A Preliminary Evaluation of the Effectiveness and Cost-Effectiveness of the State Black Spot Program in Western Australia, 2011-2012

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Title

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Abstract

This report presents the preliminary results of an evaluation of the State Black Spot sites which were treated during 2011 to 2012 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, injury and property damage only (PDO), and casualty crashes) at treated locations and the economic worth of these treatments.

One hundred and eight hazardous locations were treated throughout Western Australia at a cost of $16.7 million (excluding maintenance and operating costs). These treated sites consisted of 80 metropolitan and 28 rural sites. The results showed the State Program has been effective overall, reducing all reported crash frequencies by 11.4% and casualty crash frequencies by 25.3%. The estimated crash cost savings over the expected life of the treated sites were $34.4 million for all reported crashes. This resulted in an overall net cost savings to the community of $16.9 million after subtracting the capital costs of treating sites and maintenance and operating costs. The benefit cost ratio (BCR) across all treatment sites was 2.0. 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, the relatively short post treatment crash exposure period (average 26 months) or the treatment may genuinely have had no effect on road safety.

The preliminary results will 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 preliminary results of an evaluation of the State Black Spot treatments which were implemented during 2011 to 2012 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 casualty crashes and all reported crashes) at treated locations and the economic worth of the treatments. It is anticipated that these preliminary 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 117 sites nominated for treatment as a 'black spot' in the 2011 to 2012 Black Spot Program based on crash frequency and BCR qualifying criteria. The final sample of 108 treated sites consisted of 80 metropolitan and 28 rural sites. Of these, 72 were intersection sites and 36 were road section or non-intersection sites. One site was removed as it had no reported crashes in the previous five year period prior to treatment. The average length of follow-up exposure crash data post treatment for all treated sites was 26 months.

The results found that the Program has been effective overall, reducing all reported crash frequencies by 11.4% and casualty crash frequencies by 25.3%. Effectiveness of the treatments implemented in the Program and evaluated in this study needs to be interpreted with caution due to relatively short post-treatment exposures. The significance of effectiveness/non-effectiveness could well be attributed to randomness of the events, regression to the mean, change in traffic volumes, or other uncontrolled factors.

Summary of Results of Treatment Effect on All and Casualty Crash Reduction in the State Black Spot Program in 2011 – 2012, Western Australia

Area	Estimate (β)	Standard Error	Probability 0<p<1	Crash Reductio (%)
All Crashes*				
Whole program	-0.121	0.015	<0.001	11.4
All metro sites	-0.091	0.015	<0.001	8.7
All rural sites	-0.382	0.144	0.008	31.8
Casualty Crashes**				
Whole program	-0.292	0.045	<0.001	25.3
All metro sites	-0.277	0.044	<0.001	24.2
All rural sites	-0.386	0.283	0.173	32.0†

**Includes all crashes-fatality, hospitalisation, injury and property damage major and minor crashes*
***Includes fatal, hospitalisation, and injury crashes*
†Crash reduction is not statistically significant

Treatment Type

"*Roundabouts*" and "*modify signal"* were highly effective in reducing the frequency of both all reported crashes and casualty crashes with a 48% and 15% reduction in all crashes ($p<0.001$) and 74% and 30% reduction in casualty crashes ($p<0.001$), respectively. "*Protected left turn lane"* significantly reduced all reported crashes by 40% ($p<0.001$) and casualty crashes by 58% ($p=0.020$). There was also strong evidence that "*edgelines*" reduced all reported crashes by 44% ($p=0.005$) and "*extend left turn pocket*" reduced casualty crashes by 59% ($p=0.002$). There was weak evidence that "*seal shoulder*" and "*skid resistant treatments*" reduced all reported crashes by 50% and 33% ($p=0.033$) and "*left turn slip*" , although not statistically significant, seems to have reduced casualty crashes by 65% ($p=0.091$).

"*Seagull islands*" significantly increased both all reported crashes and casualty crashes by 77% and 87% respectively ($p<0.001$).

There was no statistical evidence that *"new traffic signal"*, "*improve priority signs*", "*improve road lighting*" and "*delineation*" could affect the frequency (either increase or decrease) of both all reported and casualty crashes during the study period.

Location

There were a total of 80 sites treated in the metropolitan area. Overall, these treatments showed a very significant 9% ($p<0.001$) reduction for all reported crashes and a very significant 24% ($p<0.001$) reduction for casualty crashes in the metropolitan area.

There were a total of 28 sites treated in rural areas. There was strong evidence that these treatments have been effective overall, reducing all reported crash frequencies by 32% ($p=0.008$).

Broad Treatment Type

It must also be noted that the treatments analysed were heavily weighted towards intersection treatments. This evaluation demonstrated the Black Spot Program was effective for reducing the frequency of **all reported crashes** as well as **casualty crashes** at both "*intersection treatment*" sites and "*road section or non-intersection*" sites within the metropolitan area. On the other hand, the effectiveness of the program in reducing **all reported crashes** within rural areas was mainly due to "*road section or non-intersection treatments*" rather than "*intersection treatments*". However, neither of the two broad treatment types was significantly effective in reducing **casualty crashes** within rural areas.

