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Foreword

The Australian Government has been funding black spot projects since 1990 with the aim of reducing the social and economic costs of road trauma by investing in projects that improve safety at hazardous road locations.

On three occasions the Government has requested BITRE to evaluate the effectiveness of the program from safety and economic viewpoints.

This, the third evaluation, is the largest in terms of the number of projects included and the most advanced in analytical techniques.

The principal researchers were Dr Mark Harvey (project leader) and Dr Troy Delbridge. Joel Mallet was a team member for part of the project. Terry Johnson contributed computer data management expertise. Thomas Belcher, James Driver, Joanna MacFadyen, and Alex Talberg made contributions during the early stages of the project. Peter Johnston and Tim Risbey commented on drafts.

Phil Potterton, Rob Stewart and Gary Dolman provided executive oversight while holding the posts of Executive Director–BITRE, General Manager–Infrastructure and Transport, and Head of BITRE, respectively.

BITRE is grateful for the assistance of state and territory road agencies for providing data. Department of Infrastructure and Transport staff responsible for administration of the National Black Spot Program, Greg Moxon and Judy Raine, assisted with data and advice.

Consultants Data Analysis Australia (DAA) Pty Ltd, ARRB Group Ltd, and John Piper Traffic Pty Ltd were commissioned to prepare reports. DAA supplied training and advice on statistical methodology and undertook the final statistical analysis. Road safety experts from ARRB Group provided input for the development of the treatment classification system.

Gary Dolman
Head of Bureau
Bureau of Infrastructure, Transport and Regional Economics
May 2012

At a glance

The evaluation covered 1599 black spot projects, — 62% of the 2578 Australian Government funded black spot projects approved during the seven-year period 1996–97 to 2002–03 and completed.

The National Black Spot Program (NBSP) is estimated to be reducing fatal and casualty crashes in total at treated sites by 30% and property damage only (PDO) crashes by 26%.

Roundabouts are the most effective treatment, reducing casualty crashes by over 70% and PDO crashes by 50%. New signals during the day and altering the traffic flow direction are the next most highly effective treatments for most severity levels, reducing crashes by more than 50%. No treatment types were found to systematically increase crashes.

On average, each project is estimated to be saving 1.7 reported crashes per year. For individual severity levels, average reported crashes avoided per project per annum are 0.01 fatal, 0.11 serious injury, 0.55 minor injury, 0.61 injury, 0.62 casualty and 1.1 PDO.

The 0.01 rate for fatal crashes implies that one fatal crash is avoided per year for every 100 projects completed.

By extrapolation, the 2578 projects approved between 1996–97 and 2002–03 and completed are estimated to be saving over 4000 reported crashes per annum of which about 1550 are casualty crashes and almost 30 are fatal crashes.

On average, there are 1.1 deaths per fatal crash, so the 2578 projects are estimated to be saving approximately 30 lives per year or one life per year for every 84 projects completed.

The National Black Spot Program has performed well in economic terms achieving an estimated benefit–cost ratio (BCR) of 7.7 at a 3% discount rate and 4.7 at a 7% discount rate based on estimated casualty crashes avoided and project costs. The average net present value per project was $1.4 million at a 3% discount rate and $0.7 million at a 7% discount rate.

Projects in metropolitan areas have higher BCRs (9.9 and 6.1 at the respective discount rates) than projects in non-metropolitan areas (6.1 and 3.7).

The best-performing treatment types in BCR terms are priority signs and altering traffic flow direction with BCRs above 20 at the 3% discount rate and above 15 at the 7% discount rate. Other high-performing treatment types are clearing obstacles, warning signs, roundabouts, and modifying signals with BCRs around 14 or 9 at the respective discount rates. The worst performing treatment types are altering width, realigning intersections, barriers/guardrails, non-skid treatments and lighting treatments with BCRs of 3 and below.

Traffic impact costs of black spot projects at intersections vary greatly between projects and can be substantial. Traffic impact costs can sometimes more than offset the safety benefits, particularly for projects involving traffic signals.

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Executive summary

BITRE's third evaluation of the Australian Government's Black Spot Program is the largest in terms of the number of projects included and the most advanced in analytical techniques. The evaluation addresses three principal questions.

- How effective are black spot treatments in reducing crash rates?
- How many crashes are avoided and lives saved annually as result of the program?
- Is the program a good use of resources compared with alternatives?

The first two questions are answered using statistical analysis — Poisson regression — which compares crash counts before and after black spot projects.

The third question, which concerns the economic worth of the program, is answered using cost–benefit analysis.

Scope and data

The evaluation aimed to include all Australian Government funded black spot projects approved during the seven-year period 1996–97 to 2002–03 inclusive and that had been completed.

The final database used for the regression analysis contained 1599 projects, which was 62% of the 2578 projects in scope. Crash data from project sites covered periods up to seven years before and after project implementation. The database contained 31 522 casualty crashes and 40 302 property damage only (PDO) crashes.

Effectiveness

The program is estimated to be reducing fatal and casualty crashes in total at treated sites by 30% and reported PDO crashes by 26%.

Roundabouts are the most effective treatment, reducing casualty crashes by over 70% and PDO crashes by about 50%.

New signals during the day and altering the traffic flow direction are the next most highly effective treatments across most severity levels, reducing crashes by more than 50%.

For treatment types with statistically significant effects, crash reduction factors are mostly in the 20% to 50% range.

No treatment types were found to systematically increase crashes. Warning signs and priority signs may have little effect at night.

The sizes of the estimated crash reduction factors for individual treatment types are generally consistent with factors reported in the literature. Exceptions are:

- altering road width — considerably more effective
- roundabouts, medians, and realigning intersections — slightly more effective, and
- lighting treatments at night, non-skid treatments and realigning road lengths — less effective.

Of the projects in the database, 38% consisted of multiple treatments undertaken together — in three cases this was as many as six.

