less effective the treatment appears to be.

Some of the factors that may affect the evaluation of the effectiveness of sealed shoulders and audible edgelines treatments are described below. These include site-specific factors, regression- to- the mean, and crash migration.

2.4.1 Site Specific Factors

Specific events other than treatment could account for some of the observed change in the number and severity of crashes at a site. These can include weather conditions and increased publicity about the safety of the site. Both these may lead to an increase in driver caution which could lead to a reduction in crashes that has little to do with the treatment at the site. While it was not possible to assess these effects in this report it does appear unlikely that site specific factors would have a significant effect on the evaluation of the Black Spot Program's sealed shoulder and audible edgeline treatments as a whole (Bureau of Transport Economics, 2001). However it may have an effect on the analysis at a particular site (Bureau of Transport Economics, 2001).

2.4.2 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 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) 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 providing sufficient evidence of any trend or change in an established pattern of crashes. All sites evaluated in this study used five-years of pre treatment crash data and on average five years of post treatment crash data. The statistical methodology also used in this report recognised the level and distribution of random variation in the data and provided appropriate confidence intervals and significance levels.

2.4.3 Crash (accident) Migration

The term crash migration (also referred as accident migration) describes an increase in crashes at sites in the vicinity of a Black Spot following the treatment of that Black Spot away from the treated site to the surrounding area. Whether crash migration is a real effect in a Black Spot treatment remains a controversial topic, which has not been adequately resolved by road safety experts. Therefore the analysis has not attempted to deal with crash migration. For the purpose of this report the assumption was made that no treatment could be associated with crash migration resulting from traffic migration away from the treated site.

For a more in-depth discussion of crash migration see Elvik (1997).

2.5 Cost Data

Two types of cost data were used in the evaluation of the economic worth of the State Black Spot 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 cost of treating black spots included only the capital outlay associated with treatment, and excluded operating and maintenance costs, which were assumed to be minimal. As discussed previously (section 2.3.2), Main Roads Western Australia provided the information on treatment costs, with this information obtained from recorded program expenditure.

The cost savings from fewer road crashes at treated sites were calculated based on the road crash severity costs for Australia in 1996 produced by the Bureau of Transport Economics (2000), adjusted for price increases and state variations in costs (Willett, 2004). These are the most recent road crash costs available for Australia and 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 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 program was the road crash, with unit road crash costs expressed in 2003/04 Australian dollars shown below.

Crash severity	**$**
Fatal	2,226,093
Hospital admission	494,773
Medical treatment	29,949
Property damage only	11,867

The use of crash costs based on crash severity rather than type of crash (e.g. head on, right angle turn) has the disadvantage that a single serious crash at a site can potentially have a considerable impact on the calculation of the cost-effectiveness of a site. However, if the number of treatment sites being assessed is sufficiently large, this effect should cancel out. Recent Australian studies evaluating the cost-effectiveness of black spot programs have used crash costs based on severity rather than crash type (Bureau of Transport Economics, 2001; Newstead & Corben, 2001).

2.6 Statistical Analysis

2.6.1 Effectiveness of the Program

The analysis compared the rate of crashes for the treated sites and the comparisons sites "*before*" and "*after*" treatment periods using a generalising estimating equation (GEE) Poisson regression model. The number of crashes in one year is a discrete "count" variable and is assumed to follow a Poisson distribution. The use of Poisson regression is appropriate to establish whether changes in the number of all reported and casualty crashes that occurred at treated sites were significantly different to changes in the number of all-reported and casualty crashes at non-treated sites. However, the longitudinal nature of the observations render the application of standard Poisson regression analysis inappropriate, and methods such as the GEE Poisson model should be used to accommodate the inherent correlation of the longitudinal data. A GEE Poisson model was to take account of the correlated nature of the repeated measures taken before and after Black Spot treatment.

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. The model was used to estimate the overall treatment effects and specific treatment effects. The statistical modelling also took account of the different crash exposure periods post treatment. Details about the GEE technique can be found in Dupont (2002) and Twisk (2003).

An interaction term was included in each model to examine the effect of the road treatment post intervention for the treated sites compared to the untreated or "comparison" sites. This is because the changes in the number of crashes over time are different between the treated and untreated sites. Therefore an interaction term between time (before treatment and after treatment) and group (treated sites and untreated sites) will account for these changes in the model.

The crash data was extracted using SAS data package. The model was fitted to the data using the Stata (Version 10) statistical package.

2.6.2 Economic Analysis

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. 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 –

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

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

where Bi = benefits in year i resulting from savings in road crash costs
Ci = costs of installing Black Spot 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 (10 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 expected treatment life (iii) the observed effectiveness of treatments in reducing the number of road crashes and (iv) the unit road crash cost data. Basing the economic evaluation on the observed effectiveness of treatments in reducing the number of road crashes assumes that the number of crashes at the treated sites would have remained at the pre-treatment level without shoulder sealing or the installation of audible edgelines. The treatment life of projects was assumed to be 15 years based information provided by Main Roads, WA. This was varied to 10 years and 20 years in the sensitivity analysis. 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 Main Roads, Western Australia. NPVs and BCRs were calculated for (i) all treated sites and (ii) sites at which both sealed shoulders had been constructed and audible edgelines installed. The sensitivity analysis was conducted only for the analysis based on all treated sites. NPV and BCR calculations were made on the basis of all reported crash data and casualty crashes only.

