AN EVALUATION OF THE EFFECTIVENESS OF A LARGE SCALE ACCIDENT BLACK SPOT PROGRAM

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ABSTRACT

The vital role played by road infrastructure design in determining road safety outcomes is increasingly being recognised. Accident black spot programs have been implemented in many countries of the world, in some for more than three decades. In Victoria, Australia, there has been a major increase in investment in black spot programs, the most recent involving an expenditure of $240M (AUD) over the four-year period from 2001/02-2004/05. This paper presents the results of a comprehensive evaluation of this four-year program on key indicators of safety, including percent reduction in casualty crashes and cost-effectiveness. The evaluation examined the effectiveness of the program overall for broad categories of treatment that targeted off-path, intersection or pedestrian crashes, and for individual types of treatment. Insights gained from the evaluation are presented to assist with enhancing future investment strategies for safe road infrastructure. Treatment types that are compatible with ambitious road safety philosophies such as Sweden's Vision Zero, The Netherlands's Sustainable Safety and Australia's recent derivative, the Safe System, are also discussed.

1 INTRODUCTION

In 2000, the State Government of Victoria, Australia, commenced the four-year $240 million Statewide Blackspot Program (SBP). It comprised two distinct parts: the Accident Blackspot and Potential Blackspot components. Sites to be treated under the Accident Blackspot component were identified based on their poor crash history, while sites treated under the latter component were identified using predicted crash risk. This paper presents the results of evaluating over 800 sites treated under the Accident Blackspot component.

Sites identified as candidates for treatment were prioritised according to predicted benefits of a planned treatment relative to the treatment costs. Black spots were defined either as discrete points on the road network or segments of a defined length of road. If the crashes along a stretch of road had similar crash attributes and the geometry and features of the road were generally consistent along its length, the road could, instead, be defined as a black length. The term "black spot sites" refers here to both black lengths and black spots, while the term "discrete black spot" refers to a black spot site that is not a black length.

Monash University Accident Research Centre (MUARC) was commissioned to evaluate the blackspot program to estimate effects for both the program as a whole and for different groups of treatments. This would enable the identification of the most effective treatments in reducing crashes occurring at a site (as well as unsuccessful treatments). Economic analysis of the entire program and different groups of treatments enables road authorities to invest future resources to minimise road trauma in the most cost-effective way.

Study Aim, Scope and Hypotheses

The aim of this study was to estimate blackspot program effectiveness, while the scope was limited to measuring effectiveness in terms of reductions in casualty crash frequency at treated locations, as well as the economic worth of the program and its individual treatment types. Reductions in both casualty and serious casualty crash frequency and estimates of economic benefits were measured for the entire blackspot program and for different treatment categories. Treatment sites were grouped according to the type of works completed at sites, whether the site was located on an arterial or local road or in a rural or metropolitan area. Where appropriate, estimates of the number of lives saved and injuries prevented over the project lives are also presented.

A quasi-experimental analysis, with Poisson regression, was used to compare before- and after-treatment casualty crash frequencies at treated sites with those at suitably chosen control sites over the same period. While the analytical methods used in this evaluation are crucial to the validity of, and level of confidence in, the results, the methods cannot be presented in full detail here within the permitted maximum length for a paper. References to relevant publications are included for readers desiring additional details.

Several null hypotheses were tested; they made the assumption that the blackspot program and its individual components had no effect on casualty crash frequency at treated sites. Each hypothesis was tested against a two-side alternative hypothesis that the blackspot program has resulted in a change, either increase or decrease, in casualty crash frequency at sites treated. Previous evaluations of blackspot programs have shown that such programs are generally effective in reducing casualty crash frequency at treated sites when compared with control sites. Based on these previous results the program can be tested against a one-sided alternative hypothesis that assumes the program will result in a reduction in casualty crashes at treated sites. However a two-sided alternative hypothesis gives more conservative statistical significance estimates of program effects and so was deemed more appropriate for this evaluation. The reader can change from a two-sided to a one-side alternative hypothesis by simply halving the statistical significance values presented for the two-sided test. Changing from a two- to a one-sided hypothesis only affects the calculated statistical significance values and does not alter the point estimates of the program effects on casualty crash frequency.

Each null hypothesis tested in this program can be represented by the generic form listed below along with its corresponding two-sided alternative hypotheses. The following hypotheses relate only to overall program effects.

N: That the SBP had no effect on casualty (or serious casualty or other injury) crash frequency at treated sites.

A: That the SBP has resulted in a change, either increase or decrease, in casualty (or serious casualty or other injury) crash frequency at sites treated.

The hypotheses below relate to comparisons between different groups of treatments.

N: That the effect of treatments on casualty (or serious casualty or other injury) crash frequency at treated sites did not differ for different types of treatments.

A: That the effect of treatments on casualty (or serious casualty or other injury) crash frequency at treated sites differed according to the type of treatment completed at sites (for all sites, for rural sites compared with metropolitan Melbourne sites, or for local roads compared with arterial roads).