Some pairs of treatment types occurred with sufficient frequency for the statistical analysis to discern interactions between treatments.

Diminishing returns, that is, the combined impact less than the sum of the impacts of the treatments implemented singly, occur for turning lanes combined with any of medians, modifying signals and other turning lane treatments.

Synergies, that is, the combined impact greater than the sum of the impacts of the treatments implemented singly, occur between the treatment pairs sealing/resealing–line marking, altering road width–realigning road width, medians–priority signs, and sealing/resealing–realigning road length, and between pairs of modifying signals treatments.

Sites are selected for black spot projects because of past high crash rates. In some cases, the high crash rates are due to chance rather than an underlying road safety problem. Without any project being undertaken, the high crash rate is likely to be lower (regress to the mean) in subsequent periods. Crashes during the interval of time between the date on which the funding application was submitted to the Australian Government and the date on which work on the project commenced provide an estimate of the pre-treatment crash rate, uncontaminated by selection bias (selecting projects due a chance high crash rate).

Pre-application crash rates were found to be higher than post-application crash rates by statistically significant amounts in four of the statistical models estimated — 25% for fatal crashes, 17% for serious injury crashes, 6% for injury crashes and 7% for casualty crashes. A certain amount of regression to the mean is to be expected in any black spot program.

Other findings :

- Treatments are becoming more effective over time.
- Treatments are more effective in non-metropolitan areas compared with metropolitan areas (probably due to the higher speed environments in rural areas) and more effective on local roads compared with state roads.
- Significant variations exist in treatment effectiveness between jurisdictions for some regression models. Much of the variation can be attributed to differences in the way crashes are assigned to sites and in the crash reporting requirements for PDO crashes.
- Only the PDO crash model found that projects selected by road safety audit were less effective than projects selected by benefit–cost ratio by a statistically significant amount.

Crashes avoided

Estimated crashes avoided are presented for 2006 — the first full year when all the projects in the database had been completed.

The average number of reported crashes avoided per project in the database was 1.7 crashes.

For individual severity levels, average reported crashes avoided per project were 0.01 fatal, 0.11 serious injury, 0.55 minor injury, 0.61 injury, 0.62 casualty and 1.1 PDO. The 0.01 rate for fatal crashes implies that one fatal crash is avoided per year for every 100 projects completed.

Making indicative adjustments for unreported minor injury and PDO crashes, there could be as many as 6.0 crashes avoided per year of which 2.3 is a casualty crash and 3.7 a PDO crash.

Extrapolating across the entire program, the 2578 projects approved between 1996–97 and 2002–03 and completed are estimated to be saving over 4000 crashes per annum of which about 1550 are casualty crashes and almost 30 are fatal crashes.

On average, there are 1.1 deaths per fatal crash, so the 2578 projects are estimated to be saving about 30 lives per year or one life per year for every 84 projects completed. The indicative under-reporting adjustments for minor injury and PDO crashes increase the total number of crashes avoided to 14 500 of which 5700 are casualty crashes.

Even though treatments in non-metropolitan achieve higher crash reduction factors compared with metropolitan areas, predicted numbers of crashes avoided per project per year are higher in metropolitan areas. Higher traffic levels in metropolitan areas lead to greater crash exposure, so the crash reduction factor is applied to higher base crash rate.

Economic evaluation

In economic terms, the National Black Spot Program has performed well overall, achieving an estimated benefit–cost ratio (BCR) of 7.7 at a 3% discount rate and 4.7 at a 7% discount rate — hereafter written as 7.7 (4.7) — based on estimated casualty crashes avoided and project construction, operating and maintenance costs. At 4% and 5% discount rates, the BCRs are 6.7 and 5.9 respectively.

The present value of average benefits per project is $1.6 million ($0.9 million) comprised of 24%, 63% and 13% savings in fatal, serious and minor injury crashes respectively.

The present value of average costs per project is $0.2 million regardless of discount rate. Subtracting costs from benefits, the average net present value per project is $1.4 million ($0.7 million).

Projects in metropolitan areas have higher BCRs, 9.9 (6.1), than projects in non-metropolitan areas, 6.1 (3.7). The greater average numbers of crashes avoided per project in metropolitan areas are offset by higher unit crash costs for rural areas so benefits per project are fairly similar. However, significantly higher project construction costs in non-metropolitan areas cause the BCRs to differ.

BCRs for six of the eight jurisdictions are bunched in a range from 6.4 (3.9) for Queensland to 8.5 (5.2) for Victoria. The two smallest jurisdictions had outlying results, ACT 13.0 (7.9) and Northern Territory –0.2 (–0.1), but due to small sample sizes, it is uncertain whether they are representative.

Single-treatment projects have a BCR of 9.1 (5.4). Each additional project reduces the BCR indicating diminishing returns from multiple-treatment projects with a BCR of 4.8 (3.1) for projects comprised of four or more treatments. This indicates successful combining of treatments.

The best performing treatment types in BCR terms are priority signs and altering traffic flow direction with BCRs above 20 (15).

Other high performing treatment types are clearing obstacles, warning signs, roundabouts, and modifying signals with BCRs around 14 (9).

The worst performing treatment types are altering width, realigning intersection, barriers/guardrails, non-skid treatments and lighting treatments with BCRs of 3 (2) and below.

BCRs show no general trend over time.

The BCRs reported so far are based on benefits from casualty crashes avoided only. Adding benefits from PDO crashes avoided increases benefits by 8.5% (13% urban and 5% rural) regardless of discount rate. The increase could be as high as 30% if estimated unreported PDO crashes were included.

Project costs

The total reported cost of the 1599 projects in the database in 2007 dollars was $251 million, an average cost per project of $157 000.

A regression analysis of project costs in 2007 dollars indicated that project construction costs were rising by 4.7 per annum in real terms, much higher than the BITRE Road Construction and Maintenance Price Index, which rose at 0.6% per annum in real terms over the period.