3. RESULTS

This section summarises the results of the analyses for all-reported crash frequency and casualty crash frequency by all crash types and non-collision crashes only for sealed shoulders and audible edgelines.

3.1 Statistical Analysis

There were a total of 14 sites treated with either audible edgelines or sealed shoulders on Albany Highway. One site was removed as there were no crashes reported prior to treatment. The average length of follow up exposure crash data post treatment for all treated sites was 58.9 months (SD=2.576) months with a minimum of 53 months and a maximum of 60 months.

Table 3.1 shows the effect of treatments on road safety for all-reported crashes and Table 3.2 shows the effect for casualty crashes only. In both tables, β represents the regression coefficient in terms of the log-scale of the outcome variable so that the reduction rate is given by $1\text{-}e^{\beta}$. A negative value for β indicates that all-reported crash rate (including fatality, hospitalisation/ injury and PDO crashes) and casualty crash rate decreased following treatment, and vice versa for a positive value for β. The statistical significance of treatment is given by p. For example, $p<0.001$ means that the probability of obtaining such a result by chance is less than one in a thousand. The incidence rate ratio (IRR) is shown in the last column of Table 3.1 and Table 3.2. The percentage reduction in the number of all reported crashes and casualty crashes was obtained from the IRR.

In this analysis, very strong evidence meant that the probability of an event occurring by chance is less than one in one thousand ($p <0.001$); strong evidence meant that the probability is less than one in one hundred ($p<0.01$); moderate evidence meant that the probability is less than one in fifty ($p<0.02$); weak evidence meant that the probability is less than one in ten ($p<0.1$) and not significant was indicated by $p>0.1$. This was consistent with the criteria adopted by the National Black Spot Program evaluation.

3.1.1 All-Reported Crash Reduction for All Crash Types

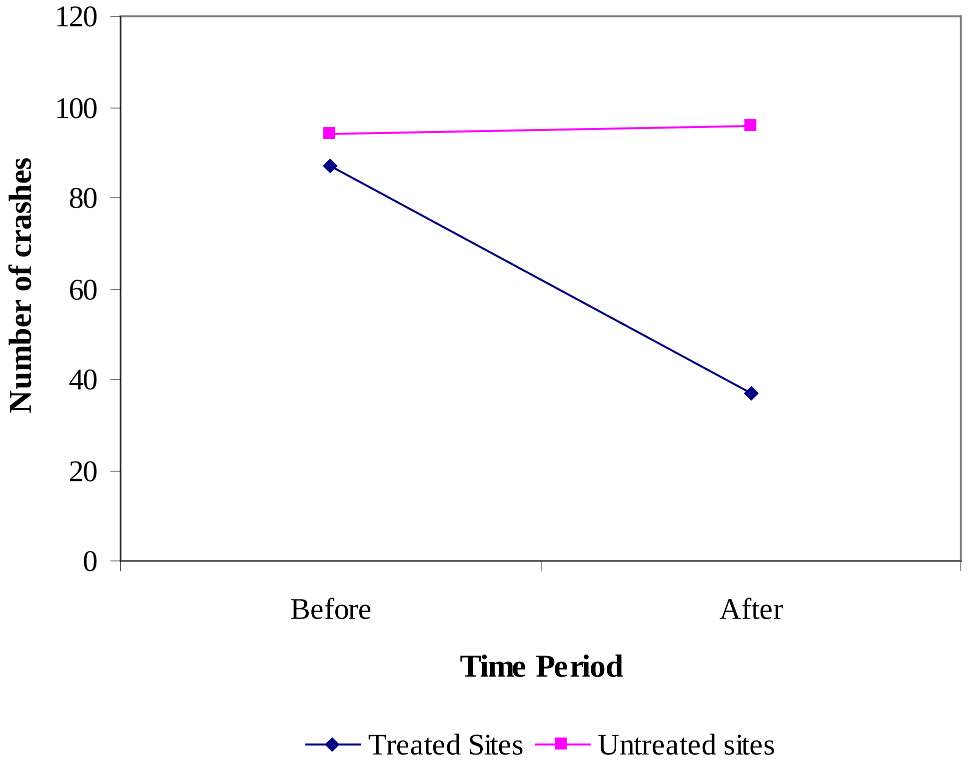
Based on the estimated incidence rate ratio for the interaction term between time (*before treatment and after treatment*) and group (*treated sites and untreated sites*) a very strong significant reduction of 58% (p<0.001) in all severity crashes for all crash types was found in the post treatment period for the 13 treated sites compared to the untreated sites (see Table 3.1 and Figure 3.1). To view full results see Appendix F and G.