Economic Analysis

The reduction in the number of reported crashes were estimated to reduce crash costs by $34.4 million over the expected life of the treated sites, with all of this reduction attributable to a reduction in casualty crashes. After accounting for program costs of $17.5 million (including maintenance and operating costs), the net cost savings to the community from the Black Spot Program were estimated at $16.9 million. Expressed as a benefit cost ratio (BCR), the net economic worth of the State Black Spot Program across all treatment sites was 2.0. Sites treated in the metropolitan areas had a better rate of return than those in rural areas, with a BCR of 2.9 compared with 1.2 in the rural area.

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 of Cost Savings	Benefit Cost Ratio
Whole program	17 481 165	34 379 318	16 898 153	2.0
All Metro Sites	10 004 399	29 450 177	19 445 778	2.9
All Rural Sites	7 476 766	9 068 718	1 591 952	1.2

Limitation of the Study

A major limitation of the study was that the exposure period post treatment was not long enough (recommended three to five years post treatment) to provide valid and conclusive results. The average length of post-crash data for treated sites was 26 months (range from 12 months to 44 months) which was well below the recommended three years minimum post treatment crash data. Consequently, the results were inconclusive for most 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.

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:

- It is strongly recommended that this evaluation be repeated when there is sufficient post-crash exposure data with five years available.

- 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 "*new traffic signal*", "*improve/reinforce priority signs*", "*improve road lighting*" and "*delineation*".
- Further in-depth evaluation of "*seagull islands*" treatments that have produced inconsistent result in the current State Black Spot evaluation compared with the results reported in previous evaluations.

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

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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 2011 to 2012 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 preliminary results of this study will provide Main Roads, WA and other responsible agencies with reliable and objective information for future investments in developing road safety infrastructure 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 crashes and all reported crash frequencies (include fatalities, hospitalisation, medical treatment and property damage only PDO crashes) at sites treated under the State Black Spot Program for the years 2011 to 2012. 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 Western Australian State Black Spot Program defines Black spots as locations with a high incidence of all crash types. The 2011-2012 State Black Spot Program provided funding of $16.7 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. A Black Spot 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. 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, 2009):

- 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 seal shoulder and 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 (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 at least 9 months 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. 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 of each treatment;
- 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 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 Spots 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 does not need to 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-

treatment crash data and at least 9 months 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.

2.5.3 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 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 initial capital outlay was unknown for one site, and this site was allocated the mean treatment cost of $142,346. Treatment type was unknown for 9 sites, with zero operating and maintenance costs assumed for the sites. These sites were included only in the total sample size to assess the overall effectiveness of the Program.

The cost savings from fewer road crashes at treated sites were calculated using the road crash severity costs for Western Australia as provided by Main Roads WA, based on the Willingness To Pay (WTP) approach of estimating crash severity costs. These costs include the human costs of treating injuries plus any associated productivity losses and loss of functioning, vehicle repair and related costs, and general crash costs. Excluded are road user costs such as vehicle operating costs and travel time. Applying certain treatments may change the travel time on particular routes as well as vehicle operating costs and maintenance costs. However, to include this type of analysis in calculating the benefits and costs of treated sites requires extensive data and for this reason studies evaluating the cost-effectiveness of 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	7,648,989
Hospital admission	351,226
Medical Treatment	77.395
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 7 to 0, 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 between "*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 Dupont (2002) and 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 12) 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 –

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

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

where B_i = benefits in year i resulting from savings in road crash costs

C_i = 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 for all reported crash 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 exposure crash data 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 117 sites nominated for treatment as a "Black Spot" in the 2011 to 2012 Black Spot Program. The final sample of 108 treated sites consisted of 80 metropolitan and 28 rural sites of which 72 were intersection sites and 36 were road section or non-intersection sites. One site was removed as it had no reported crashes in the previous five year period prior to treatment. The follow-up exposure crash data post treatment for all treated sites had an average length of 26 months with a standard deviation of 6.5 months, a minimum of 12 months and a maximum of 44 months.

Table 3.1 shows the effect of the Black Spot Program for all reported crashes (fatal, hospitalisation, injury and PDO crashes) and Table 3.2 shows the effect on 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 value for β indicates that all reported police crash rate (includes fatality, hospitalisation and injury crashes and PDO) 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 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 $p\geq0.1$. This was consistent with the criteria adopted by the National Black Spot Program evaluation.

The overall effect of the Black Spots sites treated during 2011 to 2012 for all crash severities showed a very strong reduction of 11.4% ($p<0.001$) for all crashes (see Table 3.1) and a very strong reduction of 25.3% ($p<0.001$) for casualty crashes (see Table 3.2).

