An Evaluation of the Effectiveness and Cost-Effectiveness of the State Black Spot Program in Western Australia: 2007-2008

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Title

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Abstract

This report presents the results of an evaluation of the State Black Spot Program sites which were treated during 2007 to 2008 in Western Australia. The report evaluated the effectiveness and cost-effectiveness of the State Black Spot Program in terms of reduction in crash frequency (presented for all crashes including fatal, hospitalisation, property damage only (PDO) and casualty crashes) at treated locations and the economic worth of these treatments.

One hundred and fifty-eight hazardous locations were treated throughout Western Australia at a cost of $15.7 million (excluding maintenance and operating costs). These treated sites consisted of 106 metropolitan and 52 rural sites.

The results showed the State Program has been effective overall, reducing all reported crash frequencies by 13.5% and casualty crash frequencies by 23.8%. The estimated crash cost savings over the expected life of the treated sites were $82.6 million for all reported crashes. This resulted in an overall net cost savings to the community of $65.9 million after subtracting the capital costs of treating sites and maintenance and operating costs. The benefit cost ratio (BCR) across all treatment sites was 4.9. Evaluation of the program has identified treatment types that were highly successful, while others have not been shown to be successful. This could be due to insufficient number of sites having undergone the treatment or the treatment may genuinely have had no effect on road safety.

The results provide Main Roads, WA and other road safety organisations with reliable, objective information for enhancing strategies for future road safety investment.

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 State Black Spot treatments which were implemented during 2007 to 2008 in Western Australia (WA). It evaluated the effectiveness and cost-effectiveness of the State Black Spot Program in terms of reduction in crash frequency (presented for all crashes including fatal, hospitalisation, property damage only (PDO) and casualty crashes) at treated locations and the economic worth of the treatments. 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 major findings from the evaluation are summarised below.

Overall

There were a total of 160 sites nominated for treatment as a 'Black Spot' in the 2007 to 2008 Black Spot Program. The final sample of 158 treated sites consisted of 106 intersections and 52 road section or non-intersection sites. Two sites were removed as there were no crashes in the previous five year period. The length of follow up crash data post treatment for all treated sites was 60 months.

The results found that the Program has been effective overall, reducing all reported crash frequencies by 13.5% and casualty crash frequencies by 23.8%.

Summary of Results of Treatment Effect on All and Casualty Crash Reduction in the State Black Spot Program in 2009 – 2010, Western Australia

	Estimate (β)	Standard Error	Probability 0<p<1	Crash Reductio (%)
All Reported Crashes*				
Whole program	-0.144	0.007	<0.001	13.5
All metro sites	-0.141	0.008	<0.001	13.2
All rural sites	-0.167	0.021	<0.001	15.4
All intersection sites	-0.321	0.010	<0.001	25.7
All road section/non-intersection sites	0.162	0.009	<0.001	-17.6†
Casualty Crashes				
Whole program	-0.272	0.024	<0.001	23.8
All metro sites	-0.261	0.026	<0.001	23.0
All rural sites	-0.345	0.076	<0.001	29.3
All intersection sites	-0.493	0.029	<0.001	37.1
All road section/non-intersection sites	0.117	0.035	<0.001	-12.4†

**Includes all crashes-fatality, hospitalisation, injury and property damage major and minor crashes*
***Includes fatal, hospitalisation, and injury crashes*
†Negative crash reductions indicates an increase

Analysis by Broad Treatment Categories

Reported crash data by **broad treatment categories** (intersection and road section/non-intersection treatment) were also analysed. There was strong evidence of a 25.7% (p<0.001) reduction in the number for all crashes and a 37.1% (p<0.001) reduction in number of casualty crashes for intersection treatments. The most frequently used treatments at an intersection for this evaluation were: "*roundabouts*" (n=16), "*traffic island on approach*" (n=23), and "*protected left turn lane in crossing street*" (n=10).

There was very strong evidence of a 13.2% (p<0.001) reduction in all crashes and a 20.0% reduction in casualty crashes for the 29 **road section treatment and non-intersection sites** implemented in the rural area only. The most frequently used treatment at **road section treatment and non-intersection sites** was **"***seal shoulder*" (n=17).

Treatment Type

The "*seal shoulders*" treatment was very effective in reducing the frequency of both all reported crashes and casualty crashes with a 44.4 % ($p<0.001$) and a 42.9% ($p=0.003$) reduction respectively. Other treatments that were very effective in significantly reducing all reported crashes included:

- "*roundabouts*" by 40.9%;
- '*traffic island on approach* " by 37.9%;
- "*indented right island*" by 56.9%;
- "*extend median through intersection*" by 35.0%;
- "*traffic signal: overhead mast arms*" by 18.2%;
- "*extend right turn pocket*" by 11.9%;
- "*line marking*" by 22.2%;
- "*left turn slip*" by 40.8; and
- "*protected left turn lane"* by 27.9%.

Treatments that were very effective in significantly reducing casualty crashes included:

- "*roundabouts*" by 40.7%;
- '*traffic island on approach* " by 48.4%;
- "*indented right island*" by 82.4%;
- "*traffic signal: overhead mast arms*" by 24.1%;
- "*extend right turn pocket*" by 50.0%;
- "*left turn slip*" by 35.7%; and
- "*protected left turn lane"* by 46.2%.

The "*extend median through intersection*" reduced casualty crashes by 33.3% but the reduction in crashes was not significant ($p=0.428$). "*Line marking*" also reduced casualty crashes by 75.0% but was a weak association only ($p=0.092$).

Analysis by Location

There were a total of 106 treatment sites in the metropolitan area. Overall, these treatments showed a significant 13.2% ($p<0.001$) reduction for all reported crashes and a 23.0% ($p<0.001$) reduction for casualty crashes.

There were a total of 52 sites treated in rural areas. There was evidence of a 15.4% ($p<0.001$) reduction for all reported crashes and a 29.3% ($p<0.001$) reduction for casualty crashes.

The reduction in the number of reported crashes were estimated to reduce crash costs by $82.6 million over the expected life of the treated sites. After accounting for program costs of $16.7 million (including maintenance and operating costs), the net cost savings to the community from the Black Spot Program were estimated at $65.9 million. Expressed as a benefit cost ratio (BCR), the net economic worth of the State Black Spot Program across all treatment sites was 4.9. Sites treated in the metropolitan area had a better rate of return than those in rural areas, with a BCR of 5.4 for the former compared with 4.1 for the latter.

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	16 688 597	82 556 715	65 868 118	4.9
All Metro Sites	10 888 353	59 058 361	48 170 008	5.4
All Rural Sites	5 800 243	23 498 365	17 698 122	4.1

Limitations to the study include the lack of a suitable control treatment sites and the fact that some treatment types may not have been used often enough to produce statistically significant effects. Also, it was not possible to code some of the treatments. Consequently, the results were inconclusive for some treatment types. However, this does not necessarily mean that the treatment was ineffective. The

treatment types that do not appear to have been as successful require further monitoring and reassessment for their future use. The lack of exposure data or travel flow data at each site is also a limitation of the study.

Recommendations and Conclusion

In conclusion, as traffic patterns and road use change over time, new Black Spots will emerge. Since road authorities tend to treat the worst sites first, the benefits from treating remaining sites will reduce. This means that ongoing evaluations are necessary to help governments determine if the benefits from further treatment justify the treatment costs.

Recommendations include:

- Maintaining accurate and timely recording of details of treatments, including location, treatment types, costs, start and completion dates and any other details relevant to future evaluations.
- LGs supply more detailed information about the treatment implemented at the nominated Black Spot to ensure the treatment can be correctly allocated to the appropriate treatment type.
- Collect information on traffic volumes at individual Black Spot sites and include in any subsequent analysis as it is necessary to determine whether any change in crash history is due to the treatment or changes in traffic volume.
- Further in-depth evaluation of treatments that did not significantly reduce crash frequency such as "*improve/reinforce priority signs*".
- Further in-depth evaluation of treatments such as "*seagull islands*" that have produced inconsistent results based on the results of the current State Black Spot evaluation and previous evaluations.