Table 3.1 Spot treatment effect on all-reported crashes for all crash types on Albany Highway, 2000 – 2004**

	Estimate (β)	Standard Error	Probability 0<p<1	IRR*
All treatment sites (n=13)				
Group 0=untreated sites 1=treated site	-0.077	0.150	0.608	0.925
Time 0=before treatment 1=after treatment	0.039	0.146	0.791	1.039
Time* group	**-0.876**	**0.247**	**<0.001**	**0.416**
Specific Treatments				
Sealed shoulders & audible edgelines (n=7)*******				
Group 0=untreated sites 1=treated site	3.551	0.209	1.000	1.000
Time 0=before treatment 1=after treatment	0.101	0.204	0.621	1.106
Time* group	**-1.243**	**0.363**	**<0.001**	**0.288**

** Incidence rate ratio*
***Includes all crashes-fatality, hospitalisation, injury and property damage major and minor crashes*
****Both treatments done at treatment site*

Figure 3.1 Number of all reported crashes for treated and untreated sites before and after treatment



3.1.2 Casualty Crash Reduction for All Crash Types

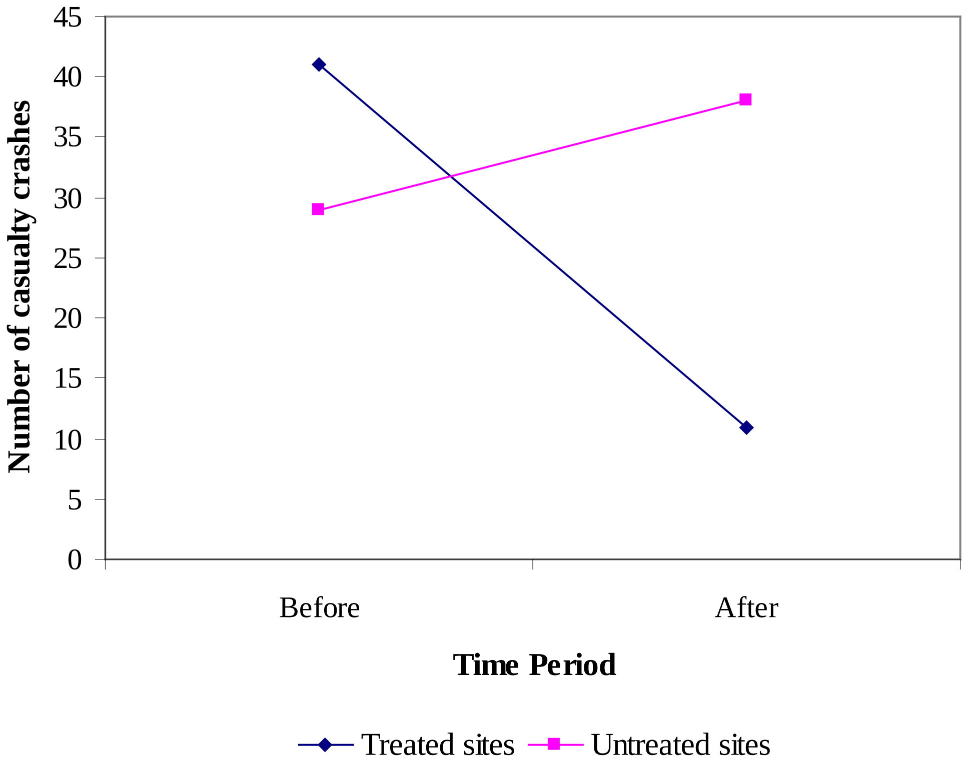
Based on the estimated incidence rate ratio for the group* time interaction a very strong reduction of 79% ($p<0.001$) for casualty crashes for all crash types was found in the post treatment period for the treated sites compared to the untreated sites (see Table 3.2 and Figure 3.2). To view full results see Appendix G.

Table 3.2 Black Spot treatment effect on casualty crashes for all crash types on Albany Highway, 2000 – 2004**

	Estimate (β)	**Standard Error**	**Probability 0<p<1**	**IRR***
All treatment sites (n=13)				
Group	0.346	0.248	0.163	1.413
0=untreated sites 1=treated site				
Time	0.288	0.252	0.253	1.334
0=before treatment 1=after treatment				
Time* group	**-1.585**	**0.427**	**<0.001**	**0.204**
Specific treatments				
Sealed shoulders & audible edgelines (n=7)***				
Group	0.773	0.352	0.028	2.166
0=untreated sites 1=treated site				
Time	0.459	0.373	0.218	1.583
0=before treatment 1=after treatment				
Time* group	**-2.108**	**0.617**	**<0.001**	**0.121**

** Incidence rate ratio*
***Includes fatality, hospitalisation and injury crashes*
****Both treatments done at treatment site*

Figure 3.2 Number of casualty crashes for treated and untreated sites before and after treatment



3.1.3 Analysis of All Crash Types by Specific Treatment Type

There was very strong evidence of a 71% reduction (p<0.001) in all-reported crashes post treatment for the seven sites which were treated with both sealed shoulders and audible edgelines. An 88% decrease in casualty crashes was also significant (p<0.001) (Table 3.1 and Table 3.2).

It was not possible to determine the reduction for audible edgelines as the number of crashes at each site was small.

3.2 Analysis of Non-Collision Type Crashes

Non-collision type crashes represented 62% (n=54) of the total number of crashes before treatment and 54% (n=20) of crashes after treatment for the 13 treated sites. It was not possible to determine the reduction for the seven treated sites of audible edgelines and seal shoulders as the number of crashes at each site was small.

3.2.1 All-Reported Crash Reduction for Non-Collision Crashes

The results of the statistical modelling found a significant reduction of 59% (p=0.007) for non-collision all-reported crashes in the post treatment period compared to untreated sites based on the estimated incidence rate ratio for the group*time interaction term (see Table 3.3 and Figure 3.3). To view full results see Appendix F and H.