Project construction costs are considerably higher for work undertaken in the months of July, August and October.

Costs are, on average, 55% higher in non-metropolitan areas than in metropolitan areas, and 35% higher on state roads compared with local roads. The greater distances that workers, equipment and materials have to travel to reach sites in rural areas would be a contributing factor.

Treatments involving significant construction works — roundabouts, sealing/resealing, widening, barriers and guardrails, realigning, — and new traffic signals, which involve electronic equipment and software programming, have significantly above-average costs. Treatments involving warning signs, priority signs and line marking have below-average costs.

The proportion of multiple-treatment projects and the number of treatments per multiple-treatment project have been rising over time increasing the average construction costs of projects.

There is strong evidence of significant under-reporting of contributions to project costs from state and territory road agencies and local governments. Upward adjustments were made to project costs to correct for such under-reporting. Adjustments ranged from zero for ACT and Queensland to 19% for South Australia, Victoria and Western Australia. The adjustments caused a 10% increase in the combined cost of all projects to $277 million or $173 000 per project.

Traffic impacts

Black spot projects at intersections can delay traffic imposing additional vehicle operating, time and emissions costs. In cost–benefit analyses of black spot projects, it is normal to omit benefits and costs from traffic impacts altogether. To provide some information about the relative size of traffic impact benefits or costs compared with safety benefits, BITRE commissioned a traffic modelling consultant to undertake case studies of 18 black spot projects at intersections.

The present values of traffic impact costs showed great variation ranging from a benefit of $5.4 million to a cost of $26.1 million present values at a 3% discount rate, or a benefit of $2.8 million to a cost of $16.2 million at a 7% discount rate.

Installation and modification of traffic signals have more pronounced impacts than roundabouts reflecting the higher traffic levels at signalised intersections. Four of the projects produced traffic benefits rather than costs because, at high traffic volumes, roundabouts and signals can improve traffic flows.

In ten cases, the traffic costs were greater than the road safety benefits leading to overall negative net present values for the individual projects.

The case studies show that traffic impact costs of black spot projects vary greatly between projects and can be substantial. They are more likely to be negative and can more than offset the safety benefits, particularly for projects involving traffic signals.

Lessons for future evaluations

The study shows how data from a very large number of black spot projects can be analysed using Poisson regression providing practical solutions to a number of methodological issues that arose in the course of the evaluation. A detailed treatment classification system has been developed specifically to facilitate expost evaluations.

Future evaluations will be quicker, more comprehensive and more accurate with the following:

- improved crash data collection and management
- standardised crash severity definitions and reporting requirements
- a standardised way of assigning crashes to sites
- reduced under-reporting levels for minor injury and PDO crashes
- availability of legal speed limit and traffic flow data for all sites
- greater consistency and care in describing treatments
- reporting of all contributions to project construction costs.

CHAPTER 1
Introduction

Black spot projects

Motor vehicle crashes can usually be attributed to one or a combination of three factors — the road user, the road environment, and the vehicle.

Drivers need to continually adjust their performance levels to meet the changing demands of the road environment. Black spots sites have comparatively high performance demands. Crashes occur when driver performance falls below that required level. Black spot projects alter the road environment to lower the performance demands on the driver at black spot sites, reducing the probability of a crash (BTCE 1995, pp. 11–13).

The sites are either intersections or lengths of road. Common measures or 'treatments' undertaken at intersections are installation of roundabouts, traffic signals and turning lanes. Common treatments applied to lengths of road are sealing the surface, installation of barriers or guardrails, and widening. For the black spot projects in the database for the present study, the median cost in 2007 dollars is around $100 000.

Sites are identified for treatment either because they have had unusually high rate of crashes involving fatalities or injuries in the recent past or because, on the basis of expert judgement, they are expected to do so in the future. The particular type of treatment is selected to address the specific road safety problems at the site taking account of the specific characteristics of the site and traffic throughput. A single project can consist of more than one treatment.

Australian Government Black Spot programs

The first Australian Government black spot program ran from 1 July 1990 to 30 June 1993. A total of 3176 projects were approved with an average cost of $85 000 per project (BTCE 1995, pp. 1–2). The program was reintroduced from July 1996, and was extended a number of times, continuing up to the present. During the 1 July 2002 to 30 June 2006 extension, the program was called the National Black Spot Program (NBSP), the term used to refer to the program throughout this report. Currently, the Australian Government funds black spot projects under the 'Nation Building Program', not as a distinct NBSP.

Previous BITRE Evaluations

In 1995, the Bureau of Transport and Communications Economics (BTCE) evaluated the first black spot program using a sample of 254 projects out of the total of 3176. A simple 'before and after' methodology was used, comparing crash rates (crashes per year) before and after implementation of projects. A benefit–cost ratio of 5.9 was estimated for the program at an 8% discount rate and categorising crashes by severity level.

In 2001, the Bureau of Transport Economics, (BTE) evaluated the first three years of the 1996–2002 program from a sample of 604 projects out of a total of 983 projects completed up to 30 June 1999.

The present study covers projects completed in the same time period as BTE (2001) with an additional four years after.

None of the data from BTE (2001) were reused. BTE (2001) also adopted a 'before and after' approach but with a Poisson regression procedure. The Poisson regression used crash frequencies rather than crash counts as in the present study and had the treatment as the sole explanatory variable. A benefit–cost ratio of 14.4 was estimated for the program at a 7% discount rate.

Present evaluation

The present report is the third BITRE evaluation of Australian Government's black spot program. Each evaluation has progressively employed larger sample sizes and more sophisticated methodologies.

BITRE was asked to undertake the evaluation in 2005, and wrote to state and territory road agencies requesting data. It took considerable time to obtain and process the data and to convert it into a form suitable for analysis. A treatment classification system was developed for the study by BITRE with input from road safety experts from the ARRB Group. The treatments applied for each project had to be classified according to the new system.

Questions addressed

The evaluation answers three principal questions.