Table 3.1 State Black Spot Treatment Effect on All Crash Reduction in Western Australia, 2011 – 2012

Area	Estimate (β)	Standard Error	Probability 0<p<1	All Crash Reduction (%)**
Whole program	-0.121	0.015	<0.001	11.4
All Metropolitan Sites	-0.091	0.015	<0.001	8.7
All Rural Sites	-0.382	0.144	0.008	31.8
Broad Categories				
Intersection Treatments	-0.076	0.015	<0.001	7.3
• Metro	-0.060	0.014	<0.001	5.8
• Rural	-0.184	0.208	0.376	16.8*
Road Section and Non Intersection Treatment	-0.234	0.056	<0.001	20.9
• Metro	-0.145	0.061	0.017	13.5
• Rural	-0.598	0.214	0.005	45.0
Treatment Types				
All Roundabouts	-0.651	0.114	<0.001	47.8
• Metro	-0.814	0.126	<0.001	55.7
• Rural	0.157	0.173	0.363	-17.0*†
Seal shoulder	-0.694	0.325	0.033	50.1
Modify signals	-0.161	0.028	<0.001	14.9
Skid resistant treatment	-0.395	0.185	0.033	32.7
Protected left turn lane	-0.506	0.130	<0.001	39.7
Seagull island	0.568	0.022	<0.001	-76.5†
Left turn slip	0.010	0.334	0.976	-1.0*†
Extend left turn pocket	-0.176	0.156	0.258	16.2*
Edgelines	-0.578	0.207	0.005	43.9
New traffic signal	-0.250	0.350	0.475	22.1*
Improve priority signs	0.073	0.097	0.452	-7.6*†
Improve road lighting	-0.206	0.163	0.205	18.6*
Delineation	0.323	0.449	0.473	-38.1*†

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

Table 3.2 Black Spot Treatment Effect on Casualty Crash Reduction in Western Australia, 2011-2012

Area	Estimate (β)	Standard Error	Probability 0<p<1	Casualty Crash Reduction (%)**
Whole program	-0.292	0.045	<0.001	25.3
All Metropolitan Sites	-0.277	0.044	<0.001	24.2
All Rural Sites	-0.386	0.283	0.173	32.0*
Broad Categories				
Intersection Treatments	-0.260	0.045	<0.001	22.9
• Metro	-0.252	0.044	<0.001	22.3
• Rural	-0.343	0.464	0.460	29.0*
Road Section and Non Intersection Treatment	-0.539	0.171	0.002	41.7
• Metro	-0.625	0.203	0.002	46.5
• Rural	-0.373	0.338	0.269	31.1*
Treatment Types				
All Roundabouts	-1.339	0.389	0.001	73.8
• Metro	-1.670	0.457	<0.001	81.2
• Rural	0.122	0.569	0.830	-12.9*†
Seal shoulder	-0.397	0.320	0.215	32.7*
Modify signals	-0.353	0.105	0.001	29.7
Skid resistant treatment	-0.624	0.615	0.310	46.4*
Protected left turn lane	-0.860	0.369	0.020	57.7
Seagull island	0.627	0.042	<0.001	-87.3†
Left turn slip	-1.056	0.625	0.091	65.2*
Extend left turn pocket	-0.880	0.280	0.002	58.5
Edgelines	-0.592	0.402	0.141	44.7*
New traffic signal	-1.018	0.848	0.230	63.9*
Improve priority signs	-0.401	0.245	0.101	33.1*
Improve road lighting	-1.116	0.811	0.168	67.2*
Delineation	0.125	0.989	0.899	-13.4*†

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

3.1.1 Analysis by Broad Treatment Categories

An evaluation of the effectiveness by **broad treatment categories** (intersection and road section/non-intersection treatment) on all reported and casualty crashes was undertaken. There were a total of 72 sites which received a treatment at an **intersection**. There was very strong evidence of a 7.3% reduction in the number for all crashes ($p<0.001$) and a 22.9% reduction in casualty crashes ($p<0.001$). The most frequently used treatments at an intersection were: roundabouts (n=16), modify signals (n=15), and improve/reinforce priority signs (n=14).

There were a total of 36 sites which received a treatment at **road section and non-intersection treatment**. The decrease in the number of all reported crashes (20.9%) was significant ($p<0.001$), as well as the decrease in the number of casualty crashes (41.7%, $p=0.002$). The most frequently used treatments at road sections and non-intersection sites were: improved route lighting (n=13), and seal shoulder (n=7).

3.1.2 Analysis by Specific Treatment Type

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

"*Roundabouts*" were highly effective in reducing the frequency of both all reported crashes and casualty crashes with 47.8% ($p<0.001$) and 73.8% ($p=0.001$) reductions respectively. Other treatments that were very effective in significantly reducing all reported crashes included:

- "*seal shoulder*" by 50.1%;
- "*edgelines*" by 43.9%;
- "*protected left turn lane*" by 39.7%;
- "*skid resistant treatment*" by 32.7%; and
- "*modify signal"* by 14.9%.

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

- "*left turn slip*" by 65.2%;
- "*extend left turn pocket*" by 58.5%;
- "*protected left turn lane*" by 57.7%; and
- "*modify signal"* by 29.7%.

"*Seagull island*" significantly increased both all reported crashes and casualty crashes by 76.5% and 87.3% ($p<0.001$).