Table 3.3 Black Spot treatment effect on all-reported crashes for non-collision crashes only on Albany Highway, 2000 – 2004

	Estimate (β)	Standard Error	Probability 0<p<1	IRR*
All treatment sites (n=13)				
Group 0=untreated sites 1=treated site	0.117	0.192	0.540	1.125
Time 0=before treatment 1=after treatment	-0.091	0.203	0.653	0.912
Time* group	**-0.883**	**0.325**	**0.007**	**0.413**

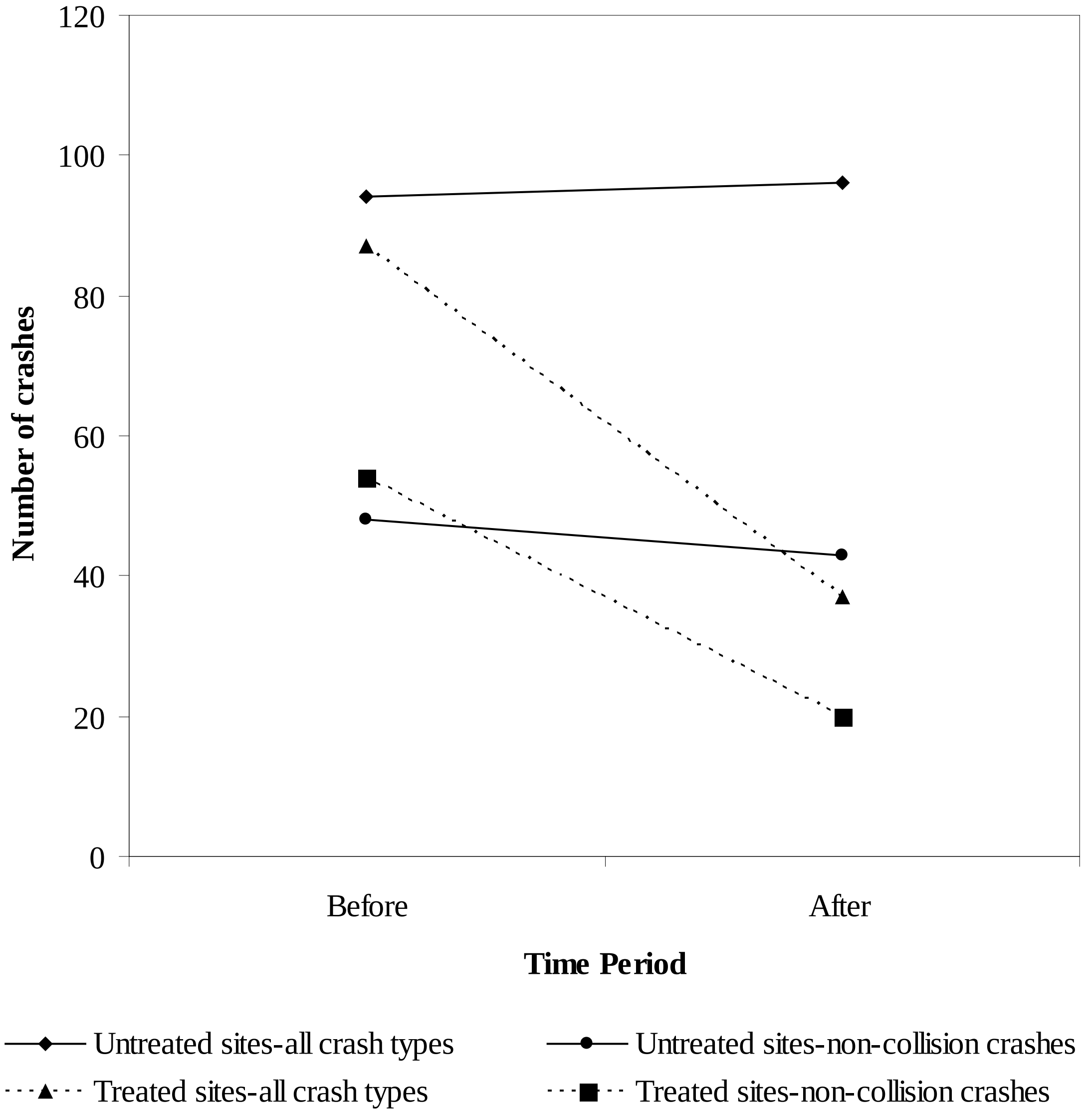
3.2.2 Casualty Crash Reduction for Non-Collision Crashes

Based on the estimated incidence rate ratio for the group*time interaction a significant 80% reduction (p=0.002) was found post treatment for the treated sites compared to untreated sites for non-collision casualty crashes (see Table 3.4). To view full results see Appendix H.

Table 3.4 Black Spot treatment effect on casualty crashes for non-collision crashes on Albany Highway, 2000 – 2004

	Estimate (β)	**Standard Error**	**Probability 0<p<1**	**IRR***
All treatment sites (n=13)				
Group 0=untreated sites 1=treated site	0.594	0.308	0.054	1.812
Time 0=before treatment 1=after treatment	0.336	0.325	0.300	1.400
Time* group	**-1.606**	**0.512**	**0.002**	**0.200**

Figure 3.3 A comparison of number of all-reported crashes by all crash types and non-collision type crashes before and after treatment



3.3 Economic Evaluation of the State Black Spot Program

Table 3.5 presents the results of the economic evaluation of the Black Spot Program's sealed shoulder and audible edgeline treatments in terms of its reduction in all reported crashes. Appendix F shows the economic worth of the treatments in terms of the reduction in casualty crashes only. The estimated crash cost savings over the expected life of the treatments were $51.9 million for all-reported crashes, of which $51.4 million were attributable to a reduction in casualty crashes. This will result in an overall net cost saving to the community over the expected life of the treated sites of $50.6 million after subtracting the capital costs of installing treatments. The BCR across all treatment sites was estimated to be 40.3, which indicates benefits in the form of cost savings to the community of $40.30 for each $1 invested in the program. Excluding treatments at which only audible edgelines had been installed (without sealing shoulders), the estimated crash cost savings over the expected life of the treatments were $41.2 million and the NPV and BCR were $40.2 million and 38.2 respectively.