Effectiveness

How effective are black spot treatments in reducing crash rates?

Effectiveness can be measured with crash reduction factors — the percentage reduction in the crash rate at a project site engendered by a black spot treatment or combination of treatments, other things being equal. Statistical analysis of crash data provides estimated crash reduction factors for individual treatment types in a range of circumstances.

Crashes avoided, lives saved

How many crashes are avoided and lives saved annually as result of the NBSP?

The pre-treatment annual crash rate at the site of a black spot project multiplied by the crash reduction factor gives an estimate of the number of number of crashes avoided per year as a result of the project.

Economic value

Is the NBSP a good use of resources compared with alternatives?

The resources society invests in black spot projects could be used in other ways to the benefit of society. Cost–benefit analysis (CBA) of the program compares the costs with the benefits expressed in monetary terms to see if it has a net positive value to society as a whole.

Consultancies

Three consultants were engaged to assist. Their reports are published in full in volume 3.

Statistical consultancy

BITRE engaged a consulting firm of expert statisticians, Data Analysis Australia Pty Ltd (DAA) initially to advise on the methodology. DAA's report, Henstridge et al. (2006), reviewed the statistical methodology employed in the two previous BTRE black spot program evaluations, BTCE (1995) and BTE (2001), and proposed a methodology for the current study.

BITRE later decided to engage DAA to undertake the final Poisson regression modelling. DAA (2009) describes the methodology and regression model results.

Road safety consultancy

ARRB Group Ltd (Turner et al. 2008) was engaged to work on three topics.

- a review of how road safety treatments reduce crashes and the relative merits of using different treatments. Chapter 6 of the present report compares the crash reduction factors estimated by the regression analysis with those from ARRB's literature review for individual treatment types.[1]
- a data analysis to estimate crash reduction factors for black spot treatments by vehicle movement type. For program administration, benefit–cost ratios of prospective black spot projects are estimated using a matrix of crash reduction factors by crash type (column headings) and treatment type (row headings). An example is appendix A of DIT (2009a). ARRB used the data collected for the present study to derive new factors for such matrices.
- a data analysis to determine crash reductions for multiple engineering countermeasures used at the same location. ARRB used the BITRE data to investigate how the combined crash reduction factors for treatment types undertaken together in multiple-treatment black spot projects compares with the actual crash reduction factors.

1 The literature review was undertaken in early 2007 and so omits material published between then and publication of the BITRE report in 2012.

Traffic modelling consultancy

CBAs of black spot projects invariably count safety benefits only. Yet the CBA methodology aims to incorporate all impacts on society. Black spot projects can have significant impacts on vehicle operating costs, road users' time and emissions. The treatment types with the largest impacts are installation of roundabouts and traffic signals at intersections.

Estimating the traffic impacts of black spot projects at intersections is demanding in data and modelling. BITRE engaged John Piper Traffic Pty Ltd to undertake case studies of 18 black spot projects. The vehicle operating cost and time delay estimates from the case studies illustrate the potential effects of including traffic impacts in CBAs of black spot projects. See chapter 10 for the discussion.

Report structure

Figure 1.1 summarises the structure of the report. To improve readability, discussions of methodology, data and results have been interspersed throughout the report.

Chapters 2 to 7 relate to the Poisson regression analysis of crash counts.

This part of the report commences with an introduction to the Poisson regression technique, followed by descriptions of the data with discussion of issues arising. Reporting of the regression analysis results is spread over three chapters. Findings from the regression analysis that apply to all treatments types are presented in chapter 5. Findings for individual treatment types are set out in chapter 6. Chapter 7 details predictions of crashes avoided as a result of the program as estimated from the regression models.

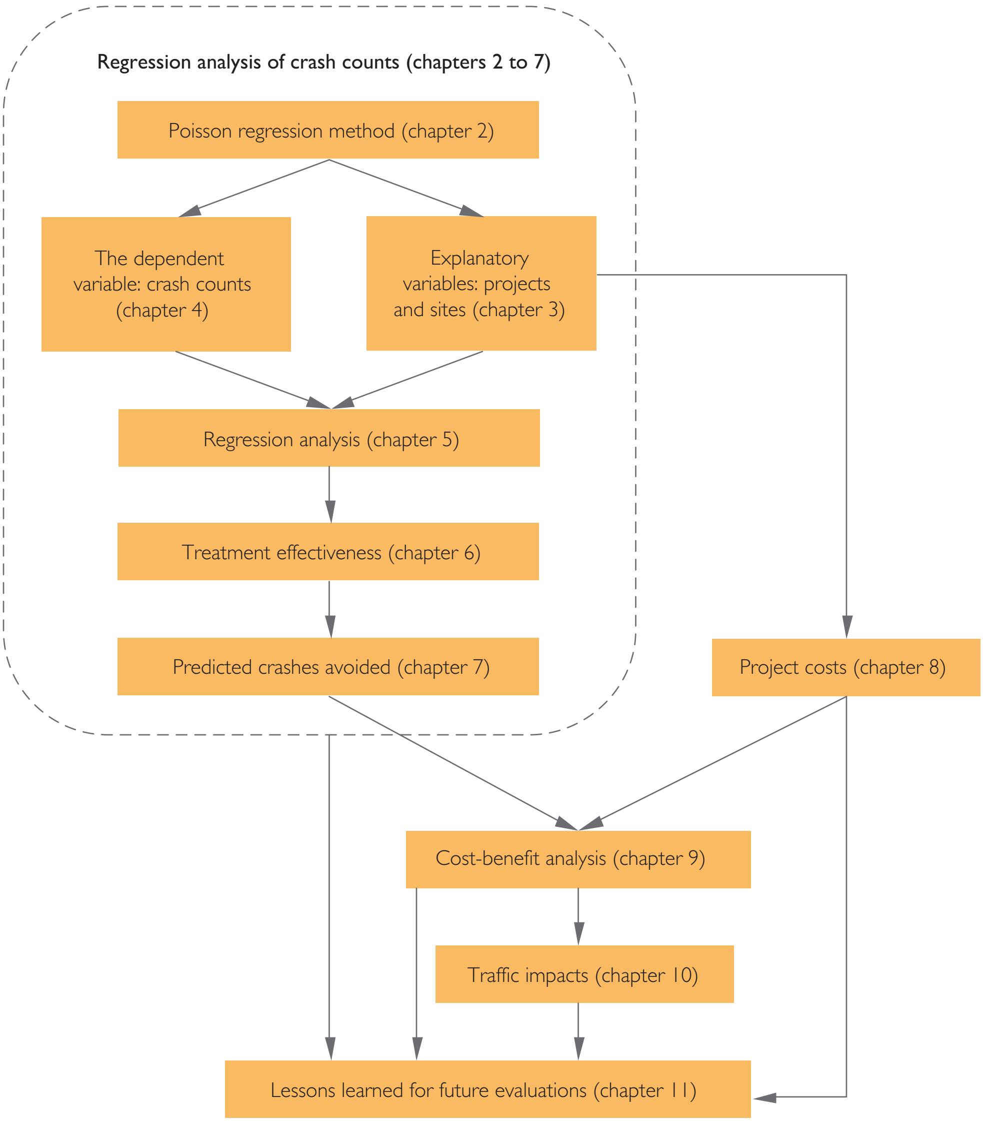
Chapter 8 opens a new topic, the construction costs of the projects in the database described earlier in chapter 3. It includes an analysis using ordinary least squares regression.