There was no statistical evidence that *"new traffic signal"*, "*improve priority signs*", "*improve road lighting*" and "*delineation*" could affect the frequency (either increase or decrease) of both all reported and casualty crashes during the study period.

3.1.3 Analysis by Location

There were a total of 80 sites treated in the metropolitan area. Overall, there was strong evidence that these treatments have been effective overall, reducing all reported crash frequencies by 8.7% ($p<0.001$) and casualty crashes by 24.2% ($p<0.001$).

There were a total of 28 treatment sites located in rural areas. These treatments showed a significant 31.8% ($p=0.008$) reduction for all reported crashes.

A breakdown of broad treatment categories by location found:

- a 5.8% reduction for all reported crashes ($p<0.001$) and a 22.3% reduction for casualty crashes ($p<0.001$) at **intersection** treatment sites within the **metropolitan area**;
- a 13.5% reduction for all reported crashes ($p=0.017$) and a 46.5% reduction for casualty crashes ($p=0.002$) at **road section or non-intersection** treatment sites within the **metropolitan area**; and
- a 45.0% reduction ($p=0.005$) for all reported crashes at **road section or non-intersection** treatment sites within **rural areas**.

There was no statistical significance ($p\geq0.1$) in the reduction of casualty crashes at **road section or non-intersection** sites within **rural areas**, or in the reduction of all

reported crashes or casualty crashes at **intersection** sites within **rural areas**. It would appear that the effectiveness of the Black Spot Program in reducing all reported crashes within **rural areas** was mainly due to **road section or non-intersection** treatments rather than **intersection** treatments.

An analysis of the differential effect of **roundabout** treatments for both the metropolitan and rural areas was also undertaken. A very significant reduction of 55.7% for all reported crashes ($p<0.001$) and an 81.2% reduction for casualty crashes ($p<0.001$) were observed at the **roundabout** treatment sites within the metropolitan area. On the other hand, there was no statistically significant reduction in crashes at the **roundabout** treatment sites within rural areas.

3.2 Economic Evaluation of the State Black Spot Program

Table 3.3 presents the results of the economic evaluation of the 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 $34.4 million for all reported crashes, all of which 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 $16.9 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 2.0, which indicates benefits in the form of cost savings to the community of $2.00 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 2.9 compared with 1.2 in rural areas.

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 $21.2 million and the BCR to 2.2. An expected treatment life of 20 years increased the NPV to $23.6 million and the BCR to 2.3.

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	17 481 165	34 379 318	16 898 153	2.0
All Metropolitan Sites	10 004 399	29 450 177	19 445 778	2.9
All Rural Sites	7 476 766	9 068 718	1 591 952	1.2

**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.*

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				
Discount rate 5% Treatment life 15 yrs	17 481 165	34 379 318	16 898 153	2.0
Sensitivity analysis				
Discount rate				
• 3% (15 years)	17 587 173	38 788 047	21 200 874	2.2
• 8% (15 years)	17 355 687	29 160 834	11 805 147	1.7
Treatment life				
• 10 years (5%)	17 269 483	25 575 744	8 306 261	1.5
• 20 years (5%)	17 647 019	41 276 954	23 629 935	2.3

4. DISCUSSION

This report presents the results of the evaluation of the State Black Spot treatments in Western Australia in terms of its effectiveness in reducing the frequency for all reported crashes, casualty crashes and associated costs from 2011 to 2012. The analysis found the program to be effective overall in reducing the frequency of all reported crashes by 11.4% and casualty crashes by 25.3% for the treated sites under the Black Spot Program.

A number of decisions were made regarding the analysis. The study examined the 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 a few specific treatment types such as "*roundabouts*", "*protected left turn lane*", and "*modify signals*" that were highly successful in reducing **all reported** and **casualty** crash frequency. Roundabouts continue to be one of the most effective treatments reducing all reported and casualty crashes by 47.8% and 73.8% respectively. This is consistent with previous evaluations of the Black Post Program undertaken in WA as well as the evaluation of the National Black Spot Program (Meuleners et al. 2005, Meuleners & Hendrie 2008, BITRE 2012).

Other types of treatment that showed statistically significant reductions in the number of **all reported** crashes including "*seal shoulder*", "*edgelines*" and "*skid*

resistant treatment". Evidence also showed a significant reduction in the number of **casualty** crashes for the treatment "*left turn slip*" and "*extend left turn pocket*".

"*Skid resistant treatment*" was found to reduce all reported crashes by 32.7%. 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 crashes associated with the treatment (Meuleners et al. 2005, Meuleners & Hendrie 2008). The reduction in casualty crashes, however, was not statistically significant for the 2011 to 2012 sites receiving such treatment, contrary to the reductions reported in previous studies.

The crash increase or reduction associated with "*improve priority signs*" was not statistically significant. However, this could be due to the small number of sites 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*".

"*Seagull islands*" significantly increased all reported and casualty crashes in this evaluation, which is inconsistent with results reported in previous Black Spot evaluations undertaken in Western Australia. A small sample size (n=2) and/or inadequate exposure time post treatment (21 months) might have produced the misleading result.

