An Evaluation of the Effectiveness and Cost-Effectiveness of the State Black Spot Program in Western Australia, 2009-2010

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Abstract
This report presents the results of an evaluation of the State Black Spot sites which were treated during 2009 to 2010 in Western Australia. The purpose of this report is to evaluate the effectiveness of the State Black Spot Program in terms of reduction in crash frequency (presented for all crashes including fatal, hospitalisation, and property damage only (PDO), and for casualty crashes) at treated locations and the economic worth of these treatments.

One hundred and thirty nine hazardous locations were treated throughout Western Australia at a cost of $16.2 million (excluding maintenance and operating costs). These treated sites consisted of 96 metropolitan and 43 rural sites.

The results showed the State Program has been effective overall, reducing all reported crash frequencies by 21.6% and casualty crash frequencies by 17.4%. The estimated crash cost savings over the expected life of the treated sites were $59.1 million for all reported crashes. This resulted in an overall net cost savings to the community of $41.6 million after subtracting the capital costs of treating sites and maintenance and operating costs. The benefit cost ratio (BCR) across all treatment sites was 3.4. 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 in order to detect statistically significant differences, the relatively short post treatment crash exposure period (average 47 months) 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 2009 to 2010 in Western Australia (WA). It evaluated the effectiveness and cost-effectiveness of the Program in terms of reduction in crash frequency (includes all crashes including property damage only (PDO) and casualty crashes) at treated sites and the economic worth of the treatments. It is anticipated that the 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 141 sites nominated for treatment as a 'Black Spot' in the 2009 to 2010 Black Spot Program. The final sample of 139 treated sites consisted of 96 metropolitan and 43 rural sites. The average length of follow-up exposure crash data post treatment for all treated sites was 47 months. The results found the Program has been effective overall, reducing all reported crash frequencies by 21.6% and casualty crash frequencies by 17.4%.

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

Area	Estimate (β)	Standard Error	Probability 0<p<1	Crash Reductio (%)
*All Crashes**				
Whole program	-0.244	0.013	0.001	21.6
All metro sites	-0.205	0.014	0.001	18.5
All rural sites	-0.517	0.042	0.001	40.4
All intersection sites	-0.194	0.014	0.001	17.7
All road section sites	-0.485	0.040	0.001	38.4
*Casualty Crashes***				
Whole program	-0.192	0.031	0.001	17.4
All metro sites	-0.122	0.033	0.001	11.5
All rural sites	-0.582	0.104	0.001	44.1
All intersection sites	-0.152	0.035	0.001	14.1
All road section sites	-0.491	0.097	0.001	38.8

**Includes all crashes-fatality, hospitalisation, injury and property damage major and minor crashes*
***Includes fatal, hospitalisation, and injury crashes*

Treatment Type Effects

"*Advisory speed sign on curves*", "*modify signal*" and "*roundabouts*" were highly effective in reducing the frequency of both all reported crashes and casualty crashes with a 57.7%, 34.7% and 32.6% reduction in all crashes ($p<0.001$), and 72.3%, 26.2% and 44.1% reduction in casualty crashes ($p<0.001$) respectively. "*New traffic signals*" also significantly reduced all reported crashes by 25.6% ($p=0.026$) and casualty crashes by 47.5% ($p=0.002$). "*Seal shoulders*", "*improve route lighting*", "*improve priority signs*" and "*seal gravel road*" significantly reduced all reported crashes by 39.0% ($p<0.001$), 24.6% ($p<0.001$), 17.8% ($p=0.004$) and 70.1% ($p=0.002$), respectively. There was evidence that "*traffic islands on approach*" reduced all reported crashes by 30.4% ($p=0.03$) and although not statistically significant, casualty crashes by 45.2%.

"*Skid resistant treatments*", "*seagull islands*", "*left turn slip" "LED traffic signals*" and "*roadside hazards-remove*" also reduced the number of all reported crashes but the reduction was not significant.

Location

There were a total of 96 sites treated in the metropolitan area. Overall, these treatments significantly reduced all reported crashes (18.5%, $p<0.001$) and casualty crashes (11.5%, $p<0.001$).

There were a total of 43 sites treated in rural areas. There was very strong evidence of a 40.4% reduction ($p<0.001$) for all reported crashes as well as a 44.1% reduction ($p<0.001$) for casualty crashes.

Broad Treatment Type

The findings from this evaluation demonstrated that the Black Spot Program was effective for reducing the frequency of **all reported crashes** at "*intersection sites"* as well as "*road section and non-intersection sites*" even though the Program treatments were heavily weighted towards intersections rather than road sections.

Economic Analysis

The reduction in the number of reported crashes was estimated to reduce crash costs by $59.1 million over the expected life of the treatments implemented at the sites. After accounting for program costs of $17.4 million (including maintenance and operating costs), the net cost savings to the community from the Black Spot Program were estimated at $41.6 million. Expressed as a benefit cost ratio (BCR), the net economic worth of the State Black Spot Program across all treatment sites was 3.4. Sites treated in the metropolitan area had a slightly higher rate of return than those in rural areas, with a BCR of 3.6 compared with 2.9 in rural areas.