2 DATA

Treatment Data - data were analysed for 865 blackspot treatments funded under the "Accident Blackspot" component. Key data fields included treatment location, description, start and finish dates, estimated treatment life, and capital, maintenance and operating costs. Only those sites with adequate details could be included and some redefinition of sites was necessary where, for example, a black length was contained entirely within another black length. After comprehensive review of treatment details, 804 of the original 865 black spot sites, treated at a total cost of $198,491,000, were available for full evaluation. The mean project life for these 804 sites was 15.8 years, ranging from 3-20 years, and the mean capital cost was $245,723 (AUD).

Each treated site was classified into one of three broad treatment categories and then into one of several more-specific sub-categories. Not only had many different types of treatments been applied to sites, but some sites had received several types of treatments. To use Poisson regression to assess the effectiveness of different treatments, each site should be associated with only one treatment type.

Casualty Crash Data - all police-reported casualty crashes occurring in Victoria from 1st of January 1995 to 30th November 2005 were obtained from the Road Crash Information System (RCIS). In all, there were 188,786 separate crashes in the dataset. Critical crash data fields included crash date, severity, identification number, municipality and the number of people killed, seriously injured or suffering other injuries. It was also necessary to append additional data such as whether the crash occurred in a rural area or the Melbourne metropolitan area; postcode of the crash location; type of road on which the crash occurred; and whether the crash was an "intersection crash" or a "non-intersection" crash. The nature of the additional data is described in detail in the original study report (Scully, Newstead, Corben and Candappa, 2006). The crash data were thoroughly checked to ensure crashes that occurred at more than one treated black spot (e.g., where two black lengths intersected) were assigned to just one site and that conservative definitions were used for treatment start and finish dates. When treatment data for the 804 blackspot sites were merged with casualty crash data, 16,628 of the 188,786 crashes were found to have occurred at one of the 804 blackspot sites, while 196 crashes occurred at one of nine sites for which there were insufficient details for inclusion in the evaluation.

Casualty Crash Cost Data - the program's economic worth was estimated by assigning different costs to crashes in metropolitan and rural areas, as well as to crashes of differing injury severities. Each crash was categorised according to the following definitions:

- Fatal Crashes: a crash in which a road user received injuries that result in their death within 30 days of the crash;
- Serious Casualty Crashes: a crash in which the most seriously injured road user was not killed within 30 days as a result of the crash but was transported to hospital or admitted to hospital as a result of the crash;
- Other Injury Crashes: a crash in which the most seriously injured road user was not killed or did not require hospitalisation or transportation to hospital.

The results presented in this paper used Austroads' (the association of Australian and New Zealand road transport and traffic authorities) crash cost estimates. Table 1 shows crash costs in Australian dollars (at June 2001) categorised by location and crash severity.

Table 1 - Crash cost values used for economic assessment

Crash Severity	Austroads Costs ($AUD June 2001)	
	Urban	Rural
Fatal	1,505,000	1,624,000
Serious Injury	385,000	404,000
Other Injury	17,300	17,900

3 EVALUATION METHODS

While only a brief outline of evaluation methods can be presented here, greater detail is provided in the original study report (Scully, Newstead, Corben and Candappa, 2006). A quasi-experimental study design involving Poisson regression was used to establish whether changes in casualty crash frequency were significantly different at treated compared with non-treated sites. This method was used to evaluate the effect of the program as a whole as well as the effect of treatments at individual sites. Sites can also be evaluated in groups sharing a common feature. This quasi-experimental approach, which was originally proposed by Bruhning and Ernst (1985), has since been modified and used by MUARC (e.g. Newstead, 2002) and other road safety researchers (BTE, 2001).

Using Poisson regression to assess a blackspot program requires the identification of the number of casualty crashes occurring at each site both before and after treatment. Each treated site must be matched to a set of non-treated control sites. The numbers of casualty crashes in pre- and post-treatment periods at each of the control sites are used to calculate the percentage reduction in the number of casualty crashes at treatment sites in the post-treatment period when compared with the pre-treatment period. The percentage reduction at treated sites is then compared with the percentage reduction at analogous control sites. Provided control sites are chosen carefully, comparing casualty crash reductions at treated against non-treated control sites enables the effects of treatments on casualty crash counts to be isolated from other factors, not due to the program.

Pre-treatment periods were defined as the period beginning five years before the date of commencement of works. The post-treatment period was defined as the period from a month after the completion of treatment works to the 30th of November 2005. All pre-treatment periods were five years in length and post-treatment periods varied from five months to over five years, for most matched pairs of treatment and control sites. However, the fact that each treated site is matched to a set of non-treated control sites enables comparison of post- and pre-treatment casualty crash counts at treated sites.

The road safety literature identifies two important issues, namely, accident migration and regression-to-the-mean, which should be considered when using a quasi-experimental study design to evaluate road safety programs. One possible outcome of treating blackspots is accident migration where the treatment leads to casualty crash risk being moved, either entirely or partly, from the treated site to another site nearby or vice versa, depending on the treatment type, which can lead to an incorrect estimate of the effect of a treatment. Because comprehensive traffic volume data were not available for sites potentially affected by accident migration, the results presented are not compensated for the possible effects of accident migration. Accident migration effects are considered unlikely to be large, given the breadth of sites and treatment types analysed.