It must also be noted that the treatments analysed were heavily weighted towards "*intersection treatments*". The evaluation demonstrated the Black Spot Program was effective for reducing the frequency of all reported crashes as well as casualty crashes at both "*intersection treatment*" sites and "*road section or non-intersection*" sites within the metropolitan area. On the other hand, the effectiveness of the

program in reducing all reported crashes within rural areas was mainly due to "*road section or non-intersection treatments*" rather than "*intersection treatments*".

The analysis yielded inconclusive results in terms of both **all reported** and **casualty** crash reduction for treatments such as "*new traffic signal"*, "*improve priority signs*", "*improve road lighting*" and "*delineation*". It must be noted that a failure to reject the null hypothesis of no difference does not necessarily mean that the treatment countermeasure was ineffective. There are several possible 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 would have 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 such as "*new traffic signal"* (n=2), "*extend left turn pocket*" (n=2), "*ban right turns*" (n=1), "*seal gravel road*" (n=1), and "*new shared path*" (n=1).

An important consideration in this analysis is the short exposure period available post treatment even if the treatments are working well. The average length of follow up exposure crash data post treatment for all treated sites was 26 months with a minimum of 12 months and a maximum of 44 months. This was not the recommended three to five years of crash data needed for this type of analysis (Nicholson, 1986).

The Western Australian 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 $16.9 million and 2.0 respectively. Sites treated in the metropolitan area had a better rate of return than those in rural areas, with a BCR of 2.9 for the former compared with 1.2 for the latter. This is also consistent with previous evaluations of the Western Australian 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 site 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 11% and is estimated to reduce crash costs by $34.4 million over the expected life of the treated sites. After accounting for project costs of $17.5 million (including maintenance and operating costs), the net cost savings to the community from the Black Spot Program were estimated as $16.9 million. This is the equivalent of a BCR of 2.0.

Limitations to the study include relatively short exposure period post treatment (recommended three to five years post treatment) and the lack of a suitable control treatment site to provide valid and conclusive results. The average length of post-crash data for treated sites was 26 months which was well below the recommended three years minimum exposure data. Consequently, the results might have been 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 such as "*seagull islands*", "*new traffic signal*", "*improve priority signs*", "*improve road lighting*" and "*delineation*".

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. 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 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 "*new traffic signal*", "*improve priority signs*", "*improve road lighting*" and "*delineation*".
- 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.

It is also recommended that this evaluation be repeated when there is sufficient post-crash exposure data of at least three and preferably five years available. Future evaluations should also include traffic flow data and the use of appropriate control sites if available.

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. 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 developed.

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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
2007/2008	KALGOORLIE-BOULDER	Improve intersection - Install seagull island
2008/2009	KALGOORLIE-BOULDER	Forrest St - Construct roundabout
2009/2010	KALGOORLIE-BOULDER	Install median islands and dedicated right turning lane Boulder Rd south into Oberthur st
2009/2010	KALGOORLIE-BOULDER	Install roundabout
2010/2011	KALGOORLIE-BOULDER	Intall traffic islands and turn lane
2010/2011	KALGOORLIE-BOULDER	Install nibs and traffic islands
2011/2012	KALGOORLIE-BOULDER	Construct Roundabout
2011/2012	KALGOORLIE-BOULDER	Median Islands & Lighting Upgrade
2011/2012	KALGOORLIE-BOULDER	Median Islands & Nib
2011/2012	COOLGARDIE	Reseal & Pavement Marking
2011/2012	COOLGARDIE	Widen Gravel Pavement
2009/2010	NEDLANDS	Modify TCS to LED Lanterns
2009/2010	COCKBURN	Reduce radius of left turn kerb; install stop or give way sign; install skid treatment to all approaches
2009/2010	ROCKINGHAM	Masking reduction; install protected left turn lane in crossing St and improve sight lines
2009/2010	GOSNELLS	Upgrade existing street lighting to AS 1158
2009/2010	MELVILLE	Install Roundabout
2009/2010	ARMADALE	Install Lighting to AS 1158 Category V
2009/2010	JOONDALUP	Install pre-deflection to Mullaloo Dr approach legs and anti skid treatment
2009/2010	CANNING	Install roundabout
2009/2010	CAMBRIDGE	Modify traffic control signals and add right turn pockets
2010/2011	ARMADALE	Upgrade Street Lighting
2009/2010	JOONDALUP	Install Median and Intersection Islands
2010/2011	SUBIACO	Lengthen Left Slip Lane; Reduce Radius on Left Turn
2010/2011	JOONDALUP	Extend right and left turn pockets
2010/2011	MELVILLE	Construct roundabout