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	17 444 509	59 074 948	41 630 439	3.4
All Metro Sites	10 058 732	36 642 021	26 583 289	3.6
All Rural Sites	7 385 777	21 647 494	14 261 717	2.9

Limitations to the study include the lack of suitable control sites that could have been used to estimate real effects of the treatments implemented in the Program, and the fact that that some treatment types may not have been exposed for longer periods of time compared to the "before" period. In addition, some of the sites were exposed to multiple treatments that could have been misclassified for the purpose of assessing effects of a particular treatment type. Consequently, the results were inconclusive for some treatment types. However, this does not necessarily mean that the treatment was ineffective. Sample sizes of some treatment types were statistically too small to reliable determine their safety effects and appeared to have been less effective or ineffective compared to other larger sizes treatment types in which case these treatment types 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.
- Local Governments (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 "*roadside hazards- remove"* (n=2), "*re-construct superelevation on curve*" (n=3) and "*LED traffic signals (n=4).*"
- 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 treatments implemented should be monitored. This will enable a more accurate assessment of the road safety benefits the treatments are expected to have on the reduction of various crash types on locations characterised by similar road safety issues.

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 2009 to 2010 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 fatal, hospitalisation and PDO crashes) at sites treated under the State Black Spot Program for the years 2009 to 2010. The analysis also included the estimation of the net economic worth of the Program.

2.2 Selection of Sites for Funding

Black spots are locations noted for a high incidence of crashes involving death and injury (Australian National Audit Office, 2007). The 2009-10 State Black Spot Program provided funding of $16.2 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. 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, 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 projects based on 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" (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 pre-treatment crash data and at least six months post treatment crash data 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 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 by treatment type;
- 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 MRWA 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 a combination of individual treatments which made it difficult to analyse by specific types of treatment. Therefore only the "dominant" treatment was chosen to be the determinant for inclusion in the treatment group in the analysis. The dominant treatment was chosen on the basis that it was likely to be the most important treatment in addressing the particular road safety problem at the site. 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 dominant 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 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 three years of post treatment crash data. The statistical methodology also used in this report recognised the level and distribution of random variation in the data and provided appropriate confidence intervals and significance levels.

2.5.3 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 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	7,648.989
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 fatal 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 to the lower severity of crashes involving hospital admission. Given the reduction of fatality crashes at treated sites from 13 to 5, the estimates of the cost-effectiveness of treated sites are conservative.

2.7 Statistical Analysis

2.7.1 Effectiveness of the Program

The analysis compared the frequency of crashes in the "*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 Perth (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. The GEE Poisson model was also able to take account of the correlated nature of the repeated measures of the study design – that is before and after the implementation of the 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 roundabout treatments 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 –

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

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

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 for casualty crashes).

3. RESULTS

This section summarised 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 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 141 sites nominated for treatment as a Black Spot from 2009 to 2010. The final sample of 139 treated sites consisted of 96 metropolitan sites and 43 rural area sites. Two sites were removed as there were no crashes recorded in the crash database. The average length of follow up exposure crash data post treatment for all treated sites was 47.3 months with a minimum of 36 months and a maximum of 60 months.

Table 3.1 shows the effect of the Black Spot Program on road safety for all crashes and Table 3.2 shows the effect for casualty crashes only. In both tables, β represents the regression coefficient in terms of the log-scale of the outcome variable so that the reduction rate is given by $1-e^{\beta}$. 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 undertaken in 2007.

The overall effect of the Black Spots sites treated during 2009 to 2010 for all crash severities showed a very strong reduction of 21.6% ($p<0.001$) for all crashes (see Table 3.1) and a very strong reduction of 17.4% ($p<0.001$) for casualty crashes (see Table 3.2).

Table 3.1 State Black Spot Treatment Effect on All Crash Reduction in Western Australia, 2009 – 2010

Area	Estimate (β)	Standard Error	Probability 0<p<1	All Crash Reduction (%)**
Whole program	-0.244	0.013	<0.001	21.6
All Metropolitan Sites	-0.205	0.014	<0.001	18.5
All Rural Sites	-0.517	0.042	<0.001	40.4
Broad Categories				
Intersection Treatments	-0.194	0.014	<0.001	17.7
• Metro	-0.184	0.015	<0.001	16.8
• Rural	-0.517	0.127	<0.001	40.4
Road Section and Non Intersection Treatment	-0.485	0.040	<0.001	38.4
• Metro	-0.235	0.062	<0.001	21.0
• Rural	-0.658	0.052	<0.001	48.2
Treatment Types				
All Roundabouts	-0.395	0.062	<0.001	32.6
• Metro	-0.431	0.068	<0.001	35.0
• Rural	-0.222	0.117	0.058	19.9
Seal shoulder	-0.495	0.113	<0.001	39.0
New traffic signal	-0.296	0.133	0.026	25.6
Modify signals	-0.426	0.020	<0.001	34.7
Improve priority signs	-0.196	0.067	0.004	17.8
Traffic islands on approach	-0.362	0.167	0.030	30.4
Seal gravel road	-1.207	0.383	0.002	70.1
Improved route lighting	-0.282	0.063	<0.001	24.6
Advisory speed sign on curves	-0.860	0.114	<0.001	57.7
Skid resistant treatment	-0.020	0.031	0.521	1.9*
Seagull island	-0.432	0.589	0.463	35.1*
Left turn slip	0.053	0.079	0.506	-5.4*†
LED traffic signals	0.077	0.059	0.191	-8.0*†
Roadside hazards-remove	-0.513	0.677	0.449	40.1*
Reconstruct super-elevation on curve	-0.823	0.473	0.082	56.1