Table 3.5 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 treatments. Lower discount rates and longer treatment lives of projects improved rates of return and vice versa. A discount rate of 3% increased the NPV of the treated sites to $57.3 million and the BCR to 45.5. An expected treatment life of 20 years increased the NPV to $61.0 million and the BCR to 48.4.

Table 3.5 Economic evaluation of State Black Spot treatment on Albany Highway, 2000 - 2004

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Whole program	1 288 200	51 903 224	50 615 024	40.3
Sealed shoulder constructed and audible edgelines installed	1 080 000	41 242 998	40 162 998	38.2

Table 3.6 Sensitivity analysis for the economic evaluation of State Black Spot treatment on Albany Highway, 2000 – 2004

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Base case Discount rate 5% Treatment life 15 yrs	1 288 200	51 903 224	50 615 024	40.3
Sensitivity analysis				
Discount rate				
• 3% (15 years)	1 288 200	58 559 174	57 270 974	45.5
• 8% (15 years)	1 288 200	44 024 749	42 736 549	34.2
Treatment life				
• 10 years (5%)	1 288 200	38 612 260	37 324 060	30.0
• 20 years (5%)	1 288 200	62 316 722	61 028 522	48.4

4. DISCUSSION

This report presented the results of the evaluation of State Black Spot Program's sealed shoulder and audible edgeline treatments implemented from 2000 to 2004 on Albany Highway in Western Australia, in terms of their effectiveness in reducing the frequency of all-reported crashes, casualty crashes for all crash types, non-collision crashes and crash costs. By including crashes of all severities, all possible beneficial and detrimental effects of the treatments were taken into consideration (Newstead and Corben, 2001). The use of post exposure crash data of at least 58 months and comparison or 'untreated' sites in the estimates of treatment reductions led to more definitive and reliable conclusions being made concerning treatment effectiveness.

The overall analysis found the treatments to be effective in reducing the frequency of all-reported crashes for all crash types by 58% and casualty crashes by 79% for all treated sites compared to untreated sites post treatment. The treatments also significantly reduced the frequency of non-collision crashes by 59% for all- reported crashes and 80% for casualty crashes.

All sites treated with sealed shoulders were also treated with audible edge lines, which demonstrated significant reductions in all-severity crashes and casualty crashes. Previous research similarly found that the sealing of shoulders in combination with edge lining and incorporating audible markers to be effective in reducing single vehicle crashes (Newstead and Corben, 2001). A report by Levett (2007) further stipulates that when the width of the shoulder seal on a straight section of the road was increased to 1.5 metres, crash frequency reduced by 42% compared to straight sections of the road with no sealed shoulders. If the shoulder seal width was 1.0 metre it reduced crash frequency by 38% and 25% for shoulders that were sealed to a width of 0.5 metres. He concluded that crash reduction occurred within the first metre of seal and that sealing wider than 1 meter provided only limited improvement in crash reduction. International evidence however, has found that increasing the sealed shoulder width on two lane roads to approximately 1.5 metres decreased crash rates significantly (Federal Highway Administration, 2001). As previously mentioned, one of the functions of the shoulder is to provide an initial recovery area for errant vehicles. There is substantial evidence that gravel shoulders can be a hazard for out of comparison vehicles (McLean, 2001). Further, unsealed shoulders have been cited as a major contributor to severe truck crashes in NSW (Sweatman et al, 1990). Consequently the safety benefits of sealing shoulders may also be extended to trucking safety.

Road and traffic authorities need to direct their funding wisely to treatments that achieve the most cost-effective returns in crash and injury reduction. Although audible edge lines have been demonstrated to reduce single vehicle run-off-road crashes (Griffith, 1999, Hickey, 1997, Morena, 2002), they may cause drivers to perform unsafe steering corrections, leading to an increase in opposite direction crashes (Griffith, 1999). The current analysis was not able to determine the specific effects of audible edgelines due to the small number of treated sites but they should continue to be monitored and further research undertaken to determine their effectiveness on crash reduction with respect to crash type.

In relation to the net economic worth of the two treatment types, the NPV and the BCR across all treatment sites were estimated to be $50.6 million and 40.3 respectively. The economic evaluation was based on a before and after analysis, which assumes the number of crashes would have remained at the pre-treatment level without shoulder sealing or the installation of audible edgelines. Given the observed increase in the number of crashes at comparison sites over the period, this assumption of no change in crash numbers is conservative. For this reason, the NPV and BCR across treatment sites are also likely to conservative estimates.

A limitation of this study was the lack of data to examine possible effects of "crash migration", where crashes prevented by road engineering treatments on one road section may occur further along another untreated road section. Furthermore, while every effort was made to match treatment and control sites on as many variables as possible, we have not accounted for other possible confounding factors such as weather condition and road lighting.