2010/2011	MELVILLE	Install new lighting on existing power poles and install pedestrian refuge islands
2010/2011	KALAMUNDA	Install pre deflection nibs
2010/2011	SWAN	Construct roundabout
2010/2011	SWAN	Install indented left turn slip lane; painted right turn lane and improve priority signs
2010/2011	COCKBURN	Install left lane on Wellard St with splitter island. Install giveway / stop signs on new splitter island.
2010/2011	MELVILLE	Install median island to reinforce stop control
2010/2011	SWAN	Install skid resistant treatment
2010/2011	SWAN	Install indented left turn slip lane; improve / reinforce prority signs.
2010/2011	MELVILLE	Install median islands
2010/2011	WANNEROO	Install protected left turn lane in Hughie Edwards Dr and a seagull island at the intersection
2010/2011	ARMADALE	Install Edge line
2010/2011	SUBIACO	Construct roundabout
2010/2011	CAMBRIDGE	Install Intersection Islands; Reinforce Priority with Central Sign; consider change to Stop Sign
2010/2011	GOSNELLS	Upgrade Street Lighting
2010/2011	CANNING	Install Median Island & Reinforce Priority Stop Sign
2010/2011	CANNING	Install Median Island & Reinforce Priority Stop Sign
2010/2011	COTTESLOE	Install Speed Platforms
2010/2011	GOSNELLS	Upgrade Street Lighting
2010/2011	COTTESLOE	Install Pre-deflection Nibs
2010/2011	SUBIACO	Install mini roundabout
2010/2011	GOSNELLS	Upgrade Existing Road Lighting
2010/2011	ARMADALE	New street lighting
2010/2011	GOSNELLS	Upgrade Existing Road Lighting
2010/2011	VICTORIA PARK	Install Islands to Ban Right Turns
2010/2011	ARMADALE	Install Median Island
2010/2011	ARMADALE	Install Street Lighting
2010/2011	SUBIACO	Construct Roundabout
2010/2011	SUBIACO	Construct Roundabout
2010/2011	CANNING	Construct Roundabout
2010/2011	ARMADALE	Construct roundabout
2010/2011	ARMADALE	Traffic calming installations - upgrade intersections

2010/2011	SUBIACO	Install Median Island & Reinforce Priority of Interseciton
2010/2011	CAMBRIDGE	Install Median Islands & Reinforce Priority Signs
2010/2011	NEDLANDS	Install Median Island & Reinforce Priority Signs
2010/2011	BELMONT	Construct Roundabout
2010/2011	ARMADALE	Install protected right turn pocket and median island at railway crossing between Railway Ave and Streich Ave
2010/2011	GOSNELLS	Install Pre-deflection Nibs @ Existing Single Lane Roundabout
2010/2011	NEDLANDS	Install LT Lane; Reduce Radius & Construct 70 degree Island
2010/2011	CLAREMONT	Modify TCS to LED Lanterns
2010/2011	CAMBRIDGE	Install LED Lanterns & Reduce Radius on LT Slip Lane
2010/2011	FREMANTLE	Construct TCS with right turn phase
2010/2011	STIRLING	Modify TCS to LED Lanterns
2010/2011	CANNING	Modification of traffic signal phasing at High Road/Metcalfe Rd, Lynwood with assicated civil works to accommodate a double diamond traffic signal phase
2010/2011	PERTH	Modify TCS to LED Lanterns
2010/2011	GOSNELLS	Upgrade Existing Street Lighting
2010/2011	GOSNELLS	Upgrade Existing Street Lighting
2010/2011	SUBIACO	Construct Roundabout
2010/2011	CAMBRIDGE	Install Right Turn Pocket & Seagull Island
2010/2011	SWAN	Apply Skid Treatment
2010/2011	CAMBRIDGE	Install Roundabout and Upgrade Lighting
2010/2011	COCKBURN	Install pre-deflection on all approaches
2011/2012	ARMADALE	New Road Markings
2011/2012	GOSNELLS	Install Pedestrian Refuge Island
2011/2012	GOSNELLS	Improve & Reinforce Priority Signs
2011/2012	GOSNELLS	Install Median Islands
2010/2011	GOSNELLS	Install median island and upgrade street lighting to AS 1158
2011/2012	KWINANA	Install Pre Deflection on North Approach
2011/2012	NEDLANDS	New street lighting
2011/2012	NEDLANDS	Install median and reinforce priority
2011/2012	NEDLANDS	New street lighting