**Crash increase/reduction is not statistically significant*
***Includes all crashes-fatality, 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, 2009-2010

Area	Estimate (β)	Standard Error	Probability 0<p<1	Casualty Crash Reduction (%)**
Whole program	-0.192	0.031	<0.001	17.4
All Metropolitan Sites	-0.122	0.033	<0.001	11.5
All Rural Sites	-0.582	0.104	<0.001	44.1
Broad Categories				
Intersection Treatments	-0.152	0.035	<0.001	14.1
• Metro	-0.145	0.035	<0.001	13.5
• Rural	-0.378	0.414	0.361	31.5*
Road Section and Non Intersection Treatment	-0.491	0.097	<0.001	38.8
• Metro	-0.075	0.140	0.593	7.2*
• Rural	-0.683	0.121	<0.001	49.5
Treatment Types				
All Roundabouts	-0.582	0.187	0.002	44.1
• Metro	-0.648	0.199	0.001	47.7
• Rural	-0.067	0.662	0.919	6.5*
Seal shoulder	-0.098	0.121	0.418	9.3*
New traffic signal	-0.644	0.207	0.002	47.5
Modify signal	-0.304	0.042	<0.001	26.2
Improve priority signs	-0.067	0.178	0.707	6.9*
Traffic islands on approach	-0.601	0.503	0.232	45.2*
Improved route lighting	-0.247	0.223	0.266	21.9*
Advisory speed sign on curves	-1.282	0.399	0.001	72.3
Skid resistant treatment	-0.039	0.085	0.647	3.8*
Seagull island	0.075	1.000	0.940	-7.8*†
Left turn slip	-0.278	0.262	0.289	24.3*
LED traffic signals	0.186	0.157	0.235	-20.4*†
Roadside hazards-remove	-0.630	0.561	0.261	46.7*
Reconstruct super-elevation on curve	-1.078	0.671	0.108	66.0*

**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 reductions by **broad treatment categories** (intersection and road section/non-intersection treatment) were also analysed. There were a total of 83 sites which received a treatment at an **intersection**. There was very strong evidence of a 17.7% reduction in the number for all crashes ($p<0.001$) and a 14.1% reduction in casualty crashes ($p<0.001$). The most frequently used treatments at an intersection for this evaluation were: *"roundabouts"* (n=20), *"improve/reinforce priority signs"* (n=17), *"modify signals"* (n=9), and *"traffic islands on approach"* (n=7).

There was very strong evidence of a 38.4% reduction ($p<0.001$) in all crashes and a 38.8% reduction in casualty crashes ($p<0.001$) for the 36 **road section treatments and non-intersection treatments**. The most frequently used treatments at road sections and non-intersection sites were: "*seal shoulders*" (n=10), "*improve route lighting*" (n=10), and "*seal gravel road*" (n=3).

3.1.2 Analysis by Specific Treatment Type

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

"*Advisory speed sign on curves*", "*modify signal*" and "*roundabouts*" were highly effective in reducing the frequency of both all reported crashes and casualty crashes with a 57.7%, 34.7% and 32.6% reduction in all crashes ($p<0.001$), and 72.3%, 26.2% and 44.1% reduction in casualty crashes ($p<0.001$) respectively. "*New traffic signals*" also significantly reduced all reported crashes by 25.6% ($p=0.026$) and casualty crashes by 47.5% ($p=0.002$). "*Seal shoulders*", "*improve route lighting*", "*improve priority signs*" and "*seal gravel road*" significantly reduced all reported crashes by 39.0% ($p<0.001$), 24.6% ($p<0.001$), 17.8% ($p=0.004$) and 70.1% ($p=0.002$), respectively. There was evidence that "*traffic islands on approach*" reduced all reported crashes by 30.4% ($p=0.03$) and although not significant, casualty crashes by 45.2%.

"*Skid resistant treatments*", "*seagull islands*", "*left turn slip*" "*LED traffic signals*" and "*roadside hazards-remove*" also reduced the number of all reported crashes but the reduction was not statistically significant.

3.1.3 Analysis by Location

There were a total of 96 sites treated in the metropolitan area. Overall, these treatments showed a very significant 18.5% ($p<0.001$) reduction for all reported crashes and a very significant 11.5% ($p<0.001$) reduction for casualty crashes.

There were a total of 43 sites treated in rural areas. There was very strong evidence of a 40.4% reduction ($p<0.001$) for all reported crashes as well as a 44.1% reduction ($p<0.001$) for casualty crashes.