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the results found sealed shoulders and audible edgelines to be effective, producing positive outcomes for the community in terms of road safety. These treatments reduced all-reported crash numbers by 58% and casualty crashes by 79% and are estimated to reduce crash costs by $51.9 million over the expected life of the treated sites. After accounting for project costs of $1.3 million, the net cost savings to the community were estimated as $50.6 million. This is the equivalent of a BCR of 40.3.

Recommendations

This project highlighted the potential role for good road engineering and road design such as sealing shoulders and audible edgelines to contribute towards reducing road trauma in Western Australia on rural roads. It is also in line with the Safe System approach, which is designed to make roads more forgiving by improving the road infrastructure to make crashes less likely to occur or less serious if they do.

Recommendations include:

- ❑ Identification of road sections where similar treatments would be effective in reducing single vehicle crashes in rural areas.
- ❑ Further monitoring of both sealed shoulders and audible edgelines and the benefits of these treatments.

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APPENDIX A

BLACK SPOT PROGRAM – PROJECT CRITERIA

Criteria	National Black Spot State and Local Roads	State Black Spot Highways and Main Roads	State Black Spot Local Roads
General ***Owner***	DOTARS	WA State Government	WA State Government and Local Government
Co-ordination	MRWA Road Network Services Program Co-ordinator (RNSPC)	MRWA State Black Spot Program Manager	MRWA Regional Managers and Regional Road Group
State Panel Meeting	Yes – Senator Alan Eggleston (November)	N/A	N/A
Recommendation	WA Black Spot State Consultative Panel	MRWA - EDRNS	Regional Road Groups
Approval	Federal Minister for Transport	Commissioner of Main Roads	State Road Funds to Local Government Advisory Committee
Period	4 years, 2002/2003 to 2005/2006	2005/06 onwards	2005/06 onwards
Funding ***Allocation***	$ 4.982 annually	$ 7.5M annually	$11.25M annually (Including LGs contribution)
Distribution ***Metro*** ***Rural***	50% 50%	50% 50%	50% 50% (Based on 25% four way proportional formula for regional allocations)
Contributions	Yes – encouraged	Yes (eg. Developers – service roads)	Yes 2:1 mandatory (State and Local Govt)
Over fund	Yes up to 25%	Yes (decided at the programming stage)	Yes (based on merit)
Variations	No, fully allocated program	Fully allocated - Managed by MRWA	Fully allocated -Managed by RRG
Project Min Cost ***Project Max Cost***	≥ $ 2 000 ≤ $ 750 000	≥ $ 2 000 ≤ $ 1 000 000	≥ $ 2 000 ≤ $ 1 000 000

Criteria	National Black Spot State and Local Roads	State Black Spot Highways and Main Roads		State Black Spot Local Roads	
Funding Cont.					
Components paid for successful projects					
Administration Overheads	No, paid by MRWA	No, paid by MRWA		No, paid by local govt.	
Road Safety Audit	Yes	Yes		Yes	
Design/Land/Services and Design Audit (Where Required)	Yes	Yes		Yes	
Capital Costs	Yes	Yes		Yes	
Specific & Routine Maintenance	No	No		No	
Roads					
National Highways	No	Yes		Optional	
Road of National Importance	No	Yes		Optional	
State Roads	Yes	Yes		Optional	
Local Roads	Yes	Yes (for intersection treatments only)		Yes	
Crash criteria (see note 2)		**Metro**	**Rural**	**Metro**	**Rural**
Intersection or Mid-block or Short road section (< 3 km)	3 casualty crashes over a five-year period	10 crashes over 5 years	3 crashes over 5 years	5 crashes over 5 years	3 crashes over 5 years
Road length ($\geq$ 3km)	1 casualty crashes per kilometre over 5 years, or top 10% of sites which have a demonstrably higher crash rate than other roads in a region.	Average of 3 crashes per km over 5 years	Average of 1 crash per km over 5 years	Average of 2 crashes per km over 5 years	Average of 1 crash per km over 5 years
Crash Period	5 years (eg.1999 to 2003 for 2005/2006 program)	5 years (eg. 1999 to 2003 for 2005/2006 program)		5 years (eg.1999 to 2003 for 2005/2006 program)	

Criteria	National Black Spot State and Local Roads	State Black Spot Highways and Main Roads	State Black Spot Local Roads
BCR			
Minimum	≥ 2.0	≥ 1.0	≥ 1.0
Discount rate	5%	5%	5%
Crash Reduction % Factors	DOTARS and MRWA	DOTARS and MRWA	DOTARS and MRWA
Costs for calculating BCR	Includes capital costs, contributions by others, routine maintenance and specific maintenance	Includes capital costs, contributions by others, routine maintenance and specific maintenance.	Includes capital costs, contributions by others, routine maintenance and specific maintenance.
Projects based on Road Safety Audit (see note 2)			
Projects	Yes up to 20% of program	Yes up to 50% of program. RM may apply to Executive Director to vary percentage up to a higher level.	Yes up to 50% of program. RRG's may apply to Advisory Committee to vary percentage up to a higher level.
Ranking of Audit Projects	Yes - ARRB Risk Cost Ratio	Yes	Yes
Project Completion	Project should be completed within the time frame of the program	June 30 of funding year	June 30 of funding year
Staged construction	Not normally	Yes	Yes
Recognition			
Signing during construction	≤ $100,000 during construction only.	$50,000 - $100,000 during construction only.	$50,000 - $100,000 during construction only.
Signing post construction	≥ $100,000, + permanent signing for 2 years Any other signposting relating to the project must be endorsed by the Minister.	Over $100,000 - permanent signing for 1 year.	Over $100,000 - permanent signing for 1 year.