The CBA in chapter 9 brings together the predictions of crashes avoided from chapter 7 and project costs from chapter 8 to assess the economic value of the program.

Chapter 10 covers the supplementary topic of traffic impacts and how their inclusion affects the CBA results.

A brief discussion in chapter 11 of lessons learned for the benefit of future evaluations concludes the report.

F1.1 Report structure



CHAPTER 2
Poisson regression

Summary

Evaluation of the National Black Spot Program (NBSP) in hindsight, involves comparing crash counts over a period of years before and after implementation of each project. An effective project would be expected to result in a lower number of crashes per annum after implementation compared with before.

There is a large random element in crash counts. For any individual project, it is difficult to determine how much of the difference between the pre-treatment and the post-treatment crash rate is due to the project and how much is due to chance. Information from a large number of projects needs to be combined to average out the randomness so as to discern the impact of the black spot projects.

The technique employed to do this is based on an assumption about the probability distribution of crashes. The Poisson distribution is a standard probability distribution for counts of discrete events where the probability of occurrence is low, and the events are statistically independent — that is, the probability of occurrence in one period is not in any way affected by occurrences in other periods.

The Poisson distribution has just one parameter, the mean, which is the rate of occurrence — for example, the average number of crashes per year. The variance is equal to the mean. In the regression model, the mean of the Poisson distribution for crashes at the site of each project during an observation period is a function of a number of parameters including whether or not a black spot project is in place at the time.

The model is fitted to data consisting of crash counts during observation periods at project sites before and after black spot treatments. A variable is created for each project site set to one for all observation periods at the project site and zero for observation periods at other sites. The regression coefficient estimated for each site variable is the pre-treatment crash rate at the site. The site coefficients separate out all the characteristics associated with the site leaving the effect of the black spot treatment to be explained by the treatment variable.

The variable for the black spot treatment is set at zero for pre-treatment observation periods and one for post-treatment observation periods. The regression coefficient for a black spot treatment indicates the proportionate change in the crash rate as a result of the treatment. A given treatment type is assumed to have the same proportionate impact across all sites. Other coefficients, discussed in later chapters, enable factors affecting treatment effectiveness to be distinguished.

The coefficients are estimated using the maximum likelihood method, that is, the set of coefficients that has the highest likelihood of producing the data set. Measures of goodness of fit exist to compare model specifications with different sets of explanatory variables. The statistical software also provides standard errors of individual coefficient estimates. The estimates have an approximate normal distribution enabling statistical significance testing to be undertaken using a z-statistic.

Introduction

BITRE used Poisson regression analysis to estimate the effectiveness of black spot treatments and numbers of crashes avoided as a result of the treatments from the data on black spot projects and crashes at project sites. BITRE commissioned a consulting firm of expert statisticians, Data Analysis Australia (DAA) to advise on the methodology and undertake the statistical modelling. DAA's written reports (Henstridge et al. 2006 and DAA 2009) are reproduced in volume 3.

Terminology

Before proceeding, it is useful to clarify some terms: *site*, *treatment*, and *project*.

A *site* is the geographical location at which a project or projects have been undertaken. A site can be either a *spot*, usually an intersection, or a *length* of road, or a combination of both.

A black spot *treatment* is a single alteration made to the infrastructure at a *site* with the intention of improving road safety. At some sites, multiple treatments are undertaken together.

A black spot *project* consists of a single treatment or multiple treatments carried out over a limited and continuous time period at a given site. The engineering works comprising the project have a defined start and end date. A project with an unsatisfactory safety outcome might be followed by another project at the same site some years later using different treatments.

Choice of statistical methodology

The choice of a statistical methodology depends on the question to be answered and the statistical properties of the data available. The basic question is whether the National Black Spot Program, taken as whole, leads to a measurable reduction in the number and severity of crashes.

Then there are two supplementary questions.

First, what is the size of the reduction in crashes? The size of the reduction measured in crashes avoided is an essential input to the cost–benefit analysis.

Second, what factors affect the reduction in crashes — for example, type of treatment, site location?

Information about factors affecting the reduction can help to improve the effectiveness of the program in the future, for example, altering the selection of treatments in favour of types found to be more effective.

Each question has a before and after-treatment context. In other words, the questions are concerned with changes over time. There is, further, the need to link any apparent change in crashes with a cause.

The data takes the form of crash counts. A standard probability model for the counting of events is the Poisson distribution.