A breakdown of broad treatment types by location found:

- a 16.8% reduction ($p<0.001$) for all reported crashes and a reduction of 13.5% ($p<0.001$) for casualty crashes in the **metropolitan area** for **intersection** treatments.
- a 40.4% reduction ($p<0.001$) for all reported crashes in the **rural area** for **intersection treatments.**
- a 21.0% reduction ($p<0.001$) for all crashes in the **metropolitan area** for **road section and non-intersection** treatments.
- a 48.2% reduction ($p<0.001$) for all crashes and a reduction of 49.5% ($p<0.001$) 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 35.0% for all crashes ($p<0.001$) and a 47.7% reduction for casualty crashes ($p<0.001$) were reported in metropolitan Perth. There was also evidence for a reduction of 19.9% ($p=0.06$) for all 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 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 $59.1 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 $41.6 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 3.4, which indicates benefits in the form of cost savings to the community of $3.40 for each $1 invested in the program. Sites treated in metropolitan areas had a slightly better rate of return than those in rural areas, with a BCR of 3.6 compared with 2.9 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 $49.0 million and the BCR to 3.8. An expected treatment life of 20 years increased the NPV to $53.2 million and the BCR to 4.0.

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	17 444 509	59 074 948	41 630 439	3.4
All Metropolitan Sites	10 058 732	36 642 021	26 583 289	3.6
All Rural Sites	7 385 777	21 647 494	14 261 717	2.9

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	17 444 509	59 074 948	41 630 439	3.4
Discount rate 5%				
Treatment life 15 yrs				
Sensitivity analysis				
Discount rate				
• 3% (15 years)	17 606 575	66 650 604	49 044 029	3.8
• 8% (15 years)	17 252 676	50 107 878	32 855 202	2.9
Treatment life				
• 10 years (5%)	17 120 888	43 947 518	26 826 630	2.6
• 20 years (5%)	17 698 067	70 927 349	53 229 282	4.0

4. DISCUSSION

This report presented the results of the evaluation of State Black Spot treatments implemented from 2009 to 2010 in WA in terms of its effectiveness in reducing the frequency of all reported crashes, casualty crashes as well as costs. The study examined both the effects of the Black Spot treatments on all severity of crashes (including PDO) and casualty crashes. 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.

The analysis found the program to be effective overall in reducing the frequency of all reported crashes (21.6%) and casualty crashes (17.4%) for all treated sites under the Black Spot Program.

The evaluation of the Program also identified specific treatment types such as "*advisory speed sign on curves*", "*modify signal*", and "*roundabouts*" that were highly successful in reducing **all reported** and **casualty** crash frequency in WA. "*New traffic signals*" also significantly reduced all reported crashes and casualty crashes.

"*Roundabouts*" continue to be an effective treatment in reducing crashes which 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., 2008a, Meuleners et al., 2008b, Zhang et al., 2014; BITRE, 2012). Turner et al. (2008) reported that high severity and fatal crashes could be expected to reduce by a greater amount than lower severity crashes after the installation of a roundabout which is consistent with the results found in the current study. "*Modify signals*" reduced all reported crashes by 34.7% and is consistent with Turner et al.'s (2008) report which found that re-modeling of existing signals can provide large safety benefits of around 30% to 45%. Turner et al. (2008) also stated that reductions of between 35% and 50% in all crashes can be expected from the introduction of new traffic signals, which is consistent with the results of this study. While the current study did not distinguish between daytime and night-time crashes due to the small

sample size (n=5), future evaluations should consider this factor when evaluating the impact of this treatment.

Other types of treatment that showed statistically significant reductions in the number of **all reported** crashes included "s*eal shoulders*", "*improve priority signs*", "*seal gravel road*", "*improve route lighting*" and "*traffic islands on approach*". In particular, "*seal shoulders*" reduced all reported crashes by 39% and is consistent with previous WA Black Spot evaluations (Meuleners et al., 2008a; Meuleners et al., 2008b) as well as a report by Turner et al; (2008). Turner reported that a reduction of 30% could be expected from shoulder sealing. The results of the National Black Spot evaluation found that "*sealing*" or "*resealing*" reduced injury crashes by approximately 20% (BITRE, 2012). This reduction in crashes was particularly significant in the rural areas compared to urban areas.

It must also be noted that this evaluation demonstrated the Black Spot Program was effective for reducing the frequency of all reported crashes at "*intersection sites"* as well as "*road section and non-intersection sites*" even though the treatments analysed were heavily weighted towards intersection treatments.

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, as was the case in this study for treatments such as "*roadside hazards- remove*" or "*LED traffic signals*". 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 may have changed at some of the treated sites over the study period. It is well known that traffic volume rose at least 16% from 2001 to 2006 (Meuleners et al., 2006). 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 during the study period, which was the case for "*roadside hazards- remove"* (n=2), "*re-construct superelevation on curve*" (n=3) and "*LED traffic signals"* (n=4).