In conclusion, as more Black Spot sites are treated the effectiveness of the countermeasures implemented should be monitored. This will enable a more accurate evaluation of treatments to be completed.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 Aim

The aim of this study is to evaluate the effectiveness and cost-effectiveness of the State Black Spot treatments which were implemented from 2007 to 2008 in terms of the net reduction in crash frequency and crash costs at treated sites in WA. The evaluation also examined the effectiveness of the program by treatment category at both broad and specific levels of categorisation.

1.2 Significance

The results of this analysis will provide Main Roads, WA 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 injury from road trauma is minimised.

2. METHODS

2.1 Study Design

The study adopted a quasi-experimental "*before*" and "*after*" comparison of casualty crash and all reported crash frequencies (including fatality, hospitalisation, medical treatment and property damage only (PDO) crashes) at sites treated under the State Black Spot Program for the years 2007 to 2008. The analysis also included the estimation of the net economic worth of the Program.

2.2 Selection of Sites for Funding

Black spots are defined as locations noted for a high incidence of crashes involving death and injury under the National Black Spot Funding Program (Australian National Audit Office 2007). However, the WA State Black Spot Program defines Black Spots as locations with a high incidence of all crash types. The 2007-08 State Black Spot Program provided funding of $15.7 million for road safety related works on State and Local Government roads. All road classifications were eligible for funding. The 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. Black lengths were lengths of road greater than three kilometres with a proven crash history. Potentially hazardous locations were selected on the basis of formal road safety audits however these treatments have not been included in the analysis. Approximately two thirds of funding was spent on roads in the Perth metropolitan region and one third on roads outside the Perth metropolitan region. For a more detailed list of the criteria used for the selection of sites please see Appendix A.

Typical major road safety improvements included (Main Roads WA 2003):

- the installation of roundabouts at various intersections;
- realignment and improvement of the road geometry at intersections and selected road sections;
- improvements to road surface treatments such as anti-skid treatments; and
- traffic calming treatments and improvements to street lighting.

2.3 Data Collection

Information on each treated site was obtained from the Road Safety Section at Main Roads, WA. Only BCR applications (and not road safety audits) were included in the evaluation. Crash data was obtained from the Integrated Road Information System (IRIS) using police reported data which is maintained by Main Roads, WA.

2.3.1 Integrated Road Information System (IRIS)

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 December 31, 2013.

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. 2005). 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, it is mandatory to report a crash to the police if a person is injured or if property damage exceeds $3,000.

Critical data retrieved for use in the study were:

- Crash date;
- Crash severity;
- Local government area of crash;
- Specific crash location.

The approach adopted in this study was to use five years of pre-treatment crash data and five years of post-treatment crash data (up to December 31, 2013) which excluded the construction period. Crash data which was used in the analysis included all fatality, injury 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 crashes rather than casualty crashes only. However, a separate analysis by casualty crashes only was also undertaken.

2.3.2 State Black Spot Treatment Site Data

Main Roads, WA provided details about each Black Spot treatment. This included information related to Black Spot location and municipality, treatment description, and precise treatment start and finish dates (to within one week). See Appendix B for a list of State Black Spot Program treatment sites.

Information provided included:

- treatment number;
- Black Spot location and LG;
- treatment description;
- treatment start and finish dates;
- treatment cost;
- estimated annual maintenance and operating costs;
- estimated treatment life.

Using information obtained from the treatment description, one of the treatment codes described in Appendix C was assigned to each treatment for use in the analysis. These codes are based on tables obtained from the Main Roads WA Road Safety Branch.

2.4 Categorisation of Treatment Types

An aim of the study was also to estimate the effectiveness of specific treatment types. However some of the Black Spot sites had multiple treatments in the data, a combination of individual treatments, which made it difficult to analyse by specific types of treatment. Therefore only the "primary treatment" for each multiple-treatment project based on road safety considerations was chosen to be included in the analysis (Bureau of Infrastructure, Transport and Regional Economics 2012). While this resulted in a loss of accuracy in what could be concluded about individual types of treatment, the increase in sample size for the overall evaluation improved the accuracy of the analysis. The primary treatment also need not be the most costly to implement.

2.5 Factors that may Affect the State Black Spot Evaluation

All known factors that have the potential to affect the Black Spot 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 Black Spot treatments are described below. These include site-specific factors, regression- to-the mean, and crash migration.

2.5.1 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 as a whole (Bureau of Transport 2001). However it may have an effect on the analysis at a particular site (Bureau of Transport 2001).

2.5.2 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 the subsequent period even if no treatment is carried out because the number of crashes will tend to gravitate to the long-term mean. Under these conditions the effect of any treatment is likely to be over-estimated. Failing to allow for the regression to the mean effect can result in statistically significant results for treatments that are in fact ineffective.

On the basis of work reported by Nicholson (1986) 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

and 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.

2.5.3 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).

2.6 Cost Data

Two types of cost data were used in the evaluation of the economic worth of the State Black Spot Program: the total 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 Black Spots include both the initial capital outlay as well as operating and maintenance costs. As discussed previously (section 2.3.2), Main Roads, WA provided these details for each Black Spot treatment 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 by Main Roads, WA.

The cost savings from fewer road crashes at treated sites were calculated based on the road crash severity costs for WA as provided by Main Roads WA. 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 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 2013 Australian dollars shown below.

Crash severity	**$**
Fatal	7 116 751
Hospital admission	296 896
Medical Treatment	73 469
Property Damage Only	11 651

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 fatality crash at a site can potentially have a considerable impact on the calculation of the cost-effectiveness of treating a site. To take account of this problem, the economic evaluation assigned all fatality crashes at the lower severity of crashes involving hospital admission. Given the reduction of fatality crashes at treated sites from 10 to 4, the estimates of the cost-effectiveness of treated sites is conservative.

2.7 Statistical Analysis

2.7.1 Effectiveness of the Program

The analysis compared the rate of crashes "*before*" and "*after*" treatment periods based on the total program, broad treatment categories (i.e. intersection treatments and non-intersection/road section treatments), and specific treatment types (e.g. non-skid treatment). The analysis was also stratified by metropolitan Perth and non-metropolitan (rural) to assess differential program effectiveness between Perth and the rest of WA.

A generalised estimating equation (GEE) Poisson regression model was used to evaluate the State Black Spot Program. The number of crashes in one year is a

discrete “count” variable and is assumed to follow a Poisson distribution. However, the longitudinal nature of the observations render the application of standard Poisson regression analysis inappropriate, and methods such as the GEE should be used to accommodate the inherent correlation of the longitudinal data. While a Poisson regression model was used in the National Black Spot Program, the decision to use the 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, broad category treatment and specific treatment effects. Similar treatment types were grouped together to attain a higher statistical power. For example, all treatments involved in the provision of a roundabout were grouped together regardless of the size of the roundabout installed. Details about the GEE technique can be found in Twisk (2003).

Information on traffic volumes over time at individual Black Spot sites is useful to determine whether any changes in crash history are due to a treatment at the Black Spot site or whether changes in traffic flow give rise to the observed discrepancies before and after treatment. Unfortunately, it was not possible to obtain before and after treatment traffic volumes for all treated sites. For the purpose of this analysis it was thus assumed that before and after traffic volumes remained constant. Sites with zero crashes were also excluded from the analysis.

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

2.7.2 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. In the case of the Black Spot 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 –

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

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

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 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 Main Roads, WA. NPVs and BCRs were calculated for the whole Black Spot Program and separately for metropolitan and rural sites. The sensitivity analysis was only conducted for the whole Black Spot Program. NPV and BCR calculations were made on the basis of all reported crash data and casualty crashes only (see Appendices F and G).

3. RESULTS

This section summarises the results of the analyses for all reported crash frequency and casualty crash frequency. The sample of treated sites for which sufficient data was obtained were evaluated by broad categories (intersection and road section/non-intersection), by specific treatment type and by geographic area (metropolitan Perth and rural WA). The full results of the analysis which include the number of sites, the number of crashes before and after treatment and the average follow-up crash data pre and post treatment are detailed in Appendix D and Appendix E with the main findings summarised below.

3.1 Statistical Analysis

There were a total of 160 sites nominated for treatment as a 'Black Spots' in the 2007 to 2008 Black Spot Program. The final sample of 158 treated sites consisted of 106 intersections and 52 road section or non-intersection sites. Two sites were removed as there were no crashes recorded in the previous five year period. The length of follow up crash data post treatment for all treated sites was 60 months.