2011/2012	MELVILLE	Construct Roundabout
2011/2012	MOSMAN	Upgrade Pavement Markings & Ban Parking to Improve Sight Lines
2011/2012	ROCKINGHAM	Install Median Island & Improve/Reinforce Priority Signage
2011/2012	WANNEROO	Install Seagull Island; Close Right turn Auxillary Lane & Construct Median Island
2011/2012	WANNEROO	install Median Island; Reinforce Give Way Priority; Upgrade Pedestrian Crossing
2011/2012	FREMANTLE	Modify Traffic Control Signals Extend Right Turn Pocket & Improve Pedestrian Facilities
2011/2012	JOONDALUP	Modify Traffic Control Signals to LED Lanterns
2011/2012	SUBIACO	Modify Traffic Control Signals LED Lanterns Upgrade
2011/2012	SUBIACO	Modify Traffic Control Signals LED Lanterns Upgrade
2011/2012	PERTH	Modify TCS LED Lanterns Upgrade
2011/2012	SUBIACO	Modify Traffic Control Signals LED Lanterns Upgrade
2011/2012	SUBIACO	Modify Traffic Control Signals LED Lanterns Upgrade
2011/2012	SOUTH PERTH	Install Anti Skid Treatment
2011/2012	STIRLING	Install Pre Deflection Nibs on Existing Single Lane Roundabout
2011/2012	STIRLING	Install Median Islands & Improve/Reinforce Priority
2011/2012	PERTH	Modify Traffic Control Signals LED Lanterns Upgrade
2006/2007	DONNYBROOK-BALINGUP	Seal shoulders & remove vegetation
2009/2010	HARVEY	Install Street Lighting between 0.00 and 1.06 SLK
2010/2011	WAROONA	Reconstruct and seal shoulders; remove vegetation; install advisory signs RRPM's and guideposts between 0.0 and 1.75 SLK
2010/2011	HARVEY	Recondition shoulders; remove roadside vegetation; install advisory signs and guideposts between 3.0 and 8.0 SLK
2010/2011	COLLIE	Remove roadside vegetation install advisory signs RRPM's and guideposts between 2.0 and 7.0 SLK
2010/2011	COLLIE	Seal shoulders remove roadside vegetation improve drainage install advisory signs RRPM's edgelines and guideposts between 1.0 and 4.0 SLK
2010/2011	BUSSELTON	Construct and seal shoulders install edgelines RRPM's and guideposts between 0.27 to 5.19 SLK
2010/2011	MANJIMUP	Install pre deflection nibs to single lane roundabout
2010/2011	BUSSELTON	Seal Gravel Road to 5.5m wide between 0.01 to 1.25 SLK
2010/2011	BUSSELTON	Seal Gravel Road 5.5m wide between 0.02 and 2.12 SLK
2011/2012	HARVEY	Construct and seal shoulders; install advisory signs on curves and install additional guideposts

		between 2.00 and 5.00 SLK
2011/2012	HARVEY	Construct and seal shoulders; install advisory signs on curves and install additional guideposts between 3.00 and 6.00 SLK
2011/2012	DARDANUP	Install additional guideposts between 0.00 and 3.39 SLK
2011/2012	WAROONA	Reconstruct shoulders; install advisory signs on curves install additional guideposts and clear roadside vegetation between 10.70 and 13.70 SLK
2011/2012	BUSSELTON	Install longitudinal edgelines and additional guideposts between 0.00 to 8.84 SLK
2011/2012	BUSSELTON	Install shared footpath between 9.84 and 11.92 SLK
2011/2012	CAPEL	Install centreline and improve advisory signage between 0.00 and 11.56 SLK
2011/2012	COLLIE	Widen seal to 7.0m wide; install additional guideposts and advisory signs on curves between 4.00 to 12.00 SLK
2011/2012	HARVEY	Construct and seal shoulders; install advisory signs and RRPMs on curves and install additional guideposts between 8.42 and 11.42 SLK
2012/2013	AUGUSTA-MARGARET RIVER	Install guide Posts between 6.21 and 9.15 SLK
2012/2013	AUGUSTA-MARGARET RIVER	Install Guide Posts between 1.31 and 6.75 SLK
2008/2009	BRIDGETOWN	seal shoulders and improve cureve camber for northbound (rifle range road)
2010/2011	MURRAY	Install traffic control signals
2011/2012	NORTHAM	EDGE LINES
2012/2013	CHITTERING/GINGIN	Widen formation and seal shoulders

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	117	506	171	60	25.79	-0.292	0.045	<0.001	-0.379	-0.204	25.3
All Metropolitan Sites	88	459	159	60	26.92	-0.277	0.044	<0.001	-0.363	-0.190	24.2
All Rural Sites	29	47	12	60	22.34	-0.386	0.283	0.173	-0.940	0.169	32.0*
Broad Categories											
Intersection Treatments	72	403	141	60	27.42	-0.260	0.045	<0.001	-0.348	-0.173	22.9
• Metro	62	386	136	60	27.93	-0.252	0.044	<0.001	-0.338	-0.166	22.3
• Rural	10	17	5	60	24.25	-0.343	0.464	0.460	-1.252	0.567	29.0*
Road Section and Non Intersection Treatment	36	92	22	60	22.55	-0.539	0.171	0.002	-0.873	-0.205	41.7
• Metro	18	63	15	60	23.87	-0.625	0.203	0.002	-1.022	-0.228	46.5
• Rural	18	29	7	60	21.22	-0.373	0.338	0.269	-1.035	0.289	31.1*
Treatment Types											
All Roundabouts	16	48	6	60	28.59	-1.339	0.389	0.001	-2.102	-0.576	73.8
• Metro	13	44	4	60	28.96	-1.670	0.457	<0.001	-2.565	-0.775	81.2
• Rural	3	4	2	60	26.99	0.122	0.569	0.830	-0.993	1.236	-12.9*†
Seal shoulder	7	18	4	60	20.83	-0.397	0.320	0.215	-1.024	0.230	32.7*
Modify signals	15	160	48	60	25.47	-0.353	0.105	0.001	-0.559	-0.146	29.7
Skid resistant treatment	4	11	3	60	30.74	-0.624	0.615	0.310	-1.829	0.581	46.4*
Protected left turn lane	3	13	3	60	32.24	-0.860	0.369	0.020	-1.584	-0.136	57.7
Seagull island	2	78	57	60	20.52	0.627	0.042	<0.001	0.546	0.709	-87.3†
Left turn slip	2	7	1	60	28.44	-1.056	0.625	0.091	-2.282	0.169	65.2*
Extend left turn pocket	2	14	2	60	28.95	-0.880	0.280	0.002	-1.428	-0.331	58.5
Edgelines	4	10	2	60	21.90	-0.592	0.402	0.141	-1.380	0.196	44.7*
New traffic signal	2	18	2	60	21.04	-1.018	0.848	0.230	-2.680	0.643	63.9*
Improve priority signs	14	42	14	60	28.78	-0.401	0.245	0.101	-0.881	0.078	33.1*
Improve road lighting	13	15	2	60	23.85	-1.116	0.811	0.168	-2.705	0.472	67.2*