Regression-to-the-mean is caused by identifying blackspots from a set with the same underlying crash rate that have a high casualty crash frequency measured over a narrow window in time, due to the expression of an extreme in random variation. Selecting sites for treatment on such a basis means it is likely that casualty crash frequency at the selected site will fall in the immediate next period, merely due to chance. Numerous analysis methods have been proposed to overcome this problem, such as Abbess, Jarrett and Wright (1981). In the study described here, each treatment site had five years of pre-treatment casualty crash data, which ensures accurate estimates of pre-treatment casualty crash frequency. In addition, this period did not generally coincide with the casualty crash data period from which the treated sites were selected. Finally, an analysis technique was used that properly recognises the level and distribution of random variation in the data and computes confidence limits and significance probability levels that properly reflect this.

This evaluation examined changes in crash frequencies at treated sites for the entire program, and separately for metropolitan and rural areas, for arterial and local roads, and by both broad and specific treatment types. Changes in *serious* casualty crash frequency were also estimated for these levels of aggregation. The evaluation included estimates of economic worth; Benefit-Cost-Ratio (BCR), Net Present Worth (NPW), and cost-effectiveness were used to assess economic worth.

4 RESULTS

Only the main results of the evaluation can be presented here. Table 2 shows the estimated reduction in the number of casualty crashes occurring at the 804 treated blackspot sites (by crash severity). It was found that relative to chosen comparison sites, casualty crashes at treated sites fell by a highly statistically significant 31% and serious casualty crashes by about 35%, which translate to estimated annual savings of 535 casualty crashes and 179 serious casualty crashes over the program life. Upper and lower 95% confidence intervals indicate the range within which real crash savings due to the program lie with 95% probability. Statistical significance values, which give the probability that the estimated crash reduction is due to chance, rather than the effect of the program are also shown for each type of crash. The $p<0.05$ significance level has been used to determine whether results are statistically significant. Readers may prefer to interpret the results using a less conservative level of significance.

It was also estimated that the program as a whole resulted in 204 lives, 3,116 serious injuries and 8,505 other injuries would be prevented over the program life.

Table 2 - Estimated crash reductions at program level for all casualty crashes, serious casualty crashes only and other injury crashes only

Types of Casualty Crashes	Estimated Crash Reduction (%)	Statistical Significance	Lower 95% Confidence Limit (%)	Upper 95% Confidence Limit (%)	Annual Crash Frequency at Treated Sites Before Treatment	Annual Casualty Crash Saving
All Casualty	31.3	<0.0001	27.7	34.7	1,708	535
Serious	34.5	<0.0001	28.1	40.4	517	179
Other Injury	29.8	<0.0001	25.3	34.0	1191	355

To address a broad range of casualty crash types, treatments were wide-ranging and often involved several countermeasures. Categorising treatment types into hierarchical categories was therefore quite a complicated task, with each site categorised as off-path, intersection or vulnerable road user crash treatments. Treatments were designed to prevent or reduce the severity of injuries resulting from run-off road crashes or crashes between vehicles travelling in opposite directions; crashes at intersections; or crashes involving vulnerable road users, primarily cyclists or pedestrians. Within each of these broad categories, treatments were assigned to more specific categories. There are three levels of classification, with the possibility to classify a treatment into one of 70 categories.

Tables 3, 4 and 5 show the estimated casualty crash reduction for off-path, intersection and vulnerable road user crash treatments, respectively. Results that were not statistically significant ($p>0.05$) have been shaded grey. The 235 off-path crash treatments resulted in an estimated casualty crash reduction of 21%, compared with 43% for the 541 intersection crash treatments (both highly significant). Table 5 shows that the 37 vulnerable road user crash treatments had no significant effect on the number of casualty crashes occurring at treated sites ($p=0.862$). The most effective off-path crash treatments involved improving the road surface (43% reduction) and guardrails (42% reduction). The most effective intersection treatments involved road widening to allow through-vehicles to pass around (right-) turning traffic (82%), creating staggered-T layouts (81%) and constructing roundabouts (77%). Treatment-specific results are discussed further in section 5.

Estimates were also made of *serious* casualty crash reductions, with only the main results presented here. The greatest estimated reduction in *serious* casualty crashes occurred at intersections (i.e., 45% at intersections, compared with 29% for treatments targeting off-path crashes). Treatments targeting crashes involving vulnerable road users did not effectively reduce *serious* casualty crashes or all types of casualty crashes at treated sites.

Using Austroads crash costs and assuming a discount rate of 6%, the entire program was estimated to return a Benefit-Cost-Ratio of 3.7 and a Net Present Worth of $556 million, indicating the long-term savings due to reduced casualty crashes clearly outweigh the cost required to achieve these savings. The average overall cost required to prevent one fatality was about $1,000,000 and one serious casualty was about $66,000.

Types of treatments were also assessed according to their capacity to contribute to the achievement of Victoria's target of a 20% reduction in serious casualties by 2007 (VicRoads. (2002). Of the off-path crash treatments found to deliver statistically reliable reductions in serious casualty crashes, guardrails were found to be the most cost-effective, with the average investment required to prevent one casualty over the life of the treatment being $5,700 (compared with $6,400 if treatments involved improving pavement skid resistance; $10,200 for guide posts or chevron alignment markers; $29,700 for shoulder sealing without tactile edge marking; $40,400 for shoulder sealing with tactile edge marking and $56,200 for carriageway duplication or the construction of a median strip).