Table 3.1 shows the effect of the Black Spot Program for all crashes (fatal, hospitalisation, injury and PDO crashes) and Table 3.2 shows the effect for casualty crashes only (fatal, hospitalisation and injury crashes). 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 $1-e^{\beta}$. A negative percentage value for β indicates that all Police reported crashes (fatal, hospitalisation, injury and PDO crashes) and casualty crashes 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 percentage reduction in the number of all reported crashes and casualty crashes is shown in the last column of Table 3.1 and Table 3.2.

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.

The overall effect of the Black Spots sites treated during 2007 to 2008 for all crash severities showed a very strong reduction of 13.5% ($p<0.001$) for all crashes (see Table 3.1) and a very strong reduction of 23.8% ($p<0.001$) for casualty crashes (see Table 3.2).

Table 3.1 State Black Spot Treatment Effect on All Crash Reduction in Western Australia, 2007 – 2008

Area	Estimate (β)	Standard Error	Probability 0<p<1	All Crash Reduction (%)**
Whole program	-0.144	0.007	<0.001	13.5
All Metropolitan Sites	-0.141	0.008	<0.001	13.2
All Rural Sites	-0.167	0.021	<0.001	15.4
Broad Categories				
Intersection Treatments	-0.321	0.010	<0.001	25.7
• Metro	-0.332	0.011	<0.001	26.3
• Rural	-0.204	0.034	<0.001	18.4
Road Section and Non Intersection Treatment	0.162	0.009	<0.001	-17.6†
• Metro	0.265	0.011	<0.001	-30.3†
• Rural	-0.142	0.027	<0.001	13.2
Treatment Types				
All Roundabouts	-0.526	0.124	<0.001	40.9
• Metro	-0.579	0.152	<0.001	44.0
• Rural	-0.272	0.070	<0.001	23.8
Seal shoulder	-0.588	0.071	<0.001	44.4
Skid resistant treatment	-0.667	0.469	<0.001	48.7
Improve/reinforce priority signs	-0.345	0.375	0.358	29.2*
Traffic islands on approach	-0.477	0.037	<0.001	37.9
Indented right island	-0.841	0.132	<0.001	56.9
Extend median through intersection	-0.431	0.067	<0.001	35.0
Protected left turn lane	-0.327	0.071	<0.001	27.9
Seagull island	-0.276	0.027	<0.001	24.1
Left turn slip	-0.524	0.095	<0.001	40.8
Traffic signal: overhead mast arms	-0.201	0.008	<0.001	18.2
Extend right turn pocket	-0.127	0.017	<0.001	11.9
Line marking	-0.251	0.126	0.046	22.2

**Crash increase/reduction is not statistically significant*
***Includes all crashes-fatal, hospitalisation, injury and property damage major and minor crashes*
†Negative crash reductions indicates an increase

Table 3.2 State Black Spot Treatment Effect on Casualty Crash Reduction in Western Australia, 2007-2008

Area	Estimate (β)	Standard Error	Probability 0<p<1	Casualty Crash Reduction (%)**
Whole program	-0.272	0.024	<0.001	23.8
All Metropolitan Sites	-0.261	0.026	<0.001	23.0
All Rural Sites	-0.345	0.076	<0.001	29.3
Broad Categories				
Intersection Treatments	-0.493	0.029	<0.001	37.1
• Metro	-0.483	0.031	<0.001	36.4
• Rural	-0.642	0.183	<0.001	47.4
Road Section and Non Intersection Treatment	0.117	0.035	0.001	-12.4†
• Metro	0.286	0.042	<0.001	-33.0†
• Rural	-0.223	0.083	0.007	20.0
Treatment Types				
All Roundabouts	-0.523	0.288	0.069	40.7
• Metro	-0.588	0.299	0.050	44.4
Seal shoulder	-0.560	0.189	0.003	42.9
Skid resistant treatment	-0.606	0.087	<0.001	45.5
Improve/reinforce priority signs	-0.693	0.707	0.327	50.0*
Traffic islands on approach	-0.661	0.109	<0.001	48.4
Indented right island	-1.734	0.535	0.001	82.4
Extend median through intersection	-0.405	0.512	0.428	33.3*
Protected left turn lane	-0.619	0.120	<0.001	46.2
Seagull island	-0.788	0.505	0.119	54.5*
Left turn slip	-0.442	0.121	<0.001	35.7
Traffic signal: overhead mast arms	-0.275	0.119	0.021	24.1
Extend right turn pocket	-0.693	0.064	<0.001	50.0
Line marking	-1.386	0.821	0.092	75.0

**Crash increase/reduction is not statistically significant*
***Includes fatal, hospitalisation, and injury crashes*
†Negative crash reductions indicates an increase

3.1.1 Analysis by Broad Treatment Categories

Reported crash data by **broad treatment categories** (intersection and road section/non-intersection treatment) were also analysed. There was strong evidence of a 25.7 ($p<0.001$) reduction in the number of all crashes and a 37.1 % ($p<0.001$)

reduction in the number of casualty crashes for intersection treatments. The most frequently used treatments at an intersection for this evaluation were: "*roundabouts*" (n=16), "*traffic island on approach*" (n=23), and "*protected left turn lane in crossing street*" (n=10).

There was very strong evidence of a 13.2% ($p<0.001$) reduction in all crashes and a 20.0% reduction in casualty crashes for the 29 **road section treatment and non-intersection sites** implemented in the rural area only. The most frequently used treatment at **road section treatment and non-intersection sites** was **"***seal shoulder*" (n=17).

3.1.2 Analysis by Specific Treatment Type

As evident from Table 3.1 and Table 3.2 the study was able to identify treatment types which were successful in reducing both all reported crash and casualty crash frequencies at treated Black Spots.

The "*seal shoulders*" treatment was very effective in reducing the frequency of both all reported crashes and casualty crashes with a 44.4% ($p<0.001$) and a 42.9% ($p=0.003$) reduction respectively. Other treatments that were very effective in significantly reducing all reported crashes included:

- "*roundabouts*" by 40.9%;
- '*traffic island on approach* " by 37.9%;
- "*indented right island*" by 56.9%;
- "*extend median through intersection*" by 35.0%;
- "*traffic signal: overhead mast arms*" by 18.2%;
- "*extend right turn pocket*" by 11.9%;
- "*line marking*" by 22.2%;
- "*left turn slip*" by 40.8; and
- "*protected left turn lane"* by 27.9%.

Treatments that were very effective in significantly reducing casualty crashes included:

- "*roundabouts*" by 40.7%;

- ‘*traffic island on approach* ” by 48.4%;
- “*indented right island*” by 82.4%;
- “*traffic signal: overhead mast arms*” by 24.1%;
- “*extend right turn pocket*” by 50.0%;
- “*left turn slip*” by 35.7; and
- “*protected left turn lane”* by 46.2%.

The “*extend median through intersection*” treatment reduced casualty crashes by 33.3% but the reduction in crashes was not significant (p=0.428). “*Line marking*” also reduced casualty crashes by 75.0% but was a weak association only (p=0.092).

3.1.3 Analysis by Location

There were a total of 106 treatment sites in the metropolitan area. Overall, these treatments showed a significant 13.2% (p<0.001) reduction for all reported crashes and a 23.0% (p<0.001) reduction for casualty crashes.

There were a total of 52 sites treated in rural areas. There was evidence of a 15.4% (p<0.001) reduction for all reported crashes and a 29.3% (p<0.001) reduction for casualty crashes.

A breakdown of broad treatment categories by location found:

- A 26.3% (p<0.001) reduction for all reported crashes and a reduction of 36.4% (p<0.001) for casualty crashes in the **metropolitan area** for **intersection** treatments.
- A significant reduction of 18.4% and 47.4% respectively for both all and casualty crashes in the **rural area** for **intersection treatments.**
- a significant 30.3% increase for all reported crashes and a 33.0% (p<0.001) increase for casualty crashes in the **metropolitan area** for **road section and non-intersection** treatments.
- a significant 13.2% (p<0.001) reduction for all crashes and a 20.0% reduction for casualty crashes for **road section and non-intersection** treatments in the **rural area**.