The implementation of "*seagull islands*" which aims to reduce specific crash types, especially right angle crashes, continues to produce inconsistent results when compared to previous Black Spot evaluations undertaken in WA. The current evaluation found that "*seagull islands*" did not significantly reduce all crashes and casualty crashes, which is consistent with previous evaluations (Meuleners et al., 2005). However the evaluation of the 2007 to 2008 Program found that "*seagull islands*" did significantly reduce all reported crashes (Zhang et al., 2014). Radalj et al. (2006) found that improperly designed seagull islands could result in an increase in casualty crashes as well as the severity of these crashes. However a well-designed seagull island may improve traffic safety with respect to other factors not considered in the evaluations.

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 $41.6 million and 3.4 respectively. Sites treated in the metropolitan area had a slightly better rate of return than those in rural areas, with a BCR of 3.6 compared with 2.9 in rural areas.

Limitations to the study include the lack of suitable control sites that could have been used to estimate real effects of the treatments implemented in the Program, and the fact that that some treatment types may not have been exposed for longer periods of time compared to the "before" period. In addition, some of the sites were exposed to multiple treatments that could have been misclassified for the purpose of assessing effects of a particular treatment type. Consequently, the results were inconclusive for some treatment types. However, this does not necessarily mean that the treatment was ineffective. Sample sizes of some treatment types were statistically too small to reliable determine their safety effects and appeared to have been less effective or ineffective compared to other larger sizes treatment types in which case these treatment types 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 21.6% and is estimated to reduce crash costs by $59.1 million over the expected life of the treated sites. After accounting for project costs of $17.4 million (including maintenance and operating costs), the net cost savings to the community from the Black Spot Program were estimated as $41.6 million. This is the equivalent of a BCR of 3.4.

Obtaining accurate information related to type of treatment at the sites needs to be properly documented for future evaluations 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 with 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

- 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 "*roadside hazards- remove"* (n=2), "*re-construct superelevation on curve*" (n=3) and "*LED traffic signals*" (n=4).
- 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 treatments implemented should be monitored. This will enable a more accurate assessment of the road safety benefits the treatments are expected to have on the reduction of various crash types on locations characterised by similar road safety issues.

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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 Building Black 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
2005/06	Manjimup	Construct superelevation on curve, remove roadside hazards and install advisory signs
2006/07	Dardanup	Seal shoulders, improve intersection with Clifton Rd & install advisory signage/raised reflective pavement markers/guide posts
2006/07	Donnybrook/Balingup	Construct & seal shoulders, realign curve, remove/prune trees, install advisory signage, raised reflective pavement markers, guardrail & guide posts
2008/09	Augusta Margaret River	Construct & seal 5.5m wide & install signs & RRPM's
2007/08	Augusta Margaret River	Stagger cross intersection & improve signage
2008/09	Bridgetown Greenbushes	Seal Shoulders
2008/09	Harvey	Seal Gravel Rd & install signs & RRPM's
2008/09	Manjimup	Seal Shoulders Remove hazards & install edgelines
2007/08	Murray	Widen seal on bends, remove vegetation & improve sight lines
2008/09	Waroona	Seal Shoulders, install signs &RRPM's
2009/10	Augusta Margaret River	Construct & seal shoulders & install additional guideposts between 1.14 & 5.09 SLK
2009/10	Bunbury	Modify Traffic Control signals at intersection 3.44 SLK
2009/10	Bunbury	Improve Reinforce priority signs at intersection 0.13 SLK
2009/10	Murray	Install guide posts, advisory curve and animal warning signs
2009/10	Murray	Install guide posts, advisory curve and animal warning signs
2009/10	Murray	Install guide posts, advisory curve and animal warning signs
2009/10	Donnybrook/Balingup	Seal gravel road and remove roadside hazards
2009/10	Bridgetown Greenbushes	Widen seal and install edgelines chevrons and advisory speed signs
2009/10	Harvey	Reconstruct & seal shoulders; Install edgelines; RRPM's & guideposts; Remove roadside hazards between 0.00 & 2.00 SLK
2009/10	Harvey	Construct & seal; Install guideposts & lines & RRPM's on curves between 3.35 & 6.0 SLK
2009/10	Manjimup	Reconstruct superelevation on curve & remove roadside hazards between 2.68 & 10.68 (V) SLK
2009/10	Manjimup	Reconstruct superelevation on curve & remove roadside hazards between 4.36 & 8.35 SLK
2009/10	Waroona	Reconstruct widen & seal shoulders; install advisory speed signs & guide posts & remove roadside