Of the intersection crash treatments that delivered statistically reliable reductions in *serious* casualty crashes, the most cost-effective involved installing new mast arms at signals; on average, it cost $2,100 to prevent one casualty over the life of the treatments. This highly favourable result is surprising given that such treatments were not shown to be effective in previous blackspot evaluations (Newstead, 2001). The need for further investigation is discussed in more detail in section 5. Of other intersection crash treatments found to result in statistically reliable reductions in *serious* casualty crashes, only roundabouts were highly compatible with the Safe System philosophy, and required an average of $8,934 to save a serious casualty.

Table 3 - Estimated percentage casualty crash reduction attributable to the Accident Blackspot Component of the Statewide Blackspot Program by Treatment Type (Off-Path Treatments only)

Treatment Type			Number of Treated Sites	Total Capital Works Cost ($)	Est. % Casualty Crash Reduction	Statistical Significance Probability
Level 1	Level 2	Level 3				
1: Off-Path Treatments			235	106,212,000	20.6	<0.0001
	1.1: Improved Shoulder Definition		96	69,510,000	26.4	<0.0001
		1.1.1: Sealing Only	63	34,974,000	29.3	<0.0001
		1.1.2: Sealing with Tactile Edge Marking	24	33,513,000	35.7	0.0022
		1.1.3: Tactile Edge Marking only	9	1,023,000	-17.9	0.3436
	1.2: Bridge End-post Protection		12	344,000	3.5	0.8206
		1.2.1: Breakaway Cable Terminals	1	33,000	-104.8	0.2895
		1.2.2: Guard Rail	2	46,000	23.5	0.6677
		1.2.4: Guard Rail and upgrade Terminal Ends	3	96,000	-9.2	0.6835
		1.2.5: Unspecified	6	169,000	24.6	0.3034
	1.3: Barrier Construction		20	3,300,000	15.5	0.3373
		1.3.1: Guard Rail	9	701,000	42.2	0.05
		1.3.2: Guardrail plus Shoulder Sealing	11	2,599,000	-7.8	0.7349
	1.4: Hazard Removal		4	330,000	-15.4	0.4847
		1.4.1: Install Frangible Poles	2	177,000	-29.0	0.2302
		1.4.2: Remove Poles or Trees	2	153,000	0.0	0.9945
	1.5: Road Alignment and Delineation		45	18,967,000	30.2	0.0005
		1.5.1: Install Median /Duplicate Carriageway	10	15,349,000	20.5	0.1171
		1.5.2: Improved Line marking	2	46,000	75.0	0.1782
		1.5.3: Installing RRPMs	1	112,000	-1.8	0.9795
		1.5.4: Guide posts or CAMs	32	3,460,000	37.9	0.0018
	1.6: Improved Lighting		5	553,000	-18.4	0.1992
	1.7: Improved Signage		4	249,000	22.7	0.4069
	1.8: Road Surface		29	2,425,000	43.3	<0.0001
		1.8.1: Improve Skid Resistance/Re-seal Road	29	2,425,000	43.9	<0.0001
	1.9: Road Widening		15	2,568,000	25.8	0.1635
		1.9.1: Realign or Widen Curves	8	1,217,000	38.3	0.147
		1.9.2: Add Lane	5	892,000	12.9	0.6244
		1.9.3: Unspecified	2	459,000	30.2	0.6113
	1.10: Speed Reduction		4	2,456,000	-30.0	0.1526
		1.10.2: Speed Camera	1	2,020,000	21.2	0.4395
		1.10.4: Advisory Speed Signs	2	246,000	-76.5	0.0142
		1.10.5: Variable Speed Limit Signs	1	190,000	0.0	0.9976
	1.11: Ring Road Treatments		1	5,510,000	-28.7	0.3719

Results that were not statistically significant (p>0.05) have been shaded grey

Table 4 - Estimated percentage casualty crash reduction attributable to the Accident Blackspot Component of the Statewide Blackspot Program by Treatment Type (Intersection Treatments only)

