Findings on the Effectiveness of Intersection Treatments included in the Victorian Statewide Accident Black Spot Program

Nimmi Candappa, Jim Scully, Stuart Newstead and Bruce Corben,
Monash University Accident Research Centre

1.0 Abstract

Accident Black Spot programs have played a major role in creating and sustaining safer roads through significant investments in safer road infrastructure. Black Spot programs target sites of relatively high crash concentrations over a defined period of time. The most recent such program in Victoria, the Statewide Accident Black Spot Program, involved an expenditure of $240M (AUD) over the four-year period from 2000/01-2003/04 and included treatments for intersection crashes, as well as off-path and pedestrian crashes.

Following a comprehensive evaluation of this program, this paper presents findings on the effectiveness of the overall program in reducing casualty and serious casualty crashes and the effectiveness of the intersection treatments, presented in terms of crash reduction, BCR and cost-effectiveness, at both category and individual treatment type levels.

Determining the effects of infrastructure investments, and in particular effects of specific treatment types, ensures more effective investments in the future.

2.0 Background

The Victorian State Government committed $240M (AUD) over a four-year period (2000/01-2003/04) towards a Statewide Black Spot program. The program involved an Accident Black Spot component and a Potential Black Spot component and included treatments to address intersection, off-path and vulnerable road user crashes. Upon completion of the program, VicRoads commissioned Monash University Accident Research Centre (MUARC) to evaluate the effectiveness of the program in achieving its aim of reducing casualty crashes at the treated sites. This paper focuses only on the sites included in the Accident Black Spot component of the program and presents overall program effectiveness as well as detailed findings on the effectiveness of the intersection treatments.

The evaluation of the program was based on a quasi-experimental before and after study design, comparing the changes in crash frequency at the 804 treated sites meeting evaluation criteria, before and after treatment, with respect to identified control sites. Poisson regression analysis was used to evaluate the sites at program and category levels.

3.0 Overall Program Effectiveness

Overall, the program was found to be effective in reducing crashes at the treated sites at a 5% significance level. Crashes where at least one occupant was injured (all casualty crashes) were reduced by around 31%, crashes where at least one person was killed or taken to hospital (serious casualty crashes) were reduced by approximately 35% and crashes where at least one person was injured but no one was killed or taken to hospital (other injury crashes) were reduced by around 30% (see Table 1). All these findings were highly significant.

Table 1: Estimated crash reductions at Black Spot program level for all casualty crashes, serious casualty crashes only and other injury crashes only

Types of Casualty Crashes	Estimated Crash Reduction (%)	Statistical Significance	Annual Crash Frequency at Treated Sites Before Treatment	Annual Casualty Crash Saving
All Casualty	31.3	<0.0001	1,708	535
Serious	34.5	<0.0001	517	179
Other Injury	29.8	<0.0001	1191	355

These reductions convert to an estimated 204 lives, 3,116 serious injuries and 8,505 other injuries being saved over the life of all the treatments included in the program based on an average treatment life of 15.8 years. Calculation of the number of lives or injuries prevented was based on the average number of people involved in the crashes, (Table 2).

In economic terms, crash savings of $494M were produced from the capital expenditure of $202M for the final Accident Black Spot component of the program, based on a discount rate of 6%. The corresponding Benefit Cost Ratio (BCR) for the whole program was 2.4 and the estimated Net Present Worth was $287M.

Table 2: Inferred estimates of the number of injuries prevented over the project life of each treatment for the program as a whole

Type of Injury	Fatality	Serious Injury	Other Injury	All Casualties
Crash Sample Used to Infer Results	Serious Casualty Crashes	Serious Casualty Crashes	All Casualty Crashes	All Casualty Crashes
Estimated Crash Reduction (%)	34.5	34.5	31.3	31.3
Crashes Saved Over Treatment Life	2,587	2,587	7,655	7,655
People Injured Per Crash (Metro)	0.054	1.21	1.11	1.47
People Injured Per Crash (Rural)	0.12	1.20	1.11	1.57
Injuries Prevented	204	3,116	8,505	11,499

3.1 Metropolitan versus Rural Site Effectiveness

The program proved to be effective at both metropolitan and rural sites. While the Black Spot treatment sites were selected and prioritised based on crash history of the sites and predicted benefits, some consideration was given to its locality. The proportion of metropolitan to rural treated sites was around 53% to 46%, after removal of some sites that did not meet evaluation criteria. Three quarters of metropolitan treatments were intersection-related compared to approximately 57% in rural regions. At metropolitan treated sites, highly significant all casualty crash reductions of 27% were achieved compared to around 42% in rural areas, (Table 3). Similarly, estimated reductions in serious casualty crashes at treated rural sites were higher (44%) than estimated reductions at their metropolitan counterparts (30%). All these crash reduction estimates were highly significant.