		hazards between 2.5 & 6.5 SLK
2010/11	Harvey	Remove roadside vegetation, install RRPM's and additional guideposts
2010/11	Manjimup	Remove roadside hazards
2010/11	Manjimup	Correct superelevation on curve and remove roadside vegetation
2006/07	Kalgoorlie - Boulder	Install Roundabout
2006/07	Kalgoorlie - Boulder	Improve Intersection
2006/07	Kalgoorlie / Boulder	Improve intersection
2008/09	Kalgoorlie-Boulder	Construct Roundabout
2008/09	Kalgoorlie-Boulder	Construct Roundabout
2008/09	Kalgoorlie-Boulder	Construct Roundabout
2008/09	Kalgoorlie-Boulder	Improve intersection
2009/10	Kalgoorlie-Boulder	install nibs and islands
2009/10	Kalgoorlie-Boulder	Improve Intersection
2009/10	Kalgoorlie-Boulder	Install islands & lighting
2009/10	Kalgoorlie-Boulder	Install Roundabout
2006/07	Wyndham East Kimberley	Upgrade street lighting, install pedestrian refuges, pram ramps & pathway
2007/08	Broome	Install left turn pocket
2007/08	Broome	Widen land & Install Pedestrian Island
2007/08	Broome	Install left turn pocket Guy St
2009/10	Northam	Install intersection islands & reinforce Stop Sign priority
2006/07	Gosnells	Install traffic control signals
2005/06	Gosnells	Install TCS
2006/07	Bayswater	Modify traffic control signals - parallel walk phase
2006/07	Cockburn	Install pre deflection nibs at roundabout
2007/08	Gosnells	Upgrade Street Lighting
2006/07	Kwinana	Install pre-deflection nibs at roundabout
2006/07	Melville	Modify traffic control signals & reconstruct intersection
2006/07	Melville	Modify traffic control signals & reconstruct intersection
2006/07	Melville	Install two mini roundabouts at Garden City Shopping Centre
2005/06	Perth	Install anti skid treatment
2006/07	Subiaco	Install traffic control signals

2008/09	Armadale	Install right turn lane
2007/08	Bassendean	Modify traffic control signals & extend right turn lane
2007/08	Canning	Construct Seagull island & keep left turn slip lane - Reserve Project
2007/08	Canning	Upgrade Street Lighting
2007/08	Canning	Upgrade Street lighting
2008/09	Claremont	Extend left turn pocket; Reinforce priority signs - Reserve Project
2007/08	Cottesloe	Construct median island
2007/08	Gosnells	Install Median
2007/08	Gosnells	Upgrade Street Lighting
2007/08	Gosnells	Install Median Island & Bus Emb; Upgrade footpath to S path
2007/08	Gosnells	Upgrade Street Lighting
2008/09	Gosnells	Upgrade street lighting
2008/09	Gosnells	Construct roundabout
2007/08	Joondalup	Construct roundabout
2008/09	Melville	Construct roundabout
2005/06	Mundaring	Construct Roundabout
2007/08	Rockingham	Modify traffic control signals & install anti skid treatment
2007/08	Rockingham	Construct Roundabout
2007/08	Rockingham	Reinforce priority signs; install median on southern approach
2007/08	South Perth	Construct Roundabout
2007/08	Stirling	Provide indented Lt Slip Lane on Eastern Appr; Install Traffic islands & improve Stop Signs
2007/08	Stirling	Construct Traffic Control Signals
2007/08	Subiaco	Construct roundabout
2007/08	Swan	Reid Hwy - Extend left slip lane
2007/08	Swan	Construct U turn facility
2008/09	Victoria Park	Install median; Lt Slip Lane in Thomas Rd & Reinforce Priority - Reserve project
2007/08	Vincent	Install median islands in Raglan Rd on appr to Fitzgerald
2008/09	Bassendean	Extend right turn pocket & install seagull island
2008/09	Belmont	Construct Roundabout
2008/09	Canning	Install seagull island & improve priority signs
2008/09	Claremont	Construct Cul De Sac

2008/09	Cottesloe	Construct Roundabout
2008/09	Gosnells	Upgrade Street Lighting
2008/09	Gosnells	Upgrade Street Lighting
2008/09	Gosnells	Upgrade Street Lighting
2008/09	Gosnells	Upgrade Street Lighting
2008/09	Joondalup	Construct Traffic Control Signals
2008/09	Melville	Install left turn slip lane with Give Way control
2008/09	South Perth	Install left turn slip lane
2008/09	South Perth	Construct Roundabout
2008/09	Stirling	Extend right turn lanes & improve enforcement of signing priority
2008/09	Subiaco	Install Raised Plateau Remove Existing Crossing
2008/09	Subiaco	Construct three Roundabouts
2008/09	Victoria Park	Construct Roundabout
2008/09	Vincent	Modify intersection, traffic control signals & lane marking
2008/09	Wanneroo	Construct & seal shoulders; install edge lines & raised pavement markers
2008/09	Wanneroo	Construct traffic control signals with right turn arrow filter
2008/09	Wanneroo	Install edge lines & separation markers
2008/09	Wanneroo	Upgrade Street Lighting on approaches to roundabout
2009/10	Armadale	Install pre-deflection nibs on roundabout approaches
2009/10	Armadale	Install intersection islands on approaches & reinforce priority with Give Way signs in Ypres Rd
2009/10	Armadale	Install pre-deflection on roundabout approaches
2009/10	Belmont	Install protected left lane into Francisco St
2009/10	Cambridge	Replace TCS lamps with LED lamps
2009/10	Cambridge	Replace TCS lamps with LED lamps
2009/10	Cambridge	Replace TCS lamps with LED lamps
2009/10	Cambridge	Replace TCS lamps with LED lamps
2009/10	Cockburn	Reduce radius on left turn kerb; Install Stop or Give Way sign; install skid treatment to all approaches
2009/10	Cottesloe	Upgrade two intersection street lights to AS 1158
2009/10	Cottesloe	Install intersection islands & reinforce priority signage
2009/10	Cottesloe	Install intersection island in Eileen St & reinforce priority (Give Way) Signage & ban parking
2009/10	Gosnells	Install median islands