Treatment Type Level 1	 Level 2	 Level 3	Number of Treated Sites	Total Capital Works Cost ($)	Est. % Casualty Crash Reduction	Statistical Significance Probability
2: Intersection Treatments			541	70,340,000	42.8	<0.0001
	2.1: Roundabout		144	26,704,000	74.0	<0.0001
		2.1.1: Installation	133	25,567,000	76.7	<0.0001
		2.1.2: Modification	11	1,137,000	54.5	0.0036
	2.2: Signal Treatment		204	22,724,000	35.0	<0.0001
		2.2.1: New Signals	57	12,953,000	49.9	<0.0001
		2.2.2: FCRT	98	8,598,000	26.6	<0.0001
		2.2.3: New Mast Arm	39	1,005,000	33.1	<0.0001
		2.2.4: Change Phasing	3	64,000	50.0	0.1022
		2.2.5: PCRT	4	78,000	14.5	0.5436
		2.2.6: New Signal Hardware	3	26,000	27.7	0.3995
	2.3: Improved Definition		49	2,561,000	36.1	0.0002
		2.3.1: Install Splitter Islands/Median	45	2,254,000	43.4	<0.0001
		2.3.2: Line-marking	4	307,000	6.3	0.8089
	2.4: Enhanced Signage		9	374,000	33.2	0.0641
		2.4.1: Advanced Warning Signs	5	271,000	-18.5	0.5215
		2.4.2: Rumble Strips on Approach	1	1,000	0.0	0.9965
		2.4.3: Tram-activated Signs	1	67,000	65.5	0.1385
		2.4.4: Unspecified	2	89,000	73.5	0.0118
	2.5: Change Geometry		21	3,050,000	64.6	0.0026
		2.5.1: Staggered-T	14	2,474,000	81.3	0.0017
		2.5.2: Removal of Y-intersection	3	448,000	87.7	0.0583
		2.5.3: Other Realignment of approach	4	128,000	-6.9	0.8833
	2.6: Add Lane		55	10,219,000	48.0	<0.0001
		2.6.1: Add Left Turn Lane	7	1,486,000	-11.3	0.6588
		2.6.2: Add Right Turn Lane	32	4,218,000	50.6	<0.0001
		2.6.3: Widen Road around RT Lane	10	4,143,000	82.1	0.001
		2.6.4: Five Lane Treatment	1	73,000	-71.0	0.4012
		2.6.5: Add Left Turn Slip Lane	1	84,000	0.0	0.9972
		2.6.6: Unspecified	4	215,000	84.0	0.071
	2.7: Speed Reduction		23	2,203,000	-15.8	0.3439
		2.7.1: Channelisation	6	754,000	-18.9	0.6711
		2.7.2: Speed Camera	2	369,000	-6.3	0.8468
		2.7.3: Reduction of Speed Limit	1	73,000	31.5	0.5832
		2.7.4: Kerb Extension	14	1,007,000	-29.2	0.1979
	2.8: Other Treatments		31	2,084,000	38.3	0.0004
		2.8.1: Red Light Camera	2	69,000	-21.0	0.5576
		2.8.2: Obstruction Relocation	4	92,000	63.6	0.0373
		2.8.3: Banning Movements	2	322,000	53.6	0.103
		2.8.4: Improved Skid Resistance	11	859,000	44.2	0.0123
		2.8.5: Hazard Removal	3	186,000	63.2	0.1667
		2.8.6: Improve Lighting	7	146,000	22.0	0.3174
		2.8.7: Railway Crossing Treatments	2	410,000	0.0	0.9955

Results that were not statistically significant (p>0.05) have been shaded grey

Table 5 - Estimated percentage casualty crash reduction attributable to the Accident Blackspot Component of the Statewide Blackspot Program by Treatment Type (Vulnerable Road User Treatments only)

Treatment Type			Number of Treated Sites	Total Capital Works Cost ($)	Est. % Casualty Crash Reduction	Statistical Significance Probability
Level 1	Level 2	Level 3				
3: Vulnerable Road User			37	3,911,000	1.3	0.8619
	3.1: New Ped. Operated Signals		18	3,070,000	-6.7	0.5429
	3.2: Pedestrian Refuge		4	283,000	27.2	0.2922
	3.3: Pedestrian Fencing		4	137,000	-64.2	0.009
	3.4: Giveway to Ped. Sign		2	70,000	37.9	0.1131
	3.5: Coloured Walkway		3	117,000	27.4	0.1189
	3.6: Reduce Speed Limit		1	122,000	41.2	0.6246
	3.7: Other		2	86,000	12.9	0.6342
	3.8: Bicycle Lanes		1	26,000	67.2	0.1659

Results that were not statistically significant (p>0.05) have been shaded grey.

5 DISCUSSION

The evaluation reported here is comprehensive in a number of respects; over 800 individual treatments and some 69 separate treatment types were evaluated, and several key indicators of effectiveness and cost-effectiveness estimated. Overall, the program has been effective in reducing casualty crash frequency on Victorian roads. *Serious* casualties were estimated to reduce by approximately 35% and all casualty crashes to reduce by around 31%.

To use improve future investment strategies, the results must be interpreted insightfully. Assessing treatment effectiveness based on the various measures reported here, would result in different ratings; ordering treatments with respect to casualty crash reduction, *serious* casualty crash reduction, BCR, NPW or Cost-effectiveness (e.g. for casualties or serious casualties) will result in different treatment rankings, creating uncertainty about which treatments to favour in future programs to best meet a program's goals. This lack of clarity stems from each measure offering distinctly different evidence on effectiveness and economic worth. Together, they present a quite comprehensive picture but, individually, a limited view of each treatment's ability to deliver road safety benefits.

Greater insight and better guidance will result from understanding the relationships between the alternative treatments and specific goals of an infrastructure program. Future investment in safe road infrastructure should seek to make the maximum contribution, for the funds available, to achieving the overall target of reducing *serious* casualties by the end of a strategies life (VicRoads, 2002). It follows, therefore, that the single most valuable indicator among those estimated in this study is cost-effectiveness; it indicates which treatments can save one *serious* casualty for the least cost. Future investment in blackspot (or other safety-oriented infrastructure) programs should favour such treatments. Other measures, such as BCR, NPW and crash reduction have a valid place but do not quantify serious casualty savings in the way that is possible from using cost-effectiveness.