An analysis of the differential effect of "*roundabout*" treatments for both the metropolitan and rural area was also undertaken. A very significant reduction of 44.0% ($p<0.001$) was reported in the metropolitan area and a 23.8% reduction in rural area for all reported crashes. There was a significant reduction of 44.4% ($p=0.050$) for casualty crashes in the metropolitan area. Unfortunately it was not possible to calculate if a reduction occurred for casualty crashes in the rural area.

3.2 Economic Evaluation of the State Black Spot Program

Table 3.3 presents the results of the economic evaluation of the State Black Spot Program in terms of its reduction in all reported crashes. Appendix F shows the economic worth of the Program in terms of the reduction in casualty crashes only. The estimated crash cost savings over the expected life of the treatments were $82.6 million for all reported crashes. This will result in an overall net cost saving to the community over the expected life of the treated sites of $65.9 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 4.9, which indicates benefits in the form of cost savings to the community of $4.90 for each $1 invested in the program. Sites treated in the metropolitan area had a better rate of return than those in rural areas, with a BCR of 5.4 for the former compared with 4.1 for the latter.

Table 3.4 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 Black Spot 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 Black Spot Programs to $76.3 million and the BCR to 5.5. An expected treatment life of 20 years increased the NPV to $82.2 million and the BCR to 5.9.

Table 3.3 Economic Evaluation of the State Black Spot Programs in Relation to All Crash Reduction in Western Australia

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Whole program	16 688 597	82 556 715	65 868 118	4.9
All Metropolitan Sites	10 888 353	59 058 361	48 170 008	5.4
All Rural Sites	5 800 243	23 498 365	17 698 122	4.1

Note: Figures for metropolitan and rural sites do not add exactly to whole program sites due to rounding errors.

Table 3.4 Sensitivity Analysis for the Economic Evaluation of the Whole State Black Spot Programs in Relation to All Crash Reduction in Western Australia

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Base case	16 688 597	82 556 715	65 868 118	4.9
Discount rate 5%				
Treatment life 15 yrs				
Sensitivity analysis				
Discount rate				
• 3% (15 years)	16 816 338	93 143 609	76 327 271	5.5
• 8% (15 years)	16 537 394	70 025 309	53 487 915	4.2
Treatment life				
• 10 years (5%)	16 433 518	61 416 260	44 982 742	3.7
• 20 years (5%)	16 888 452	99 120 331	82 231 879	5.9

4. DISCUSSION

This report presented the results of the evaluation of State Black Spot treatments in WA in terms of its effectiveness in reducing the frequency for all reported crashes, casualty crashes and costs from 2007 to 2008. The analysis found the program to be effective overall in reducing the frequency of all reported crashes by 13.5% and casualty crashes by 23.8% for the sample of treated sites under the Black Spot Program.

A number of decisions were made regarding the analysis. The study examined both the effects of the Black Spot treatments on all severity of crashes (including PDO) and casualty crashes only. This was in keeping with Main Roads WA threshold criteria, which allowed for the application of funds to a wider range of projects based on the total number of crashes at sites which varied between regions and road types. The alternative to this would be to study treatment effect on only crash types most likely to be affected by the particular treatment being examined. However an evaluation of specific crash types only, may have the potential to miss all possible benefits of a treatment as well as potential detrimental effects. According to Newstead & Corben (2001) an evaluation that includes all crash types is more relevant when examining Black Spot treatment effectiveness, which was the aim of the present study.

The evaluation of the Program identified specific treatment types such as "*roundabouts*" and "*seal shoulders*" that were highly successful in reducing crash frequency in both the metropolitan and rural areas. Roundabouts continue to be one of the most effective treatments reducing all reported and casualty crashes by 40.9% and 40.7% respectively. This is consistent with previous evaluations of the Black Spot Program undertaken in WA as well as the evaluation of the National Black Spot Program (Meuleners et al. 2005, Meuleners & Hendrie 2008, BITRE 2012). However, the reductions in casualty crashes in this study were smaller than reported in previous State Black Spot evaluations (a 62% reduction in casualty crashes) (Meuleners et al. 2005).

Other types of treatment that showed statistically significant reductions in the number of all reported crashes and casualty crashes included "*traffic island on approach"* and "*left turn slip"*. These results are consistent with previous evaluations of the WA Black Spot Program (Meuleners et al. 2005, Meuleners & Hendrie 2008).

"*Non-skid treatments*" were found to reduce all reported crashes and casualty crashes by 48.7 % and 45.5% respectively. This finding is consistent with previous research which estimated crash reductions of approximately 35% from the improvement of skid resistance (Turner et al. 2008). This is also consistent with previous evaluations of the WA Black Spot Program which reported a decrease in all reported and casualty crashes by 32.1% and 45.4% respectively (Meuleners et al. 2005).

Treatments such *as "indented right island", "extend median through intersections", "protected left turn lane", "traffic signal: overhead mast arms"; and "extend right turn pocket"* also reported statistically significant reductions in the number of all reported crashes and casualty crashes in the current evaluation. These treatments have not been evaluated in previous State Black Spot evaluations (sample size not large enough or not used) and further monitoring is required regarding their long term effectiveness.

"*Priority/reinforce signs*" were found to reduce all reported and casualty crashes but the reduction was not significant. However this could be due to the small number of sites (n=3) which implemented this treatment. The National Black Spot Program evaluation also found that "*priority sign treatments*" did not have a significant effect during the night nor on fatal and PDO crashes during the day. However, they did reduce injury crashes by 30% to 50% during the day (BITRE 2012). A report by Turner et al. (2008; pg 27) found that "*the benefits of installing Stop signs are greater for two-way Stop signs at a four legged intersection than for a one-way Stop sign at a T intersection*".

"*Line marking*" significantly reduced all reported crashes by 22.2% and this is consistent with findings from the recent evaluation of the National State Black Spot Program (BITRE 2012) which reported reductions in minor injury and PDO crashes by 20% to 30%, day and night. Turner et al. (2008) stated that "*an average reduction*

of 30% in all crashes could be expected with the installation of new centerline markings".

The implementation of "*seagull islands*" which aim to reduce specific crash types, especially right angle crashes, has produced inconsistent results when compared to previous Black Spot evaluations undertaken in WA. (Meuleners et al. 2005, Meuleners & Hendrie 2008). In this report *"seagull islands"* significantly reduced all reported crashes but not casualty crashes.

It must also be noted that this evaluation demonstrated that the Black Spot Program was effective for reducing the frequency of crashes at intersection sites and is consistent with previous Black Spot evaluations undertaken in WA. Road section and non-intersection sites did not perform as well in the metropolitan area but did significantly reduce all reported crashes and casualty crashes in the rural area.

Failure to reject the null hypothesis of no difference does not necessarily mean that the treatment countermeasure was ineffective. There are several reasons why the treatment did not have an effect on treated sites. The first is that the treatment may genuinely have had no effect on road safety contrary to what the literature may say. Second, traffic flow has changed significantly at some of the treated sites over the study period however it was not possible to measure this effect in the evaluation or control for it in the analysis. Third, some treatment types may not have been used often enough to produce statistically significant effects or were too rare to undertake an analysis such as "*new signals with turn arrows"* (n=1), and "*LED traffic signals*" (n=1).

The WA Black Spot program performed well in economic terms. In relation to the net economic worth of the State Black Spot Program, the NPV and the BCR across all treatment sites were estimated to be $65.9 million and 4.9 respectively. Sites treated in the metropolitan area had a better rate of return than those in rural areas, with a BCR of 5.4 for the former compared with 4.1 for the latter. This is also consistent with previous evaluations of the WA program and the National Black Spot Program (Meuleners et al. 2005, BITRE 2012).

Limitations to the study include the lack of a suitable control treatment sites and the fact that some treatment types may not have been used often enough to produce statistically significant effects. Also it was not possible to code some of the treatments. Consequently, the results were inconclusive for some treatment types. However, this does not necessarily mean that the treatment was ineffective. The treatment types that do not appear to have been as successful require further monitoring and reassessment for their future use. The lack of exposure data or travel flow data at each site is also a limitation of the study.

5. CONCLUSIONS AND RECOMMENDATIONS

The results found the Program to be effective producing positive outcomes for the community in terms of road safety. The Program has reduced all reported crash numbers by 14% and is estimated to reduce crash costs by $82.6 million over the expected life of the treated sites. After accounting for project costs of $16.7 million (including maintenance and operating costs), the net cost savings to the community from the Black Spot Program were estimated as $65.9 million. This is the equivalent of a BCR of 4.9.