2009/10	Joondalup	Install pre-deflection to Mullaloo Dr approach legs & anti skid treatment
2009/10	Joondalup	Install median and intersection islands
2009/10	Kwinana	Install Roundabout
2009/10	Kwinana	Install indented left turn slip lane
2009/10	Melville	Install pre-deflection on both the east & west approaches of roundabout
2009/10	Melville	Install pre-deflection on roundabout
2009/10	Melville	Install Roundabout
2009/10	Nedlands	Install anti skid treatment
2009/10	Rockingham	Install Roundabout
2009/10	Rockingham	Install Roundabout
2009/10	Rockingham	Install median island on approaches with protected right turn pocket on Mandurah Rd
2009/10	South Perth	Install anti skid treatment
2009/10	South Perth	Install anti skid treatment
2009/10	Stirling	Modify TCS with Right arrow (filter) & parallel walk phase remove pelican crossing
2009/10	Subiaco	Install predeflection nibs
2009/10	Subiaco	Install pre-deflection nibs
2009/10	Subiaco	Install Roundabout
2009/10	Victoria Park	Install median islands to ban right turns
2009/10	Victoria Park	Install Roundabout
2009/10	Victoria Park	Install intersection islands & reinforce priority sign (Stop)
2009/10	Vincent	Install Roundabout
2009/10	Wanneroo	Install median island in Raynor Dr & Give Way sign to reinforce priority
2009/10	Gosnells	Install median Islands
2010/11	Cambridge	Install intersection islands in Pangbourne (south) Reinforce Priority with central sign
2010/11	Cambridge	Improve sight distance by clearing verge - remove 3 large pines
2010/11	Joondalup	Modify Traffic signals - Install LED lanterns
2010/11	Stirling	Install medians and improve priority signs
2010/11	Subiaco	Install traffic islands in Herbert Street Reinforce priority of intersection
2010/11	Subiaco	Install traffic island in Hensman Reinforce priority of intersection
2010/11	Wanneroo	Widen Sydney Rd on the approach to the intersection
2010/11	South Perth	Install anti skid treatment

2010/11	Stirling	Install median islands and improve priority signing
2010/11	Bassendean	Install medians on Ida St approaches
2008/09	MRWA	Improve left lane camber
2008/09	MRWA	Seal shoulders remove roadside hazards and improve curve
2007/08	MRWA	Extend right turn lanes and construct double right turn lane from Wanneroo rd into Ocean Reef Rd
2009/10	MRWA	Install audible edgelines
2009/10	MRWA	Selective clearing of oversize trees near edge of road
2008/09	MRWA	Install traffic signals
2009/10	MRWA	Install masts arms and LEDS

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	139	559	357	60	47.30	-0.192	0.031	<0.001	-0.253	-0.130	17.4
All Metropolitan Sites	96	461	314	60	46.92	-0.122	0.033	<0.001	-0.186	-0.057	11.5
All Rural Sites	43	98	43	60	48.13	-0.582	0.104	<0.001	-0.787	-0.377	44.1
Broad Categories											
Intersection Treatments	83	428	281	60	46.62	-0.152	0.035	<0.001	-0.220	-0.084	14.1
• Metro	72	415	274	60	46.59	-0.145	0.035	<0.001	-0.215	-0.075	13.5
• Rural	11	13	7	60	46.85	-0.378	0.414	0.361	-1.189	0.433	31.5*
Road Section and Non Intersection Treatment	36	100	48	60	47.41	-0.491	0.097	<0.001	-0.682	-0.230	38.8
• Metro	13	25	19	60	47.97	-0.075	0.140	0.593	-0.350	0.200	7.2*
• Rural	23	75	29	60	47.08	-0.683	0.121	<0.001	-0.920	-0.445	49.5
Treatment Types											
All Roundabouts	20	46	20	60	47.85	-0.582	0.187	0.002	-0.948	-0.216	44.1
• Metro	15	42	17	60	47.97	-0.648	0.199	0.001	-1.039	-0.258	47.7
• Rural	5	4	3	60	47.47	-0.067	0.662	0.919	-1.364	1.230	6.5*
Seal shoulder	10	13	10	60	50.40	-0.098	0.121	0.418	-0.334	0.139	9.3*
New traffic signal	5	33	14	60	49.74	-0.644	0.207	0.002	-1.051	-0.238	47.5
Modify signals	9	141	79	60	45.91	-0.304	0.042	<0.001	-0.386	-0.223	26.2
Improve priority signs	17	27	21	60	43.65	0.067	0.178	0.707	-0.283	0.417	-6.9*
Traffic islands on approach	7	16	7	60	47.54	-0.601	0.503	0.232	-1.587	0.384	45.2*
Improved route lighting	10	16	10	60	47.64	-0.247	0.223	0.266	-0.684	0.189	21.9*
Advisory speed sign on curves	3	36	7	60	42.08	-1.282	0.399	0.001	-2.064	-0.501	72.3
Skid resistant treatment	6	67	46	60	42.99	-0.039	0.085	0.647	-0.205	0.128	3.8*
Seagull island	2	2	2	60	55.68	0.075	1.000	0.940	-1.885	2.035	-7.8*
Left turn slip	4	14	9	60	51.38	-0.278	0.262	0.289	-0.792	0.236	24.3*