Poisson regression analysis

Poisson probability distribution

The Poisson probability distribution is often used to model rates of occurrence. When the probability that an event occurs is small, but the number of occasions when it can occur is large and the events are statistically independent, the Poisson distribution gives the probability of 0, 1, 2, 3, … events occurring in the time period $(t, t+1]$. Because the Poisson distribution is often used to describe failures or errors, it has been called the 'model of catastrophic events' (BTCE 1995 p. 50).

The Poisson distribution gives the probability of a random quantity *Y* taking on the value *y* as

$$p(Y=y) = \frac{e^{-m}m^{y}}{y!} \quad y = 0,\ 1,\ 2,\ 3\ \ldots$$

where m is the mean of the random variable, that is $E(Y) = m,$ and e is the base for natural logarithms.

For example, say that on average, a crash occurred at a particular site once every two years. The mean number of crashes is then 0.5 per year. The Poisson distribution then predicts a 0.61 probability of zero crashes per year, a 0.30 probability of one crash per year, a 0.08 probability of two crashes per year, and a 0.01 probability of three crashes per year. The probability of four or more crashes occurring in a year is extremely small, 0.002. When m is less than one, the mode of the distribution is zero crashes. In general, the mode of a Poisson distribution is the largest integer less than m.[2] Hence, the distribution is highly skewed for low values of m.

The Poisson distribution can be derived from the binomial distribution by allowing the number of Bernoulli trials to approach infinity and the probability of success to approach zero, with the mean (= number of trials × probability of success) held constant.

The variance of the Poisson distribution equals the mean. The standard deviation is then $\sqrt{m}$ and the coefficient of variation $\sqrt{m}/m = 1/\sqrt{m}$. Poisson variables with low mean values therefore have high coefficients of variation.

The choice of time units does not affect the distribution because the sum of two independent Poisson variables is a Poisson variable with mean equal to the sum of the means. Data can be aggregated over a day, a month or a year. Substituting a value of m of 13 crashes per year into the Poisson distribution would give probabilities for zero, one, two and so on crashes per *year*. Redefining m as 13/52 = 0.25 crashes per week, the Poisson distribution produces probabilities for zero, one, two and so on crashes occurring in a *week*. The probability of any given number of crashes occurring during a week will, of course, be much smaller than the probability of the

2 When m is a positive integer, there are two modes, m and $m-1$.

same number occurring in a year. The coefficient of variation will be much larger because a single crash is a much larger percentage of 0.25 than of 13.

Generalised linear models

In the classical linear regression model, the dependent variable Y is assumed to be related to the explanatory variables $X_1, X_2, X_3, \ldots, X_n$ in the following way

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n + \varepsilon$$

where the βs are the regression coefficients and ε is the error term or random component. This random component is assumed to be normally distributed with a mean of zero.

The above equation can be rewritten as

$$Y - \varepsilon = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n$$

showing that Y is normally distributed as well, with

$$E(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n \,.$$

Generalised linear models extend the concepts of the classical model in two ways.

First, instead of assuming that the random component has a normal distribution with unknown mean value, it assumes that the random component has a distribution from the exponential family, which includes the Poisson distribution. For purpose of modelling crashes, the value of Y in the last equation is assumed to have a Poisson distribution.

Second, instead of assuming that the mean value of the distribution is a linear function of the parameters, it assumes that the mean value is a non-linear function of the parameters. This non-linear function is called the 'link function' given by the function $h(\cdot)$

$$h[E(Y)] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n$$

For each distribution used with generalised linear models, there is a canonical (natural) link function that has desirable mathematical properties. In the case of the Poisson distribution, the canonical link is the logarithmic function.

$$log[E(Y)] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n$$

For analysis of crash counts, use of a logarithmic link function means that

- the predicted average number of crashes per time period can never be negative — a desirable property, and
- all the Xs have multiplicative impacts — which is mostly desirable.

The multiplicative property means that a black spot treatment is assumed to reduce crashes by a proportion that is constant across sites, not by a constant absolute number of crashes.

To illustrate, say the same treatment is implemented at two sites, *A* and *B*. Prior to treatment, site *A* has an average of four crashes per year and site *B* has an average of two. If the treatments cause the same proportional reduction in crashes at each site, say 50%, then in absolute terms, the reduction in the average number of crashes will be two at site *A* and one at site *B*.

The classical regression model is fitted using the 'least squares' method, that is, finding the regression coefficients that minimise the sum of squared differences between the actual and estimated values for *Y* in the data set.

Where the *Y*s follow a Poisson distribution, the least squares method does not produce the regression equation with most efficient estimate of *Y*, that is, the estimate with the lowest possible variance.

The most efficient estimate is obtained by using the 'maximum likelihood' method. Given a set of parameter values (βs) and the X values for any observation in the data set, one could estimate the probability or likelihood that the Y value for that observation could occur. One could estimate the likelihood (p_i) for each observation in the data set from 1 to n. The likelihood for the entire data set is the product of the likelihoods for all the observations $p_1 \times p_2 \times p_3 \times \ldots \times p_n = \prod p_i$.

The maximum likelihood set of parameter values is the one that has the highest likelihood of producing the data set, that is, the one that maximises $\prod p_i$. In practice, it is simpler to maximise the log of the likelihood, which is a summation $\sum ln(p_i)$ and leads to the same result. Statistical software packages use search algorithms to locate the maximum log-likelihood set of regression coefficients via an iterative process.

Goodness of fit

The 'deviance' is one of the measures most often used to test the goodness of fit of Poisson models (how well the model fits the data). The deviance is defined as twice the difference between the maximum log likelihood achievable and the log likelihood achieved by the model. The maximum log likelihood achievable occurs where the model has a parameter for each observation, called the 'full model'. In the case of the Poisson model, for a single observation *i* with Y_i crashes, the maximum log likelihood achievable (setting the estimated mean of the distribution equal to Y_i) is

$$Y_i \, log(Y_i) - Y_i - log(Y_i!) \, .$$

The log likelihood for the observation with the mean estimated by the model, $\hat{m}_i$, is

$$Y_i \, log(\hat{m}_i) - \hat{m}_i - log(Y_i!) \, .$$

The deviance is therefore $D = 2\sum_i[Y_i log(Y_i/\hat{m}_i) - (Y_i - \hat{m}_i)]$.