Table 3: Comparison of estimated casualty crash reductions associated with Black Spot treatments in metropolitan and rural areas.

Treatment Location	Estimated Casualty Crash Reduction (%)	Statistical Significance	Annual Casualty Crash Frequency at Treated Sites Before Treatment	Annual Casualty Crash Saving
Metropolitan				
All Casualty	27.0	<0.0001	1203	325
Serious	29.8	<0.0001	344	103
Other Injury	25.5	<0.0001	859	219
Rural				
All Casualty	41.8	<0.0001	505	211
Serious	44.2	<0.0001	174	77
Other Injury	41.5	<0.0001	332	138

3.2 Local Versus Arterial Road Effectiveness

Of the total sites examined, 534 (65%) were located on the Arterial Road Network, and 270 (33%) were on the Local Road Network. It can be seen that sites on the local road network resulted in an estimated 56% reduction in the number of casualty crashes in the post-treatment period, compared with a 24% reduction for sites on the arterial road network (Table 4). Similarly, sites on the local road network resulted in a 61% reduction in the number of serious casualty crashes post-treatment, compared with 27% for crashes on the arterial network. Of the treatments installed on local street sites, 80% were intersection treatments compared with 60% on arterial roads. All these crash reduction estimates were highly significant.

Table 4: Comparison of estimated casualty crash reductions associated with Black Spot treatments on the Local Road Network and the Arterial Road Network

Road Network	Estimated Crash Reduction (%)	Statistical Significance	Annual Crash Frequency at Treated Sites Before Treatment	Annual Casualty Crash Saving
Local				
All Casualty	56.4	<0.0001	279	158
Serious Only	61.0	<0.0001	84	51
Other Injury Only	55.4	<0.0001	195	108
Arterial				
All Casualty	24.1	<0.0001	1429	344
Serious Only	26.8	<0.0001	433	116
Other Injury Only	22.5	<0.0001	996	224

4.0 Intersection Treatment Component

A major component of the Accident Black Spot Program consisted of treatments to address crashes at intersections. These included new roundabouts and roundabout modifications, new signals and signal remodelling, additional lanes, lighting at intersections, intersection geometry modifications, and improvements to intersection definition.

4.1 All Casualty Crash Reduction

Intersection treatments produced an estimated highly significant reduction in all casualty crashes of around 43%, with a capital cost of around $70M. Table 5 presents the estimated effects of the individual treatments on crash numbers at the treated intersections. Grey shaded rows identify those treatments that did not produce statistically significant findings. These have been included to provide feedback on the performance of some common treatments, however the reader should interpret findings with care. Of the statistically significant findings, the most effective means of reducing intersection casualty crashes were the installation of a new roundabout (77% reduction in casualty crashes, $p<0.0001$), creating a staggered-T intersection (81%, $p=0.0017$), splitter island or median installations (43%, $p<0.0001$) and widening around a right-turn lane (82%, $p=0.001$). Estimated crash reduction for new signals was approximately 50%, fully-controlled-right-turns (FCRT) effected reductions of around 27%, and adding a right-turn lane reduced crashes by an estimated 51%. Findings suggested that mast arms reduced casualty crashes by 33%. However, this finding is not supported by previous Black Spot treatment evaluations of mast arm effectiveness and should be interpreted with care. It is a possibility that any additional works at the treated intersection may have contributed to the estimated reduction factor attributed to mast arm effectiveness.

Table 5: Estimated percentage casualty crash reduction attributable to the Accident Black Spot Component of the Statewide Black Spot Program by Treatment Type

Treatment Type			Number of Treated Sites	Total Capital Works Cost ($)	Est. % Casualty Crash Reduction	Statistical Significance Probability
Level 1	Level 2	Level 3				
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 Installation	**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

4.2 Serious Casualty Crash Reductions

Of the seven treatments that produced statistically significant reductions in serious injury crashes, the evaluation found roundabouts and staggered-T intersection designs to produce the largest reductions, 82% ($p<0.0001$) and 94% ($p=0.0366$) respectively (Table 6). Similar to the casualty crash category findings, of these treatments roundabouts produced the highest reduction with the lowest probability that the reductions were a result of chance and not attributable to the treatment. It was estimated that new signals reduced serious casualty crashes by around 51%, fully-controlled-right-turns by around 27%, new mast arms by 39% and splitter island or median installations effected reductions in serious casualty crashes by 44%. All produced Benefit Cost Ratios of over 1.