Limitations to the study include the lack of a suitable control treatment sites and the fact that some treatment types (mentioned above) may not have been used often enough to produce statistically significant effects. Also it was not possible to code some of the treatments. Consequently, the results were inconclusive for some treatment types. However, this does not necessarily mean that the treatment was ineffective. The treatment types that do not appear to have been significant in reducing crashes such as "*improve/reinforce priority signs*" require further monitoring.

Obtaining accurate information related to type of treatment at the sites needs to be properly documented for any future evaluation to ensure the validity of the results. Poor definitions of road environment countermeasures from some LGs made it difficult to determine what was actually done at the treated site. For example: the description of one treatment was "*provide parking protection*". It is also crucial that neither the before treatment period nor the after treatment period overlaps the construction period, in which case estimates of the treatment effect could result in bias towards the lesser or greater magnitude compared to the true value. Given some of the difficulties experienced in the current study, it is recommended that a comprehensive and systematic method of data collection be implemented to facilitate future Black Spot Program evaluations.

Recommendations and Conclusion

In conclusion, as traffic patterns and road use change over time, new Black Spots will emerge. Since road authorities tend to treat the worst sites first, the benefits from treating remaining sites will reduce. This means that ongoing evaluations are necessary to help governments determine if the benefits from further treatment justify the treatment costs.

Recommendations include:

- Maintaining accurate and timely recording of details of treatments, including location, treatment types, costs, start and completion dates and any other details relevant to future evaluations.
- LGs supply more detailed information about the treatment implemented at the nominated Black Spot to ensure the treatment can be correctly allocated to the appropriate treatment type.
- Collect information on traffic volumes at individual Black Spot sites and include in any subsequent analysis as it is necessary to determine whether any change in crash history is due to the treatment or changes in traffic volume.
- Further in-depth evaluation of treatments that did not significantly reduce crash frequency such as "*improve/reinforce priority signs*".
- Further in-depth evaluation of treatments such as "*seagull islands*" that have produced inconsistent results based on the results of the current State Black Spot evaluation and previous evaluations.

In conclusion, as more Black Spot sites are treated the effectiveness of the countermeasures implemented should be monitored. This will enable a more accurate evaluation of treatments to be completed.

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APPENDIX A

BLACK SPOT PROGRAM – PROJECT CRITERIA

Criteria	Australian Government Black Spot State and Local Roads	State Black Spot Highways and Main Roads	State Black Spot Local Roads
General			
Owner	Department of Infrastructure, Transport, Regional Development	WA State Government	WA State Government and Local Government
Co-ordination	Main Roads Road Network Services Program Development Co-ordinator	Main Roads State Black Spot Program Manager	Main Roads Regional Managers and Regional Road Group
State Panel Meeting	Yes – (November)	N/A	N/A
Recommendation	WA Black Spot State Consultative Panel	Program Development Coordinator Road Network Services	State Road Funds to Local Government Advisory Committee
Endorsement	Executive Director Road Network Services	Executive Director Road Network Services	Executive Director Road Network Services
Endorsement	Commissioner of Main Roads	Commissioner of Main Roads	Commissioner of Main Roads
Approval	Federal Minister for Transport	State Minister for Transport	State Minister for Transport
Period	On-going	On-going	On-going

Criteria	Nation Building Black Spot State and Local Roads	State Black Spot Highways and Main Roads	State Black Spot Local Roads
Funding ***Allocation***	$17.56 million for 2015/16 and 2016/17	$10 million annually	$15 million annually (including Local Governments contribution)
Distribution ***Metro*** ***Rural***	50% 50%	50% 50%	50% 50% (Based on recommendation of the State Black Spot Review completed in 2008 and accepted by the State Road Funds to Local Government Advisory Committee on 20 May 2009.
Contributions	Yes – encouraged	Yes (e.g. Developers – service roads)	Yes 2:1 mandatory (State and Local Govt)
Over Fund	Yes up to 25%	Yes (decided at the programming stage) (reserve projects pre- approved and funded if funds become available)	Yes (based on merit) (reserve projects pre- approved and funded if funds become available)
Variations	Yes, within the total allocated funding limit to WA only	Fully allocated - Managed by Main Roads	Fully allocated - Managed by Regional Road Group
Project Min Cost ***Project Max Cost***	≥ $ 2 000 ≤ $ 2 000 000	≥ $ 2 000 ≤ $ 3 000 000	≥ $ 2 000 ≤ $ 3 000 000

Criteria	Nation Building 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 Main Roads	No, paid by Main Roads		No, paid by Local Government.	
Road Safety Audit	No	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 Land Transport	Yes	Yes		Optional	
Road of National Importance	Yes	Yes		Optional	
State Roads	Yes	Yes		Optional	
Local Roads	Yes	Yes (for intersection		Yes	
Crash Criteria	**Metro**	**Metro**	**Rural**	**Metro**	**Rural**
Intersection or Mid-Block or Short Road (< 3 kilometres)	2 casualty crashes over a five-year period	10 crashe over 5 years	3 crashes over 5 years	5 crashes over 5 years	3 crashes over 5 years
Road Length (≥ 3 kilometres)	0.13 casualty crashes per kilometre per year over 5 years, or top 10% of sites which have a demonstrably higher crash rate than other roads in a	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 per km over 5 years

Crash Period	5 years (eg.1999 to 2003 for 2005-2006 program)	5 years (e.g. 1999 to 2003 for 2005-2006 program)	5 years (eg.1999 to 2003 for 2005-2006 program)

Criteria	Nation BuildingBlack Spot State and Local Roads	State Black Spot Highways and Main Roads	State Black Spot Local Roads
BCR			
Minimum	≥ 1.0	≥ 1.0	≥ 1.0
Discount Rate	5%	5%	5%
Crash Reduction % Factors	Department of Infrastructure, Transport, Regional Development and Main Roads	Department of Infrastructure, Transport, Regional Development and Local Government and Main Roads	Department of Infrastructure, Transport, Regional Development and Local Government and Main Roads
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			
Projects	Yes up to 40% of program	Yes up to 50% of program. Executive Director may vary percentage up to a higher level.	Yes up to 50% of program. Advisory Committee may 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	One re-programming year is allowed	One re-programming year is allowed
Staged Construction	Not normally	Yes	Yes

Recognition ***Signing during Construction*** ***Signing Post Construction***	≤ $100,000 during construction only. ≥ $100,000, + permanent signing for 2 years Any other signposting relating to the project must be endorsed by the Minister.	$50,000 - $100,000 during construction only. Over $100,000 - permanent signing for 1 year.	$50,000 - $100,000 during construction only. Over $100,000 - permanent signing for 1 year.
Criteria	Nation Building 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. Main Roads approval required	Yes Ensures needs of cyclists and pedestrians are properly catered for. Main Roads approval required	Yes Ensures needs of cyclists and pedestrians are properly catered for. Main Roads 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	Independent Research Consultant

APPENDIX B STATE BLACK SPOT TREATMENT SITES

PROGRAM YEAR	PROJECT OWNER / LG	PROJECT
2006/07	Kalgoorlie - Boulder	Install roundabout
2006/07	Stirling	Install anti skid resistant treatment
2006/07	Belmont	Install right turn lane & islands
2006/07	Canning	Install Roundabout
2006/07	East Fremantle	Provide parking protection over 1Km
2006/07	Kalamunda	Install right lane and widening (to contribute $10,000) preconstruction
2007/08	Fremantle	Install Right turn lane
2006/07	Belmont	Provide Skid Resistant treatment
2006/07	Nedlands	Install median & parking modifications
2005/06	Gosnells	Improve Street lighting
2006/07	MRWA	Stage 2 Extend right turn lanes on Leach Hwy
2006/07	Kalgoorlie - Boulder	Improve intersection; Install median islands
2006/07	Swan	Widen, install islands & improve sight lines
2007/08	Wanneroo	Install Roundabout pre-deflection nibs on Kingsway Rd
2006/07	Kalgoorlie - Boulder	Improve intersection; Install median islands (nibs) on approaches
2006/07	Gosnells	Upgrade Street lighting to AS1158
2005/06	Gosnells	Construct Median Island
2007/08	Gosnells	Construct median island and improve sight lines
2007/08	Stirling	Install pre-deflection Nibs at existing single lane roundabout
2007/08	Fremantle	Install anti skid treatment on the S approach of Hampton Rd & West approach of Douro Rd
2006/07	MRWA	Seal shoulders 0.5m either side and construct 1.2m gravel shoulder
2007/08	Stirling	Construct Roundabout; traffic islands on approach
2007/08	Albany	Construct median & other minor improvements with Young St
2005/06	Gosnells	Construct Traffic Control Signals
2007/08	Gosnells	Install left turn lane