LED traffic signals	4	33	33	60	49.84	0.186	0.157	0.235	-0.121	0.493	-20.4*
Roadside hazards-remove	2	3	1	60	37.59	-0.630	0.561	0.261	-1.729	0.469	46.7*
Reconstruct superelevation on curve	3	8	2	60	43.72	-1.078	0.671	0.108	-2.392	0.236	66.0*

- 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 fatal, hospitalisation, and injury crashes only

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	139	2569	1558	60	47.30	-0.244	0.013	<0.001	-0.269	-0. 192	21.6
All Metropolitan Sites	96	2228	1399	60	46.92	-0.205	0.014	<0.001	-0.232	-0.178	18.5
All Rural Sites	43	341	159	60	48.13	-0.517	0.042	<0.001	-0.599	-0.435	40.4
Broad Categories											
Intersection Treatments	83	2008	1264	60	46.62	-0.194	0.014	<0.001	-0.222	-0.166	17.7
• Metro	72	932	1229	60	46.59	-0.184	0.015	<0.001	-0.213	-0.155	16.8
• Rural	11	76	35	60	46.85	-0.517	0.127	<0.001	-0.767	-0.267	40.4
Road Section and Non Intersection Treatment	36	356	173	60	47.41	-0.485	0.040	<0.001	-0.564	-0.406	38.4
• Metro	13	128	82	60	47.97	-0.235	0.062	<0.001	-0.357	-0.113	21.0
• Rural	23	228	91	60	47.08	-0.658	0.052	<0.001	-0.760	-0.556	48.2
Treatment Types											
All Roundabouts	20	198	102	60	47.85	-0.395	0.062	<0.001	-0.517	-0.273	32.6
• Metro	15	166	82	60	47.97	-0.431	0.068	<0.001	-0.565	-0.298	35.0
• Rural	5	32	20	60	47.47	-0.222	0.117	0.058	-0.453	0.008	19.9*
Seal shoulder	10	43	22	60	50.40	-0.495	0.113	<0.001	-0.716	-0.273	39.0
New traffic signal	5	127	78	60	49.74	-0.296	0.133	0.026	-0.556	-0.036	25.6
Modify signals	9	627	310	60	45.91	-0.426	0.020	<0.001	-0.465	-0.386	34.7
Improve priority signs	17	137	82	60	43.65	-0.196	0.067	0.004	-0.328	-0.064	17.8
Traffic islands on approach	7	49	27	60	47.54	-0.362	0.167	0.030	-0.690	-0.035	30.4
Seal gravel road	3	16	4	60	51.40	-1.207	0.383	0.002	-1.957	-0.457	70.1
Improved route lighting	10	100	61	60	47.64	-0.282	0.063	<0.001	-0.405	-0.159	24.6
Advisory speed sign on curves	3	91	27	60	42.08	-0.860	0.114	<0.001	-1.083	-0.636	57.7
Skid resistant treatment	6	372	263	60	42.99	-0.020	0.031	0.521	-0.080	0.040	1.9*
Seagull island	2	15	9	60	55.68	-0.432	0.589	0.463	-1.586	0.722	35.1*

Left turn slip	4	51	45	60	51.38	0.053	0.079	0.506	-1.102	0.208	-5.4*
LED traffic signals	4	145	130	60	49.84	0.077	0.059	0.191	-0.038	0.192	-8.0*
Roadside hazards-remove	2	8	3	60	37.59	-0.513	0.677	0.449	-1.840	0.814	40.1*
Reconstruct superelevation on curve	3	22	7	60	43.72	-0.823	0.473	0.082	-1.751	0.105	56.1*

- 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

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	17 444 509	47 037392	29 592 883	2.7
All Metropolitan Sites	10 058 732	27 385 293	17 326 561	2.7
All Rural Sites	7 385 777	19 146 016	11 760 239	2.6

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	17 444 509	47 037392	29 592 883	2.7
Sensitivity analysis				
Discount rate				
• 3% (15 years)	17 606 575	53 069 376	35 462 801	3.0
• 8% (15 years)	17 252 676	39 897 523	22 644 847	2.3
Treatment life				
• 10 years (5%)	17 120 888	34 992 443	17 871 555	2.0
• 20 years (5%)	17 698 067	56 418 900	38 720 833	3.2