Table 6: Intersection treatments that delivered statistically reliable reductions in serious casualty crashes (H – high; M – medium; L – low)

Treatment Type	Cost Effectiveness ($k per Casualty Saved)	Estimated Serious Casualty Crash Reduction (%)	BCR (using VicRoads Crash Costs)	NPW ($M)	Safe System Compatible	Number of Treated Sites
Roundabout Installation	8.9	82.0	4.3	85.2	H	133
Staggered T	11.9	93.6	4.2	8.0	M	14
Splitter Island / Median Installation	4.7	43.6	9.1	18.5	M	45
New Signals	18.7	50.8	2.2	18.8	L-M	57

FCRT	8.2	27.4	5.3	38.6	L-M	98
New Mast Arm	2.1	38.6	20.0	20.6	L	39
Add Right-Turn Lane	7.0	37.7	5.8	20.8	L	32

5.0 Discussion

Of those evaluated, a total of seven treatment types employed at intersections were found to have resulted in statistically reliable reductions in serious casualty crashes. While acknowledging that not all treatments are suitable at all intersections, the large differences in cost-effectiveness between these alternative forms of intersection control strongly indicate that the choice of treatment type for intersections has the potential to dramatically affect serious injury outcomes, as well as the efficient use of public funds. For these reasons, close scrutiny of treatment choice is clearly warranted. Two intersection treatments in particular were revealed to be highly effective in reducing serious injury intersection crashes – roundabouts and staggered T-intersections. According to the evaluation, staggered-T intersections reduced almost completely the incidence of serious injury crashes (94%) while roundabouts reduced serious injury crashes by around 82%. While the evaluation results indicate highly effective treatments, it is worth considering possible reasons for these and establishing the potential for these treatments to produce consistently similar effectiveness in future program investment.

A recent focus in road safety in Victoria is working towards creating a ‘Safe System’, one in which a road environment is forgiving of road user error and is unlikely to allow serious injury crash consequences. In theory, roundabouts are considered to be one of the treatments more compatible with the Safe System philosophies. A roundabout, through its induced impact angle and speed reductions and hence reduced impact forces, and its physical separation of vehicles on collision course, provides a long-term solution to managing the kinetic energy of a crash to levels that are typically low-risk to vehicle occupants. Should a driver err in suitable gap selection for example, a resultant crash is unlikely to produce a serious injury at a roundabout. While in theory roundabouts generally encompass the Safe System philosophy, the evaluation shows they have not removed completely the potential for serious injury. Converting a cross intersection to a staggered T-intersection reduces the number of conflict points, and effects slower speeds on at least one leg of the intersection, reducing the likelihood of a serious injury thus creating partial compatibility with the Safe System principles. T-intersections in general however can still allow severe crash consequences, thereby being somewhat unforgiving of road user error. Periodic monitoring of crash history at these treated staggered T-intersections can provide an indication of the treatment’s long-term effectiveness. The more consistent a treatment with the Safe System principles the more likely a consistent reduction in serious injury crashes is maintained at a treated site.

A discussion of the main findings is presented below.

Metropolitan versus Rural

All casualty crashes in metropolitan Melbourne fell by 27%, while the corresponding reduction was around 42% in rural areas. Similarly with the serious casualty crashes, reductions were 30% and 44% in metropolitan and rural areas, respectively. Potential reasons for this may be that the crash types tend to be more diverse in metropolitan areas compared with rural areas, and therefore implemented treatments in rural areas are likely to be more effective in addressing a more precisely defined profile of crashes. Additionally, there is generally less pedestrian activity in rural areas, particularly on arterial roads. Although not discussed in this paper, the program evaluation indicates that the implemented pedestrian treatments were ineffective in reducing crashes and in fact may have increased pedestrian crash numbers. This may also have contributed to the fact that reductions in metropolitan areas are lower than in rural areas. Further analyses, beyond the scope of the current study, could be carried out to provide a better understanding of the differences evident in the performance of the rural and metropolitan components of this program.

Arterial versus Local Roads

Similarly, treatments implemented on local roads produced greater reductions in casualty crashes than those on arterial roads. A major contributing factor to this is the distribution of treatment types along these roads. Nearly half of the treatments on local roads were roundabouts, which were estimated to reduce serious casualty crashes by around 82%. In contrast, the major form of treatment on arterial roads (33%) was traffic signals, with an estimated reduction in serious casualty crashes of around 50%.

Geometric Design - New Roundabout

New roundabouts were constructed at 133 intersections as part of the program. As a result of the treatments, serious casualty crashes fell at the treated sites by an estimated 82% and an overall BCR of 4.3 for these 133 treatments was achieved. The cost effectiveness for a roundabout treatment was $8.9k. That is, it cost $8.9k to prevent one casualty. Among the major forms of intersection control evaluated, roundabouts were found to be the most cost-effective treatment for intersection crashes; indeed, they proved to be more than twice as cost-effective as the main alternative, namely, new intersection signals (cost effectiveness of $18.7k) and require only a small proportion of the ongoing operating and maintenance costs of intersection signals. Although treatments like splitter islands (and median treatments), have greater cost-effectiveness, these are generally suited to intersections with low-traffic volumes on the minor roads. Moreover, as mentioned earlier, roundabouts are conceptually compatible with the Safe System road safety philosophy. In each of several evaluations carried out on Black Spot treatments by MUARC over the past fifteen years, similar high-impact results have been found for roundabouts; both casualty crashes and crash costs have fallen sharply. Inadequately designed roundabouts, namely insufficient deflection and central island size, and larger roundabout designs may provide a potential explanation for the fact that serious injury crashes still exist at roundabouts.