Provided the fitted model has a constant term, the sum of $Y_i - \hat{m}_i$ over all observations is zero, enabling the last term to be omitted (McCullagh and Nelder 1989, pp. 33–4).

The Poisson deviance has an asymptotic chi-square distribution with degrees of freedom given by the number of observations minus the number of parameters. The question asked is whether the full model improves the fit over the hypothesised model. If the hypothesised model fits the data significantly less well than the full model, it indicates that a better model can be achieved by adding parameters (Hoffman, J.P. 2004, p. 38).

The deviance can be used to help decide whether or not to add groups of parameters to the model. Adding parameters increases the potential to replicate the observed values. Hence it increases the log likelihood and reduces the deviance. Inclusion of extra variable(s) is warranted only if they reduce the deviance by a statistically significant amount.[3]

The Bayesian Information Criterion (BIC) and the Akaike's Information Criterion (AIC) can also be used to compare models. They are similar to the deviance method except that they penalise models with more explanatory variables. This can be desirable because larger models may dilute the significance of more important parameters and will also be more difficult to interpret. The BIC penalises additional parameters more so than the AIC. Using the deviance test alone will lead to selection of a larger model than the AIC and BIC techniques.

The AIC was used for the present study. It is defined as $-2L + 2p$ where L is the maximised log likelihood (which has a negative value) and p is the number of parameters. Lower values of the index indicate a preferred model. The best model is the one with the fewest parameters yet still provides an adequate fit of the data.

Standard errors of coefficients

The standard errors of the coefficients of a model estimated using the maximum likelihood method are obtained from the log likelihood function.

The 'Fisher Information matrix' is negative the matrix of partial derivatives (the Hessian matrix) of the log-likelihood function at its maximum point.

The inverse of the Fisher Information matrix is the variance–covariance matrix for the model, the diagonal elements of which are the variances of the individual coefficient estimates.

The partial derivative of the maximum likelihood function with respect to any given parameter estimate measures how steep or flat the function is around the maximum point with respect to that variable. Intuitively, the steeper the approach to the maximum, the greater is the level of certainty (lower the variance) about the correctness of the estimate.

The coefficient estimates have an approximate normal distribution so *z*-statistics can be used for testing in the usual manner.

When deciding on a model, any or all of the deviance, AIC and BIC, can be considered along with the significance tests on individual variables. At same time, judgement needs to be exercised to ensure the model is sensible.

3 The statistical significance of an increase in deviance from adding parameters is tested by determining whether the test statistic $(D_S - D_L)/(p_S - p_L)$ is significantly different from zero, where D_S and D_L are the deviances of the smaller and larger models respectively and p_S and p_L are their numbers of parameters. The number of degrees of freedom for the chi square distribution is $p_S - p_L$.

Poisson regression: simple illustrative example

A simple numerical example will illustrate how Poisson regression is applied to estimate the effectiveness of black spot treatments.

Table 2.1 shows hypothetical crash count data for three black spot sites over a five-year period. Each project was implemented between the end of year 3 and the start of year 4. Data are available for all five years for sites 1 and 2, but is not available for years 1 and 5 for site 3. A zero crash count for a site in a year is not the same as data not being available.

For the pre-treatment period, there are 40 crashes in 8 observed site-years, giving an average crash rate of 5.0 crashes a year. For the post-treatment period, there are 15 crashes in 5 observed site-years giving an average crash rate of 3.0 crashes a year. A simple approach is to conclude that the ratio of pre- to post-treatment crash rates, or the treatment effectiveness index (TEI) is 60% = 3.0 / 5.0 × 100. The 'effect' of the black spot treatment or the crash reduction factor (CRF = 1 – TEI) is 40%.

T2.1 Hypothetical crash count data for three treated sites

	Pre-treatment period				Post-treatment period		
Year	1	2	3	Totals	4	5	Totals
Site 1	9	5	8	22	3	6	9
Site 2	4	7	3	14	2	3	5
Site 3	na	4	0	4	1	na	1
Total crashes				40			15
Total observed time periods				8			5
Average crash rate				5			3

If there had been no missing data for site 3, that is, the number of observation periods was the same for all sites pre-treatment and the same for all sites post-treatment, 60% would be the maximum likelihood TEI. Where numbers of observation periods differ between sites, a more complicated formula must be used (see appendix C). The maximum likelihood TEI for this example is 57.6% and the CRF 42.4%.

Table 2.2 shows how the data in table 2.1 would be arranged for regression analysis. Table 2.3 shows the coefficient output from the Stata statistical package used for this study. One of the three site variables has to be dropped, in this case, site 1.[4] The constant term is an estimate of the pre-treatment annual crash rate at site 1, and the coefficients for the other sites are comparisons with site 1.

4 If the constant term and all the site variables were left in the regression model together, there would be infinitely many ways to express the model. Any arbitrary amount could be added to the constant term and the same amount subtracted from all the site terms, without changing the estimated crash rates produced by the model.