2007/08	Stirling	Install pre-deflection Nibs at existing single lane
2006/07	Gosnells	Construct Roundabout
2006/07	Gosnells	Install Roundabout
2005/06	Kalamunda	Construct Roundabout
2007/08	Gosnells	Upgrade Street lighting to AS1158
2006/07	Joondalup	Install seagull island in median
2007/08	Albany	Seal shoulders, provide edge lines & advisory speed signs on curves
2006/07	Gosnells	Install left turn lane
2007/08	Gosnells	Install Safety barrier; delineate road edge & install speed signs
2006/07	Albany	Improve median at intersection with Angove / Wansborough Rd Roundabout
2006/07	Kalamunda	Install pre deflection nibs
2007/08	Canning	Upgrade Street Lighting to AS1158
2007/08	Wanneroo	Install TCS
2006/07	Gosnells	Install left turn lane & painted right turn lane; reinforce priority signs
2006/07	Victoria Park	Install right turn lane & islands
2006/07	Cottesloe	Construct median island
2007/08	Gosnells	Construct median island
2006/07	Albany	Seal shoulders, provide edge lines & advisory speed signs on curves
2007/08	MRWA	Construct high angle island and anti skid surfaces on Gosnells Rd West approach
2007/08	Joondalup	Install TCS and install median island
2006/07	Manjimup	SBSPOT - CONSTRUCT RAISED PEDESTRIAN CROSSINGS AND ADDITIONAL PARKING EMBAYMENT
2006/07	MRWA	Modify all existing low-angle entries to high angle entries (70 deg) for left turners under give way from all approaches, enlarge signal aspects, relocate power poles in splitter islands to outside the clear zone and upgrade pedestrian crossing facilities
2005/06	Fremantle	Provide skid resistant treatment, modify kerbs & install pedestrian facilities
2005/06	Albany	Install pre deflection nibs, improve delineation between left slip & thru, improve/reinforce priority signs
2006/07	Cottesloe	Construct median island
2006/07	Stirling	Install LED traffic control signal lanterns
2006/07	Albany	Construct Rt turning pocket & other minor improvements
2007/08	Melville	Widen & lengthen left turn lane; Install turn arrows; relocate footpath
2008/09	Wanneroo	Construct seagull island

2007/08	Gosnells	Modify Intersection
2008/09	Stirling	Extend right turn pocket
2008/09	Vincent	Install Roundabout
2006/07	Vincent	Construct Median Islands
2006/07	Melville	Install LT slip with Give Way Con a& Inst ACC Lane
2006/07	Vincent	SBSPOT - OXFORD ST / ANZAC RD CONSTRUCT ROUNDABOUT (REMOVE TCS) (LG TO CONTRIBUTE $43,333) REPROG 05/06 FUNDS EX 2005 48 3600 REPROG EX 06/07
2006/07	Cockburn	Pre deflection nibs at roundabout
2007/08	South Perth	Construct Roundabout
2005/06	Gosnells	Upgrade Street lighting to AS1158
2006/07	Serpentine-Jarrahdale	Install Anti Skid Treatment and Improve Sight Lines
2008/09	Gosnells	Construct Roundabout
2006/07	Gosnells	Install Roundabout
2005/06	Kalamunda	Construct Roundabout
2006/07	Harvey	Construct & seal 6.0m wide and install advisory signs.
2006/07	MRWA	Install traffic signals
2006/07	Waroona	Remove/prune vegetation, install advisory signage & additional guideposts
2006/07	Waroona	Construct & seal shoulders, install advisory signage & additional guide posts
2005/06	Kalgoorlie - Boulder	
2007/08	Melville	Install pre-deflection to existing single lane roundabout
2006/07	Fremantle	Install Roundabout
2006/07	Busselton	Construct Roundabout
2007/08	Belmont	Install left turn lane
2008/09	Wanneroo	Construct pre-deflection nib an northern approach to roundabout
2006/07	Dardanup	Seal shoulders, install advisory signage
2006/07	Waroona	Construct & seal 6.0m wide & install advisory signage
2006/07	MRWA	Remove right turn filters, extend right turn lanes & upgrade pedestrian facilities
2005/06	Bridgetown Greenbushes	SBSPOT - CONSTRUCT PEDESTRIAN REFUGE ISLAND, DUP & PARKING, SEAL AND KERB SHOULDERS, IMPROVE LIGHTING
2007/08	Stirling	Install traffic islands with additional stop signing on north & south approaches
2007/08	Victoria Park	Construct roundabout

2007/08	Cottesloe	Install left turn lane
2006/07	Kalgoorlie - Boulder	Improve sight lines at intersection
2007/08	Harvey	Construct Pavement & Primseal 6.0M wide & install advisory signs
2005/06	Mundaring	SBSPOT - MADDOCK ST / JACOBY ST TO PHILLIPS RD CLOSE MADDOCK ST
2007/08	Cockburn	Modify Traffic Control Signals & install anti skid treatment
2005/06	Joondalup	Install TCS
2006/07	Kwinana	Install pre-deflection nibs at roundabout
2006/07	Busselton	Seal shoulders, install edge-lining & remove roadside hazards
2006/07	Busselton	Modify traffic control signals, install right turn lane & line marking & install non-skid treatment on all approaches
2006/07	Stirling	Install traffic control signals extend left turn pocket
2006/07	Gosnells	Construct traffic control signals
2005/06	Dardanup	SBSPOT - CONSTRUCT AND SEAL SHOULDERS IMPROVE CROSSFALL AND INSTALL ADVISORY SIGNS
2006/07	Cockburn	SBSPOT - NORTH LAKE RD/FARRINGTON RD EXTEND LT POCKET
2008/09	South Perth	Install anti skid treatment
2007/08	Harvey	Seal shoulders & install advisory signs, RRPM's & Edgelines
2006/07	Augusta Margaret River	Construct slip lane, seal shoulders ,install advisory signs
2007/08	Busselton	Upgrade Street lighting
2007/08	Albany	Install median island and improve line marking
2006/07	MRWA	Install mast arms & improve intersection
2007/08	Busselton	Seal shoulders & install audible edgelines, RRPM's & delineation
2008/09	Waroona	Seal Shoulders, install signs &RRPM's
2007/08	Gosnells	Install left turn slip lane, seagull island & improve priority signs
2006/07	South Perth	Install traffic control signals
2007/08	Wanneroo	Modify traffic control signals & intersection including right turn pockets
2006/07	Augusta Margaret River	Seal shoulders and seal to 6M
2006/07	Stirling	SBSPOT - MARANGAROO DR/THE AVENUE CONSTRUCT TRAFFIC CONTROL SIGNALS
2007/08	Augusta Margaret River	Install seagull in median, traffic median & improve sightlines