Geometric Design - Staggered-T Intersection Designs

Fourteen intersections were converted to staggered-T layouts, with an estimated reduction in serious casualty crashes of 93% and a BCR of 4.2. The estimated cost-effectiveness of staggered-T treatments is $11.9k per casualty prevented. This cost-effectiveness is markedly superior to the performance of new signals but is not as low as that of roundabouts. While the staggered-T treatment appears capable of delivering large reductions in serious casualty crashes, it too is unforgiving of road user errors, especially in high-speed settings and, so, is only partially compatible with the Safe System philosophy. The very large reductions in serious casualty crashes may be the result of constructing staggered-T layouts at intersections with poor definition of conflict areas, high-speed environments and relatively few visual cues to alert drivers to the presence of the intersection. As such, staggered-T layouts may be unlikely to maintain these safety gains over the long-term, as traffic volumes build and, perhaps, surrounding areas develop. It is recommended, therefore, that a systematic, periodic monitoring procedure be established to ensure that any decay in treatment effects are detected early so long-term solutions can be implemented promptly.

Traffic Signals - New

New signals were installed at 57 Black Spot intersections, with a resultant reduction in serious casualty crashes of 51% (on average) and an estimated BCR of 2.2. To prevent one casualty at intersections treated with new signals, it cost $18.7k, more than double the equivalent cost for roundabouts and four times the cost of splitter islands. Traffic signals, while regulating movement, the design itself tends not to physically reduce the potential for a serious injury crash from occurring should a road user error be made, especially with respect to the very severe side-impact collision that characterises serious trauma at traffic signals, thereby making them generally incompatible with the principles underpinning the Safe System philosophy. It is noted that the locations of new signal installations can also impact the overall effectiveness of the treatment.

Traffic Signals - New Mast Arms

In contrast to past evaluations, 39 projects involving mast arm installations at existing traffic signals showed a statistically reliable reduction in serious casualty crashes of 39%. Of the seven intersection treatment types found to be effective in reducing serious casualty crashes, mast arms were the most cost-effective, requiring an average expenditure of just $2.1k to save one casualty and had an estimated BCR of 20.0.

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 in serious casualty crashes were the result of mast arms per se, rather than other accompanying treatments.

Mast arms are also not Safe System compatible as they assist in greater definition of the intersection and reinforcing signal regulations but do not prevent serious injury consequences.

Traffic Signals – Fully-Controlled-Right-Turn Phases

A total of 98 treatments involving the installation of fully-controlled-right-turn phases at existing intersection signals resulted in a 27% reduction in all serious casualty crashes at treated sites and an overall BCR of 5.3 for the group of treatments. It cost on average $8.2k 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.

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 (around 44%). It was estimated that, on average, one casualty could be prevented through the expenditure of $4.7k and that a BCR of 9.1 was achieved. Splitter islands better define the presence of an intersection and the appropriate vehicle paths, reducing the likelihood of cross-traffic crashes, as well as helping to reduce manoeuvring speeds, by restricting lane widths. Therefore it can encourage slower manoeuvring speeds from drivers, creating lower kinetic energy in a potential crash and so can be considered partially Safe System compatible. This treatment is more suitable to an intersection with at least one minor road.

Geometric Design - Add Right-Turn Lane

There were 32 intersection treatments at which at least one additional right-turn lane was provided per intersection. The average cost to save one casualty was $7.0k and the resultant BCR was 5.8. The estimated reduction in serious casualty crashes of 38% is expected to be mainly the result of reductions in rear-end and lane-changing types of collision, though no analysis by crash type has been undertaken. The level of effectiveness will be influenced by the numbers of right-turn lanes added per intersection treated. That is, four additional right-turn lanes per treatment can be expected to save more serious casualties on average than if just one or two additional lanes were added per treated intersection. Additional right-turn lanes are not considered to be Safe System compatible.

6.0 Reference

This paper is based on the full report commissioned by VicRoads: Scully, Jim, Newstead, Stuart, Corben, Bruce, & Candappa, Nimmi - ***Evaluation of the Effectiveness of the $240M Statewide Blackspot Program – Acccident Blackspot Component, Project Number RSD-0130,*** Monash University Accident Research Centre, September, 2006