Criteria	National Black Spot State and Local Roads	State Black Spot Highways and Main Roads	State Black Spot Local Roads
Environment, Heritage, Aboriginal clearances	Yes	Yes	Yes
Design and technical clearances **Roundabouts and pedestrian facilities** **Traffic Control Signals**	Yes Ensures needs of cyclists and pedestrians are properly catered for. MRWA approval required	Yes Ensures needs of cyclists and pedestrians are properly catered for. MRWA approval required	Yes Ensures needs of cyclists and pedestrians are properly catered for. MRWA approval required
Design Audits	May be required	Yes over $150,000	Yes over $150,000
Evaluation of completed projects/programs	BTRE (Canberra)	Independent Research Consultant eg ARRB Transport Research, BTE	Independent Research Consultant eg ARRB Transport Research, BTE

Notes:

1. Crash data is provided by Main Roads to assist Local Governments identify sites meeting the crash criteria or other hazardous locations.

2. A Road Safety Audit is encouraged for all projects not based on crash criteria. A formal Road Safety Audit is <u>MANDATORY</u> for projects over $40 000. Generally a project shall not consist solely of a Road Safety Audit; however, where agreed by the Regional Road Group, a small proportion of projects on rural local roads may consist of only a road safety audit.

APPENDIX B TREATMENT SITES

PROGRAM YEAR	LOCAL GOVERNMENT	PROJECT	SLK number
2002	Albany Hwy	Install audible edgelines	176.57-178.12
2002	Albany Hwy	Install audible edgelines	186.35-189.31
2002	Albany Hwy	Install audible edgelines	183.17-185.74
2002	Albany Hwy	Install audible edgelines	172.10-174.07
2002	Albany Hwy	Seal shoulders and Install audible edgelines	102.45-105.12
2002	Albany Hwy	Seal shoulders and Install audible edgelines	120.87-123.32
2002	Albany Hwy	Seal shoulders and Install audible edgelines	154.66-157.63
2002	Albany Hwy	Seal shoulders and Install audible edgelines	78.22-81.17
2002	Albany Hwy	Seal shoulders and Install audible edgelines	107.10-109.70
2002	Albany Hwy	Seal shoulders and Install audible edgelines	116.87-119.57
2002	Albany Hwy	Seal shoulders and Install audible edgelines	123.32-125.97
2003	Albany Hwy	Install audible edgelines	71-74
2003	Albany Hwy	Install audible edgelines	129.17-132.17

APPENDIX C EXCLUDED COMPARISON SITES DUE TO TREATMENT

PROGRAM YEAR	LOCAL GOVERNMENT	PROJECT	SLK NUMBER
2000	South Western Highway	Seal shoulders	438.35-444.57
2000	South Western Highway	Seal shoulders	60.42-82
2003	South Western Highway	Install audible edgelines	59.6-82
2004	South Western Highway	Seal shoulders	431.15-434.93
2005	South Western Highway	Seal shoulders	198.4-200.7
2006	South Western Highway	Seal shoulders	181.74-183
2006	South Western Highway	Seal shoulders	94.45-96.65
2006	South Western Highway	Seal shoulders	119.9-123.1
2006	South Western Highway	Seal shoulders	126.3-131.27
2006	South Western Highway	Seal shoulders	234.8-235.27
2006	South Western Highway	Seal shoulders	185.6-188.3
2006	South Western Highway	Seal shoulders	189.4-192.8
2007	South Western Highway	Seal shoulders	512.65-513.12
2007	South Western Highway	Seal shoulders	227.43-232.33
2007	South Western Highway	Seal shoulders	232.37-233.26
2007	South Western Highway	Seal shoulders	240.4-242.4
2008	South Western Highway	Seal shoulders	207.57-210.6

APPENDIX D

APPENDIX F

A BREAKDOWN BY SLK NUMBER OF ALL-REPORTED CRASHES BEFORE AND AFTER TREATMENT (ALBANY HIGHWAY) AND THEIR CORRESPONDING MATCHED COMPARISON SITES (SOUTH WESTERN HIGHWAY) FOR ALL CRASH TYPES.

Siteno	Albany Highway (H001-treated) SLK numbers	Crash Period B/A*	South Western Highway (H009-untreated) SLK numbers	Crash Period B/A**
1	176.57-178.12	6/4	147.67-149.22	3/4
2	186.35-189.31	12/3	159.58-162.54	13/9
3	183.17-185.74	5/1	156.4-158.97	4/8
4	172.10-174.07	5/3	145.33-147.3	10/12
5	102.45-105.12	7/6	35-37.67	5/7
6	120.87-123.32	8/2	96.9-99.35	5/9
7	154.66-157.63	7/2	132.95-135.92	4/6
8	78.22-81.17	7/1	51.45-54.4	6/3
9	107.10-109.70	9/0	85.95-88.55	14/8
10	116.87-119.57	6/4	90.1-92.8	9/8
11	123.32-125.97	3/0	99.35-102	4/11
12	71-74	7/10	44.23-47.23	4/3
13	129.17-132.17	5/1	102.4-105.4	13/8

**Total number of crashes before and after treatment*
***Total number of crashes in the corresponding time frame as treated sites*

APPENDIX F

A BREAKDOWN BY SLK NUMBER OF ALL-REPORTED CRASHES BEFORE AND AFTER TREATMENT (ALBANY HIGHWAY) AND THEIR CORRESPONDING MATCHED COMPARISON SITES (SOUTH WESTERN HIGHWAY) FOR NON-COLLISION CRASHES.