2006/07	Albany	Seal shoulders, delineation & edge lines
2007/08	Wanneroo	Extend seagull island & cons R/T lane in Alexander Dve
2006/07	Armadale	SBSPOT - FORREST RD/TOWNLEY ST INSTALL ANTI SKID TREATMENT AND IMPROVE SIGNS AND LINES
2007/08	Melville	Install pre-deflection to existing single lane roundabout
2006/07	Katanning	Provide kerb nib at Broome St, relocate centre markings & provide signage
2008/09	Waroona	Seal Shoulders, install signs &RRPM's
2007/08	East Fremantle	Extend median, install turn pocket, prune large tree and remove small tree
2007/08	Cottesloe	Install left turn lane
2007/08	Murray	Reconstruct superelevation
2007/08	Murray	Improve linemarking & advance warning & seal approaches
2006/07	Nedlands	Install roundabout
2008/09	South Perth	Construct Roundabout
2005/06	Bunbury	SBSPOT - INSTALL NEW STREET LIGHTING AND UPGRADE EXISTING LIGHTING
2005/06	Kalgoorlie / Boulder	Install Traffic Signals with right turn arrows with filter
2006/07	Armadale	Install Roundabout
2006/07	Stirling	Install pre-deflection nibs & modify alignment
2007/08	Cottesloe	Construct median island & reinforce priority Stop Sign
2007/08	Rockingham	Install anti skid treatment north & south
2006/07	Murray	Construct nibs & improve sight lines
2007/08	Dardanup	Install advisory signs, additional guide posts & RRPM's
2006/07	Cambridge	Install islands & improve signs
2006/07	Albany	Line marking & signing
2006/07	Albany	Install seagull in median, traffic median islands on approaches & improve lane delineation
2007/08	Albany	Install seagull in median, traffic median islands on approaches & improve lane delineation
2007/08	Murray	Widen seal on bends, remove vegetation & improve sight lines
2006/07	South Perth	Install pre-deflection nibs at roundabout
2006/07	Melville	Install left turn lane
2006/07	Kalgoorlie - Boulder	Provision of street lighting and median islands
2006/07	Albany	Provide line marking, signing & improve sight distance
2007/08	Cambridge	Improve priority Stop signs

2005/06	Cockburn	Improve Street Lighting 2.87 - 3.86 SLK
2006/07	Albany	Provide skid resistant treatment & line marking
2006/07	Albany	Provide delineation & edge lines
2008/09	Bassendean	Install median island Palmerston St; Improve / reinforces priority
2006/07	MRWA	Install mast arms
2007/08	Albany	Line marking & signing
2006/07	Cambridge	Install islands & improve signs
2006/07	Albany	Provide line marking & signing
2006/07	MRWA	Widen and seal shoulders
2006/07	MRWA	Signalise left turn slip onto Fwy south
2006/07	Albany	Extend median through intersection, line mark to improve definition between L slip & thru, improve/reinforce priority signs.
2006/07	MRWA	Install mast arms
2007/08	Joondalup	Install seagull island in median
2006/07	Kwinana	Install pre-deflection nibs at roundabout
2007/08	Wanneroo	Install Seagull island in Hester Ave
2007/08	Joondalup	Upgrade street lighting
2007/08	Fremantle	Install Lt only splitter island to the S approach leg of Stirling St; Pavement marking & signage
2006/07	MRWA	Install mast arms
2007/08	Manjimup	Extend median through intersection with Brockman St
2007/08	Albany	Install edgelines, improve signage
2006/07	Albany	Install pre deflection nibs, line marking & signing
2007/08	Busselton	Install painted right turn lane at intersection
2007/08	Joondalup	Install seagull island in median
2007/08	Stirling	Install left turn slip lane on north approach; install traffic islands and improve STOP Signs

APPENDIX C Intersection Treatment Codes

Code	Treatment Type
K1	Roundabout
K2	New traffic signal (no turn arrows)
K3a	New signal with turn arrows (with filter)
K3b	New signal with turn arrows (without filter)
K4a	Remodel signal - new right turn arrows (with filter)
K4b	Remodel signal - new right turn arrows (without filter)
K4c	Remodel signal - new ped phase
K4d	Remodel signal - reconstruct intersection (without right turn arrows but add turn pocket)
K4e	Remodel signal - reconstruct intersection (without right turn arrows without turn pocket)
K4f	Remodel signal - reconstruct intersection (with right turn arrows with filter)
K4g	Remodel signal - reconstruct intersection (with right turn arrows without filter)
K4h	Remodel signal - ban right turn movements during am & pm peak
K4i	Remodel signal - prevent right turn filter (for existing right turn arrows with filter)
K4j	Remodel signal - signalise left slip (from stop or give way control)
K5	Grade separation
K6a	Improve sight lines for right approach (eg clear verge)
K6b	Improve sight lines for opposing turns (eg clear median)
K6c	Improve sight lines for rear end crashes (eg remove crest or bend)
K6d	Improve sight lines for left approach (eg clear median on left adjacent approach)
K7	Street closure (one leg of cross)
K8	Street closure (close stem of Tee)
K9a	Skid resistant treatment to through movement only
K9b	Skid resistant treatment to through and right movement only
K9c	Skid resistant treatment to through and left movement only
K9d	Skid resistant treatment to left turn movement only (dedicated left)
K9e	Skid resistant treatment to whole approach
MR19	Line mark to improve lane definition between L slip & thru lane (select leg with slip lane)
MR20	Remove non-essential, non-frangible infrastructure from roundabout runoff zones
MR21	Change priority at 3-way itx - make old terminator the thru road (select new terminator)
K 12a	Ban right turns (physical barrier, eg. Islands)
K 10	Stagger cross intersection (right - left) (select staggered legs)
K 11	Improve/reinforce priority signs eg STOP
K 12	Ban right turns (at signalised and non-signalised intersections with signs)
K 13a	Ban U turns
K 13b	Ban left turns
K 14a	Road lighting to AS1158 V category where none previously (night crashes only)
K 14b	Road lighting to AS1158 P category where none previously (night crashes only)
K 14c	Flag lighting at remote intersections (night crashes only)
K 14d	Upgrade existing road lighting to AS 1158 (night crashes only)
K 15	Traffic median islands on approaches
K 16	Protected right turn lane (indented right turn island)
K 17	Painted right turn lane
K 18	Ban parking adjacent to intersection
K 19	Extend median through intersection (select thru legs)
K 20	Reduce radius on left turn sliplane
K 21	Masking reduction : Protected left turn lane in crossing street

MR1	Larger signal aspects
MR2	Seagull in median (select terminating leg of Tee)
MR3a	Indented left turn slip (give way, stop or signal control)
MR3b	Indented left turn slip (free slip - not controlled)
MR4	Mini roundabout
MR5	Advanced warning flashing lights
MR6a	Kerbside acceleration lane (select departure leg)
MR6b	Median acceleration lane (select departure leg)
MR12	Traffic signal: Overhead mast arms
MR13	LED traffic signals
MR17	Extend right turn pocket to mitigate rear end crashes in through lane
MR18	Extend left turn pocket to mitigate rear end crashes in through lane
MR23	Seal gravel terminating road flares at T junction with rural highway (select terminator)
MR24	Pre-deflection nibs at existing single-lane roundabout
MR25	Pedestrian refuge nibs
MR26	Remove non-frangible hazards from within clear zone
MR27	Improve "over right shoulder" sight distance for peds (select leg behind ped)

Note: Table taken from MRWA Road Safety Section (Traffic and Safety Branch), August 2014

Road Section and Non-Intersection Treatment Codes

Code	Treatment Type
S 1	Median on existing road
S 2	Pedestrian refuge
S 3	Pedestrian crossing (zebra)
S 4	Pedestrian overpass
S 5	Pedestrian signals (midblock)
S 6	Pedestrian crossing lighting
S 7a	Road lighting to AS1158 V category where none previously (night crashes only)
S 7b	Road lighting to AS1158 P category where none previously (night crashes only)
S 7c	Upgrade existing road lighting to AS 1158 (night crashes only)
S 8a	Clearway, parking bans (time specific) (left side)
S 8b	Clearway, parking bans (time specific) (right side on one way streets)
S 9	Indented right turn island
S 10	Painted turn lanes
S 11	Roadside hazards – Remove
S 12	Safety barrier
S 13	Skid resistant treatment
S 14	Seal shoulder
S 15	Advisory speed sign on curves
S 16	Delineation
S 17	Edgelines
S 18	Reconstruct superelevation on curve
S 19	Climbing lane [overtaking lane]
S 20	Signs (rail crossing)
S 21	Flashing lights [rail crossing]
S 22	Barriers/gates [rail crossing]
S 23	Bridge/overpass [rail crossing]
MR7	New Shared Path
MR8	Upgrade Existing Footpath to Shared Path
MR9	Tactile edgelines
MR10	Raised pavement markers
MR14	Seal <5.5m width to gravel road
MR15	Seal >=5.5m width to gravel road
MR16	Fencing on open road (Hit animal or swerve to avoid animal crashes only)
MR27	Truck rest area on rural highway (not within 15km of another rest area)
MR28	Install bus embayment