This section discusses the results of the evaluation for two of the three broad treatment categories, namely, treatments for off-path crashes and for intersection crashes. The discussion centres primarily on treatment types found to have delivered statistically reliable reductions in *serious* casualty crashes. While analyses by specific crash types were not part of the scope of the evaluation, the discussion considers likely treatment effects on crash types that characterise off-path and intersection crashes. In attempting to gain new insight, the potential compatibility of treatment types with Australia's Safe System road safety philosophy is also discussed. Key criteria considered here include cost-effectiveness, estimated crash reduction, BCR, NPW, number of treatments undertaken, statistical reliability of estimates and consistency with past evaluations.

Australia's Safe System road safety philosophy, while not described in detail here, is a derivative of the Swedish Vision Zero and Dutch Sustainable Safety philosophies (Howard, 2004). In essence, the Safe System seeks to design and operate the road transport system in such a way as to be tolerant of human error, to not exceed biomechanical tolerances in foreseeable crashes and so avoid death or serious injury in traffic.

Successful Treatment Types

Treatment types successful in reducing serious casualty crashes are summarised in Tables 6 and 7, for off-path and intersection crashes, respectively. No treatments for off-path crashes delivered statistically reliable reductions in *all* casualty crashes but not in *serious* casualty crashes.

Table 6- Summary of off-path treatments that delivered statistically reliable reductions in serious casualty crashes (H – high; M – medium; L – low)

Treatment Type	Cost Effectiveness ($k per Casualty Saved)	Estimated Serious Casualty Crash Reduction (%)	BCR (using Austoads Crash Costs)	NPW ($M)	Safe System Compatible	Number of Treated Sites
Guard Rail	5.7	65.6	12.9	8.5	H	9
Improved Skid Resistance/Re-seal Road	6.4	40.0	11.5	25.5	M	29
Guide posts or CAMS	10.2	66.2	8.6	26.5	L	32
Shoulder Sealing Only	29.7	37.9	2.2	43.0	L	63
Shoulder Sealing with Tactile Edge Marking	40.4	38.6	1.8	25.4	L	24
Install Median/Duplicate Carriageway	56.2	42.6	1.1	0.9	H	10

Serious Trauma Involving Off-Path Crashes

The study found that six categories of treatment for off-path crashes were effective in reducing serious casualty crashes (statistically reliable at the $p<0.05$ level).

Shoulder Sealing - two basic forms of shoulder sealing were implemented; one with painted edgelines only and another with tactile edgelines. The estimated effectiveness of these treatments in reducing serious casualty crashes was 38% and 39%, respectively. While there is no appreciable difference in their effectiveness in treating off-path crashes, a substantial difference exists in their levels of cost-effectiveness. Shoulder sealing with painted edgelines prevents, on average, one casualty for every $29,700 invested, while shoulder sealing with tactile edgelines prevents one casualty for every $40,400 invested. That is, an additional one-third in expenditure has been required for tactile edgelines to achieve the same casualty saving. Given that 63 projects involving shoulder sealing with painted edgelines and 24 projects involving shoulder sealing with tactile edgelines were implemented, these findings are likely to be reliable indicators for comparing effectiveness and cost-effectiveness of these alternative forms of shoulder sealing. This difference in performance is reinforced by the BCR estimates of 2.2 for shoulder sealing with painted edgelines and 1.8 for shoulder sealing with tactile edgelines.

Roadside Barriers; Guardrail - there were 20 barrier treatments implemented including eleven treatments that involved the combination of guardrail and shoulder sealing. Only those treatments involving guardrail on its own showed a statistically reliable reduction in serious casualty crashes; the estimated effectiveness in reducing serious casualty crashes was 66% and the estimated cost was $5,700 to prevent one casualty. The estimated BCR was 12.9. It is highly desirable that decisions to undertake large-scale investments in guardrail be based on more than just nine individual treatment sites. Other sources of evidence should be sought to strengthen the overall assessment.

Guideposts or Curve Alignment Markers - across the 32 treatments involving guideposts or curve alignment markers (CAMs), a statistically reliable 66% reduction in serious casualty crashes was found, while the estimated cost to prevent one casualty was $10,200 and the BCR was 8.6. Given the relatively large number of sites in the sample (32) and the high level of statistical significance, this appears to be a robust finding. Treatment effectiveness may vary according to factors such as the types of location/route treated, the crash numbers and types before treatment, and traffic volumes through treatment sites.

Improved Skid Resistance/Re-seal of Road - the estimated cost-effectiveness of reducing casualties for the 29 treatments that involved improving skid resistance or resealing road surfaces was $6,400, the estimated reduction in serious casualty crashes was 40% and the BCR 11.5. This type of treatment required the second lowest investment on average to save one casualty among those treatments that targeted off-path crashes and showed statistically reliable reductions in serious casualty crashes. While the importance of skid resistance should not be understated, it is also noteworthy that skid resistance deteriorates markedly over time, especially on highly-trafficked routes with a high proportion of heavy vehicles. As such, improved skid resistance and surface resealing should only be regarded as a long-term solution at blackspots, if supported with adequate maintenance.