Siteno	Albany Highway (H001-treated) SLK numbers	Crash Period B/A*	South Western Highway (H009-untreated) SLK numbers	Crash Period B/A**
1	176.57-178.12	4/3	147.67-149.22	1/2
2	186.35-189.31	7/1	159.58-162.54	9/6
3	183.17-185.74	4/1	156.4-158.97	2/3
4	172.10-174.07	3/1	145.33-147.3	7/6
5	102.45-105.12	4/4	35-37.67	2/2
6	120.87-123.32	7/2	96.9-99.35	2/6
7	154.66-157.63	4/0	132.95-135.92	1/1
8	78.22-81.17	3/0	51.45-54.4	4/1
9	107.10-109.70	6/0	85.95-88.55	4/4
10	116.87-119.57	1/1	90.1-92.8	5/3
11	123.32-125.97	3/0	99.35-102	3/4
12	71-74	4/6	44.23-47.23	2/3
13	129.17-132.17	4/1	102.4-105.4	6/2

**Total number of crashes before and after treatment*
***Total number of crashes in the corresponding time frame as treated sites*

APPENDIX G CASUALTY CRASH REDUCTIONS FOR ALL CRASH TYPES

Area	No. of Sites	No. of Crashes before treatment	No. of Crashes after treatment	Pre – exposure data (months)	Mean Post-exposure data (months)	Estimate (β) (Interaction term only)	Standard Error	Probability 0<p<1	95% CI-Lower	95% CI Upper	Casualty Crash Reduction (%)**
All sites	13	41	11	60	58.9	-1.585	0.185	0.001	-3.655	-2.927	79.4
Sealed shoulders/audible edgelines	7	26	5	60	60	-2.108	0.617	0.001	-3.318	-0.897	87.8

* *Includes fatality, hospitalisation, and injury crashes

APPENDIX G ALL-REPORTED CRASH REDUCTIONS FOR ALL CRASH TYPES

Area	No. of Sites	No. of Crashes before treatment	No. of Crashes after treatment	Pre exposure (months)	Mean post exposure (months)	Estimate (β) (Interaction term only)	Standard Error	Probability 0<p<1	95% CI - Lower	95% CI Upper	All Crash Reduction** (%)
All sites	13	87	37	60	58.9	-0.8760	0.2470	0.001	-1.360	-0.3917	58.3
Sealed shoulders/audible edgelines	7	47	15	60	60	-1.243	0.363	0.001	-1.956	-0.530	71.2

* *Includes all crashes –fatalities, hospitalisation, injuries and property damage only crashes

APPENDIX H CASUALTY CRASH REDUCTIONS FOR NON-COLLISION CRASHES

Area	No. of Sites	No. of Crashes before treatment	No. of Crashes after treatment	Pre – exposure data (months)	Mean Post-exposure data (months)	Estimate (β) (Interaction term only)	Standard Error	Probability 0<p<1	95% CI- Lower	95% CI Upper	Casualty Crash Reduction (%)**
All sites	13	29	8	60	58.9	-1.606	0.512	0.002			80.0

* *Includes fatality, hospitalisation, and injury crashes

APPENDIX H ALL-REPORTED CRASH REDUCTIONS FOR NON-COLLISION CRASHES

Area	No. of Sites	No. of Crashes before treatment	No. of Crashes after treatment	Pre exposure (months)	Mean post exposure (months)	Estimate (β) (Interaction term only)	Standard Error	Probability 0<p<1	95% CI - Lower	95% CI Upper	All Crash Reduction** (%)
All sites	13	54	20	60	58.9	-0.883	0.325	0.007	-1.521	-0.245	58.9

* *Includes all crashes –fatalities, hospitalisation, injuries and property damage only crashes

APPENDIX I ECONOMIC EVALUATION OF STATE BLACK SPOT TREATMENT IN RELATION TO CASUALTY CRASH REDUCTION ON ALBANY HIGHWAY, 2000 - 2004

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Whole program	1 288 200	51 398 830	50 110 630	39.9
Sealed shoulder constructed and audible edgelines installed	1 080 000	40 958 471	39 878 471	37.9

APPENDIX J SENSITIVITY ANALYSIS FOR THE ECONOMIC EVALUATION OF STATE BLACK SPOT TREATMENT IN RELATION TO CASUALTY CRASH REDUCTION ON ALBANY HIGHWAY, 2000 - 2004

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Base case Discount rate 5% Treatment life 15 yrs	1 288 200	51 398 830	50 110 630	39.9
Sensitivity analysis				
Discount rate				
• 3% (15 years)	1 288 200	57 990 095	56 701 895	45.0
• 8% (15 years)	1 288 200	43 596 916	42 308 716	33.8
Treatment life				
• 10 years (5%)	1 288 200	38 237 026	36 948 826	29.7
• 20 years (5%)	1 288 200	61 389 481	60 101 281	47.7