Delineation	4	6	2	60	19.67	0.125	0.989	0.899	-1.812	2.063	-13.4*†

- 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 fatal, hospitalisation, and injury crashes only

† Negative crash reduction indicates an increase

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	117	2275	936	60	25.79	-0.121	0.015	<0.001	-0.151	-0.090	11.4
All Metropolitan Sites	88	2107	893	60	26.92	-0.091	0.015	<0.001	-0.120	-0.062	8.7
All Rural Sites	29	168	43	60	22.34	-0.382	0.144	0.008	-0.664	-0.101	31.8
Broad Categories											
Intersection Treatments	72	1801	777	60	27.42	-0.076	0.015	<0.001	-0.105	-0.046	7.3
• Metro	62	1734	754	60	27.93	-0.060	0.014	<0.001	-0.088	-0.031	5.8
• Rural	10	67	23	60	24.25	-0.184	0.208	0.376	-0.593	0.224	16.8*
Road Section and Non Intersection Treatment	36	355	113	60	22.55	-0.234	0.056	<0.001	-0.343	-0.125	20.9
• Metro	18	256	94	60	23.87	-0.145	0.061	0.017	-0.265	-0.025	13.5
• Rural	18	99	19	60	21.22	-0.598	0.214	0.005	-1.017	-0.180	45.0
Treatment Types											
All Roundabouts	16	200	49	60	28.59	-0.651	0.114	<0.001	-0.875	-0.427	47.8
• Metro	13	177	37	60	28.96	-0.814	0.126	<0.001	-1.061	-0.567	55.7
• Rural	3	23	12	60	26.99	0.157	0.173	0.363	-0.182	0.496	-17.0*†
Seal shoulder	7	41	7	60	20.83	-0.694	0.325	0.033	-1.331	-0.058	50.1
Modify signals	15	741	273	60	25.47	-0.161	0.028	<0.001	-0.217	-0.105	14.9
Skid resistant treatment	4	64	22	60	30.74	-0.395	0.185	0.033	-0.758	-0.033	32.7
Protected left turn lane	3	55	18	60	32.24	-0.506	0.130	<0.001	-0.760	-0.252	39.7
Seagull island	2	358	245	60	20.52	0.568	0.022	<0.001	0.525	0.612	-76.5†
Left turn slip	2	21	10	60	28.44	0.010	0.334	0.976	-0.646	0.665	-1.0*†
Extend left turn pocket	2	72	29	60	28.95	-0.176	0.156	0.258	-0.481	0.129	16.2*
Edgelines	4	35	7	60	21.90	-0.578	0.207	0.005	-0.984	-0.173	43.9
New traffic signal	2	49	14	60	21.04	-0.250	0.350	0.475	-0.935	0.436	22.1*
Improve priority signs	14	147	78	60	28.78	0.073	0.097	0.452	-0.117	0.263	-7.6*†
Improve road lighting	13	76	24	60	23.85	-0.206	0.163	0.205	-0.525	0.113	18.6*

Delineation	4	20	9	60	19.67	0.323	0.449	0.473	-0.558	1.203	-38.1*†

- 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 –fatal, hospitalisation, injury and property damage only crashes

† Negative crash reduction indicates an increase

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 of Cost Savings ($)	BCR
Whole program	17 481 165	34 717 629	17 236 464	2.0
All Metropolitan Sites	10 004 399	29 267 878	19 263 479	2.9
All Rural Sites	7 476 766	8 116 386	639 620	1.1

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 of Cost Savings ($)	BCR
Base case Discount rate 5% Treatment life 15 yrs	17 481 165	34 717 629	17 236 464	2.0
Sensitivity analysis				
Discount rate				
• 3% (15 years)	17 587 173	39 169 743	21 582 570	2.2
• 8% (15 years)	17 355 687	29 447 787	12 092 100	1.7
Treatment life				
• 10 years (5%)	17 269 483	25 827 419	8 557 936	1.5
• 20 years (5%)	17 647 019	41 756 135	24 109 116	2.4