Install Median or Duplicate Carriageway - ten projects involved median construction or carriageway duplication, at an aggregate cost $56,200 for every casualty saved, which is almost ten times greater than the best performing treatment type implemented to address off-path crashes, namely guardrail, and much more costly than all of the treatment categories found to reduce serious casualty crashes at intersections. Carriageway duplication and medians reduced serious casualty crashes by 43%, resulting in a BCR of just 1.1. The treatment costs for these ten projects exceeded the estimated monetary benefits due to the 56% reduction in serious casualty crashes by more than $5M. Unless crashworthy barriers are provided as part of the treatment to prevent collisions with hazards within medians, as well as cross-over crashes, this category of treatment is not considered compatible with the principles of the Safe System road safety philosophy.

Serious Trauma Involving Intersection Crashes

Intersection treatments were categorised as involving new traffic signals, modifications to existing signals or geometric changes to unsignalised intersections; some treatments, such as adding right turn lanes, also required geometric changes at existing signals. Treatment types that were successful in reducing serious casualty crashes at intersections are summarised in Table 7. Of those evaluated, only seven intersection treatment types were found to have resulted in statistically reliable reductions in serious casualty crashes. The treatment type with the fewest sites treated was the staggered-T (14 treatments), while the most common treatment type involved the construction of 133 new roundabouts.

Table 7- Intersection treatments that delivered statistically reliable reductions in serious casualty crashes (H – high; M – medium; L – low)

Treatment Type	Cost Effectiveness ($k per Casualty Saved)	Estimated Serious Casualty Crash Reduction (%)	BCR (using Austroads Crash Costs)	NPW ($M)	Safe System Compatible	Number of Treated Sites
New Mast Arm	2.1	38.6	32.2	33.8	L	39
Splitter Island/ Median Installation	4.7	43.6	13.7	29.0	M	45
Add Right Turn Lane	7.0	37.7	8.9	34.0	L	32
FCRT	8.2	27.4	8.5	67.0	L-M	98
Roundabout Installation	8.9	82.0	6.7	145.8	H	133
Staggered T	11.9	93.6	6.0	12.5	M	14
New Signals	18.7	50.8	3.5	38.9	L-M	57

Traffic Signals; New Mast Arms - in contrast with past studies, 39 projects involving mast arm installations at existing traffic signals were found to have reduced serious casualty crashes by 39%. Of the seven intersection treatment types found to be effective in reducing serious casualty crashes, mast arms had an estimated BCR of 32.2 and were the most cost-effective, requiring just $2,100 to save one casualty. Past studies did not show statistically reliable reductions due to the use of mast arms. It is recommended therefore that these 39 treatments be examined more closely to ensure that the observed reductions were the result of mast arms per se, rather than other accompanying treatments.

Traffic Signals; Fully Controlled Right Turn Phases - the 98 treatments which involved the installation of fully controlled right turn (FCRT) phases at existing intersection signals resulted in a 27% reduction in all serious casualty crashes at treated sites and an overall BCR of 8.5. It cost on average $8,200 to save a single casualty using this treatment type. While the main savings are likely to be in right-turn-against crashes, reductions may also have resulted in pedestrian and, potentially, rear-end collisions. The estimated serious casualty crash reduction for FCRT phases will be dependent upon the number of such phases introduced per treatment at any given intersection. As such, the estimated reduction of 27% is an average value reflecting the numbers of phases per treatment and may be higher or lower for more or fewer phases per treatment.

Traffic Signals; New - the current program involved installing new signals at 57 blackspot intersections, with a resultant reduction in serious casualty crashes of 51% and an estimated BCR of 3.5. To prevent one casualty at newly signalised intersections, it cost $18,700, more than double the corresponding cost for roundabouts and four times the cost of splitter islands. While splitter islands (and, to a lesser extent, roundabouts) may be unsuitable at some intersections, the large differences in performance between these alternative forms of control underline the importance of the choice of intersection treatment type with respect to effectiveness, cost-effectiveness and efficient use of public funds. Close scrutiny of treatment choice is clearly warranted, especially where intersection signals are being considered, as they are unforgiving of driver errors, especially with respect to the characteristic, typically very severe, side-impact collision type and hence incompatible with the principles underpinning the Safe System philosophy.

Geometric Design; Add Right Turn Lane - there were 32 intersections at which at least one additional right turn lane was provided, at an average cost to save one casualty of $7,000 and a BCR of 8.9. The estimated 38% reduction in serious casualty crashes is expected to result mainly from reductions in rear-end and lane-changing types of collision, though no analysis by crash type was undertaken. The various effectiveness measures reported in Table 7 will be affected by the numbers of right turn lanes added per intersection treated.