Note: Table taken from MRWA Road Safety Section (Traffic and Safety Branch), August 2014

APPENDIX D CASUALTY CRASH REDUCTIONS

Area	No. of Sites	No. of Crashes before treatment	No. of Crashes after treatment	Pre – exposure data (months)	Post-exposure data (months)	Estimate (β)	Standard Error	Probability 0<p<1	95% CI-Lower	95% CI Upper	Casualty Crash Reduction (%)**
Whole program	158	827	630	60	60	-0.272	0.024	<0.001	-0.319	-0.224	23.8
All Metropolitan Sites	106	714	550	60	60	-0.261	0.026	<0.001	-0.313	-0.209	23.0
All Rural Sites	52	113	80	60	60	-0.345	0.076	<0.001	-0.495	-0.196	29.3
Broad Categories											
Intersection Treatments	106	574	361	60	60	-0.464	0.030	<0.001	-0.522	-0.405	37.1
• Metro	83	536	341	60	60	-0.452	0.032	<0.001	-0.514	-0.390	36.4
• Rural	23	38	20	60	60	-0.642	0.183	<0.001	-1.001	-0.283	47.4
Road Section and Non Intersection Treatment	37	193	217	60	60	0.117	0.035	0.001	0.048	0.186	-12.4
• Metro	8	118	157	60	60	0.286	0.042	<0.001	0.202	0.369	-33.0
• Rural	29	75	60	60	60	-0.223	0.083	0.007	-0.385	-0.061	20.0
Treatment Types											
All Roundabouts	16	27	16	60	60	-0.523	0.288	0.069	-1.087	0.041	40.7
• Metro	14	27	15	60	60	-0.588	0.299	0.050	-1.174	0.001	44.4
• Rural	2	0	1	60	60	8.000	54.61	0.884	-99.028	115.028	Convergence not achieved
Seal shoulder	17	35	20	60	60	-0.560	0.189	0.003	-0.930	-0.189	42.9
Skid resistant treatment	6	66	36	60	60	-0.606	0.087	<0.001	-0.777	-0.435	45.5
Improve priority signs	3	6	3	60	60	-0.693	0.707	0.327	-2.079	0.693	50.0*
Traffic islands on approach	23	62	32	60	60	-0.661	0.109	<0.001	-0.875	-0.448	48.4
Indented right island	5	17	3	60	60	-1.734	0.535	0.001	-2.784	-0.685	82.4
Extend median through intersection	2	3	2	60	60	-0.405	0.512	0.428	-1.408	0.597	33.3*
Protected left turn lane	10	39	21	60	60	-0.619	0.120	<0.001	-0.855	-0.383	46.2
Seagull island	3	11	5	60	60	-0.788	0.505	0.119	-1.778	0.202	54.5*

Left turn slip	4	28	18	60	60	-0.442	0.121	<0.001	-0.679	-0.204	35.7
Traffic signal: overhead mast arms	4	79	60	60	60	-0.275	0.119	0.021	-0.508	-0.042	24.1
Extend right turn pocket	5	56	28	60	60	-0.693	0.064	<0.001	-0.819	-0.567	50.0
Line marking	5	8	2	60	60	-1.386	0.821	0.092	-2.996	0.224	75.0

- Negative casualty crash reductions indicates an increase
- Some T codes are a combination of several T codes. The T code used is based on the primary treatment given at the site
- *Reductions that are not statistically significant are indicated with an asterisk
- **Includes fatality, hospitalisation, and injury crashes

APPENDIX E ALL CRASH REDUCTIONS

Area	No. of Sites	No. of Crashes before treatment	No. of Crashes after treatment	Pre exposure (months)	Mean post exposure (months)	Estimate (β)	Standard Error	Probability 0<p<1	95% CI - Lower	95% CI Upper	All Crash Reduction (%)**
Whole program	158	4024	3483	60	60	-0.144	0.007	<0.001	-0.159	-0.130	13.5
All Metropolitan Sites	106	3497	3037	60	60	-0.141	0.008	<0.001	-0.157	-0.125	13.2
All Rural Sites	52	527	446	60	60	-0.167	0.021	<0.001	-0.209	-0.125	15.4
Broad Categories											
Intersection Treatments	106	2587	1923	60	60	-0.230	0.011	<0.001	-0.317	-0.276	25.7
Metro	83	2370	1746	60	60	-0.305	0.011	<0.001	-0.328	-0.283	26.3
Rural	23	217	177	60	60	-0.204	0.034	<0.001	-0.270	0.138	18.4
Road Section and Non Intersection Treatment	37	1062	1249	60	60	0.162	0.009	<0.001	0.143	0.181	-17.6
Metro	8	752	980	60	60	0.265	0.011	<0.001	0.244	0.286	-30.3
Rural	29	310	269	60	60	-0.142	0.027	<0.001	-0.195	-0.088	13.2
Treatment Types											
All Roundabouts	16	137	81	60	60	-0.526	0.124	0.001	-0.769	-0.282	40.9
Metro	14	116	65	60	60	-0.579	0.152	0.001	-0.877	-0.281	44.0
Rural	2	21	16	60	60	-0.272	0.070	0.001	-0.409	-0.135	23.8
Seal shoulder	17	117	65	60	60	-0.588	0.071	<0.001	-0.727	-0.449	44.4
Skid resistant treatment	6	378	194	60	60	-0.667	0.047	<0.001	-0.759	-0.575	48.7
Improve priority signs	3	24	17	60	60	-0.345	0.375	0.358	-1.081	0.391	29.2*
Traffic islands on approach	23	211	131	60	60	-0.477	0.037	<0.001	-0.549	0.405	37.9
Indented right island	5	58	25	60	60	-0.841	0.132	<0.001	-1.101	-0.582	56.9
Extend median through intersection	2	20	13	60	60	-0.431	0.067	<0.001	-0.561	-0.300	35.0
Protected left turn lane	10	165	119	60	60	-0.327	0.071	<0.001	-0.465	-0.188	27.9
Seagull island	3	58	44	60	60	-0.276	0.027	<0.001	-0.330	-0.222	24.1
Left turn slip	4	152	90	60	60	-0.524	0.095	<0.001	-0.710	-0.338	40.8

Traffic signal: overhead mast arms	4	418	342	60	60	-0.201	0.008	<0.001	-0.217	-0.184	18.2
Extend right turn pocket	5	260	229	60	60	-0.127	0.017	<0.001	-0.161	0.093	11.9
Line marking	5	45	35	60	60	-0.251	0.126	0.046	-0.499	-0.004	22.2

- Negative crash reductions indicates an increase
- Some T codes are a combination of several T codes. The T code used is based on the primary treatment given at the site
- Reductions that are not statistically significant are indicated with an asterisk
- *Includes all crashes –fatalities, hospitalisation, injuries and property damage only crashes

APPENDIX F ECONOMIC EVALUATION OF THE STATE BLACK SPOT PROGRAMS IN RELATION TO CASUALTY CRASH REDUCTION IN WESTERN AUSTRALIA

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Whole program	16 688 597	73 820 608	57 132 011	4.4
All Metropolitan Sites	10 888 353	51 541 230	40 652 877	4.7
All Rural Sites	5 800 243	22 279 368	16 479 125	3.8

Note that figures do not add up due to (i) differences in the mean length of the treatment period for the metropolitan and rural programs and (ii) rounding errors.

APPENDIX G SENSITIVITY ANALYSIS FOR THE ECONOMIC EVALUATION OF THE STATE BLACK SPOT PROGRAM IN RELATION TO CASUALTY CRASH REDUCTION ON WESTERN AUSTRALIA

Area	PV of Total Costs ($)	PV of Crash Cost Savings ($)	NPV ($)	BCR
Base case				
Discount rate 5% Treatment life 15 yrs	16 688 597	73 820 608	57 132 011	4.4
Sensitivity analysis				
Discount rate				
• 3% (15 years)	16 816 338	83 287 198	66 470 860	5.0
• 8% (15 years)	16 537 394	62 615 261	46 077 867	3.8
Treatment life				
• 10 years (5%)	16 433 518	54 917 219	38 483 701	3.3
• 20 years (5%)	16 888 452	88 631 462	71 743 010	5.2