Geometric Design; New Roundabout – new roundabouts constructed at 133 intersections resulted in an estimated 82% reduction in serious casualty crashes, an overall BCR of 6.7. while the cost per casualty saved was $8,900. Among the major forms of intersection control evaluated, roundabouts were found to be the most cost-effective treatment for intersection crashes; they proved to be more than twice as cost-effective as the main alternative, namely, new intersection signals and require only a fraction of the ongoing operating and maintenance costs of intersection signals. Although splitter islands and median treatments showed greater cost-effectiveness, they are generally suited to intersections with low-traffic volumes on the minor roads. Moreover, roundabouts are conceptually compatible with the Safe System road safety philosophy in that they are much more forgiving of road user errors and provide a long-term solution to managing the kinetic energy of vehicles on conflicting paths to levels that are typically low-risk to vehicle occupants. In each of several evaluations of blackspot treatments by MUARC over the past fifteen years, similar high-impact results have been found for roundabouts.

Geometric Design; Splitter Islands/Median Installation - a highly statistically reliable reduction in serious casualty crashes was found as a result of constructing splitter islands and medians. On average, one casualty could be prevented for the expenditure of $4,700 and a BCR of 13.7 was achieved. Splitter islands better define the presence of an intersection and the appropriate vehicles paths, reducing the likelihood of cross-traffic type crashes, as well as helping to reduce manoeuvring speeds, by restricting lane widths.

Geometric Design; Staggered-T Treatments - fourteen intersections received staggered-T layouts. Serious casualty crashes fell by an estimated 93% and a BCR of 6.0 achieved. It cost $11,900 per casualty saved, which is markedly superior to the performance of new signals but inferior to roundabouts. These large reductions in serious casualty crashes may be the result of staggered-T layouts being constructed at intersections with poorly defined conflict areas, in high-speed environments and with few visual cues to alert drivers to the presence of the intersections. Despite these impressive results, staggered-T treatments can be unforgiving of driver and rider errors, especially in high-speed settings and, so, are only partially compatible with Safe System principles. Also, staggered-T layouts may not maintain these large gains over the long-term, as traffic volumes grow and, in some cases, surrounding areas develop. A systematic, periodic monitoring procedure should therefore be established to ensure any decay in treatment effects is detected early to enable long-term solutions to be implemented promptly.

Variations in Treatment Effectiveness

Important differences in the effectiveness of various program categories were found:

- Metropolitan versus rural - all casualty crashes in metropolitan Melbourne fell by 27%, while the corresponding reduction was 42% in rural areas. Similarly, reductions in serious casualty crashes were 30% and 44% in metropolitan and rural areas, respectively. A possible explanation for this may be that crash types tend to be more diverse in metropolitan areas compared with rural areas, resulting in more efficient targeting of a more precisely defined profile of crashes in rural areas.

- Arterial versus local roads - treatments implemented on local roads produced greater reductions in both casualty and serious casualty crashes than on arterial roads (i.e., 61% serious casualty crashes by compared with just 27% on arterial roads). A probable contributing factor to this difference is the distribution of treatment types along these roads; early half of local roads treatments were roundabouts, which were found to reduce serious casualty crashes by over 80%. In contrast, the major form of treatment on arterial roads was traffic signals, with an estimated reduction in serious casualty crashes of just 50%; very few treatments on arterial roads were roundabouts.

- Intersection versus off-path crashes - intersection treatments were about 50% more effective in reducing serious casualty crashes than were off-path treatments (i.e., 45% compared with 29%), which may because serious casualty crashes at intersections are more highly concentrated and, so, more amenable to effective and efficient treatment.

Having regard to the results of this and past evaluations (including limitations on sample sizes), and assessment of operational characteristics of treatment categories, several strong findings can help guide future investment decisions for safe road infrastructure:

(i) for off-path crashes, treatment types that can be relied upon to deliver reductions in serious casualty crashes are shoulder sealing; guardrail erection; guide-posts or curve alignment markers to delineate road alignment and improved skid resistant surfaces (or pavement re-sealing). Only guardrails are considered largely compatible with the principles of the Safe System over the long-term future. Moreover, guardrails were superior to other treatment types in terms of cost-effectiveness; guardrail was found to prevent a single casualty at far lower cost than other treatment types. However, only nine such projects were evaluated, suggesting that further assessment is required to ensure conclusions are fully justified and supported by other relevant evidence.

(ii) for intersection crashes, new roundabouts; new signals; fully-controlled-right-turn phases at existing signals; splitter islands and median installations; staggered-T layouts; and the addition of right-turn lanes treatment types can be relied upon to reduce serious casualty crashes; only roundabouts are highly compatible with the Safe System road safety philosophy. Other forms of intersection treatment, while effective, still permit high-speed, high-severity impacts to occur as a result of simple errors by drivers. As such, they can deliver serious casualty savings in the short-term, which may be eroded by growth in traffic, increases in travel speeds, urban development, population ageing and growing incompatibility between vehicle types. The cost to save a casualty was more than double for new signals than for roundabouts, while splitter islands and medians cost less than roundabouts but are unlikely to provide long-term solutions compatible with the “Safe System”; for many intersections, splitter islands may eventually need to be replaced with superior treatments. For mast arms, further investigation is needed as noted earlier.

(iii) for vulnerable road user crashes, consistent with the results of past MUARC evaluations, no statistically reliable reduction was found in serious casualty crashes. Strengthened approaches to treating pedestrian black spots should be considered.

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