T2.2 Example crash count data arranged for regression analysis

Year	Crashes	Site 1	Site 2	Site 3	Treatment
1	9	1	0	0	0
2	5	1	0	0	0
3	8	1	0	0	0
4	3	1	0	0	1
5	6	1	0	0	1
1	4	0	1	0	0
2	7	0	1	0	0
3	3	0	1	0	0
4	2	0	1	0	1
5	3	0	1	0	1
2	4	0	0	1	0
3	0	0	0	1	0
4	1	0	0	1	1

T2.3 Stata coefficient output for example data

	Coeff.	Std. err.	z	P>|z|	95% Conf. interval
site_2	-0.490	0.291	-1.68	0.093	(-1.061 0.082)
site_3	-1.347	0.482	-2.79	0.005	(-2.292 -0.402)
treatment	-0.551	0.303	-1.82	0.069	(-1.145 0.043)
_cons	2.010	0.198	10.14	0.000	(1.621 2.399)

All the coefficients in table 2.3 are expressed as logarithms. The estimated pre-treatment annual crash rates at the three sites are

- site 1: $7.5 = \exp(2.010)$
- site 2: $4.6 = \exp(2.010 - 0.490)$
- site 3: $1.9 = \exp(2.010 - 1.347)$

The estimated TEI is $0.576 = \exp(-0.551)$.

The standard error of the estimated log of the TEI is 0.303 (see appendix C for a formula). Statistical significance is gauged by testing the hypothesis that the log of the estimated TEI, the coefficient from the Poisson regression, is equal to zero. The p-value of 0.069 for the estimated TEI indicates that the estimate is statistically significant at the 0.1 level but not at the standard 0.05 level. A lower p-value can be obtained with a larger decrease in crash numbers following treatment and/or with additional data showing the same decrease.

The deviance (not shown in the table) is 9.87, which is close to the number of degrees of freedom, 9 = 13 observations – 4 parameters, indicating that the model is a good fit.

End note

The Poisson regression analysis yields two important sets of the results.

First, it provides estimates of treatment effectiveness in the form of crash reduction factors, that is, the percentage reduction in the crash rate as a result of the treatment. Treatment effectiveness estimates can be tested for statistical significance.

Second, the model and data can be used together to derive predictions about numbers of crashes avoided as a result of black spot projects. Predicted numbers of crashes avoided underpin estimation of the safety and economic benefits of the program.

CHAPTER 3
Explanatory variables: projects and sites

Summary

State and territory road agencies provided data to BITRE on Australian Government-funded black spot projects and on crashes at the sites of those projects. BITRE also had access to the Australian Government's National Black Spot Program (NBSP) database. The evaluation aimed to cover all projects funded by the Program that were approved during the seven-year period 1996–97 to 2002–03 inclusive and that were completed.

According to the NBSP database, 2578 projects were approved during the period and completed. The Australian Government spent $278 million on these projects, an average of $108 000 per project. State, Territory and local governments and others also contributed funds.

Data were unavailable or incomplete for many projects. After eliminating projects with data inadequacies, 1599 projects remained in the database, 62% of the projects in scope.

From the project database, the following data for the explanatory variables for the regression analysis were assembled:

- a dummy variable for each project–site — separates out the site-specific factors that determine the pre-treatment crash rate at each site
- crash treatment status — derived from significant dates: application for NBSP funding, commencement and completion of works — indicates when the crash took place in relation to project timing, for example, pre- or post-treatment
- time of day of crashes (day or night) — enables estimation of separate daytime and night-time levels of effectiveness for treatments such as street lighting, signage and line marking, that may have different impacts depending on lighting conditions
- treatment implementation year — to determine whether treatment effectiveness is changing over time
- jurisdiction

- urban/rural — in effect, metropolitan or non-metropolitan site location according to the definition used for NBSP administration
- local/state road type
- BCR/RSA — method of project selection: benefit–cost ratio or road safety audit
- treatment type — using the BITRE classification system described in chapter 6 and appendix A

Projects in scope

State and territory road agencies provided details of NBSP projects undertaken within their jurisdictions together with data on crashes that occurred at the sites. BITRE also had access to the Australian Government's database of projects undertaken under the Program.

The evaluation aimed to cover all projects funded by the Program that were approved during the seven-year period 1996–97 to 2002–03 inclusive and that were completed. According to the NBSP database, 2578 projects were approved and completed during the period. Table 3.1 shows numbers of projects by jurisdiction and approval year.

Table 3.2 shows the funds spent on the black spot projects in table 3.1 by the Australian Government. state, territory and local governments and others — for example, private developers and the National Capital Authority in the ACT — also contributed funds, so the costs in table 3.2 do not represent the full costs.

The total amount spent by the Australian Government on projects approved over the seven-year period was $278 million. The projects are grouped by year of approval. Many of the projects would have been undertaken partially or fully in subsequent years. Hence, actual spending by the Australian Government in each year differs from the amounts shown in table 3.2. Dividing total spending by the total number of projects, the average spent per project was $108 000.

T3.1 Numbers of National Black Spot Projects by jurisdiction and approval year

Approval year	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1996–97	3	99	6	63	30	16	98	43	358
1997–98	5	112	6	62	26	13	109	76	409
1998–99		92	9	54	12	26	62	53	308
1999–2000	5	69	6	57	25	28	102	68	360
2000–01	3	128	2	66	25	36	100	85	445
2001–02	3	91	4	47	35	34	81	30	325
2002–03	2	97	7	81	36	26	65	59	373
Total	21	688	40	430	189	179	617	414	2578

Source: National Black Spot Program database

T3.2 Australian Government spending on National Black Spot Projects by jurisdiction and approval year

($ millions)

Approval year	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	Total
1996–97	0.5	12.6	0.8	8.8	3.9	1.4	10.3	5.0	43.2
1997–98	0.9	11.0	0.4	6.5	3.3	0.7	6.8	4.0	33.5
1998–99		11.4	0.6	6.7	2.0	0.9	8.5	4.4	34.5
1999–2000	0.6	9.3	1.0	8.0	3.2	0.9	8.1	4.5	35.5
2000–01	1.0	16.5	0.2	8.0	3.2	1.1	10.4	5.0	45.4
2001–02	0.5	11.9	0.5	6.0	3.0	1.1	9.9	2.8	35.7
2002–03	0.6	14.2	0.8	11.8	4.1	1.0	11.7	6.2	50.4
Total	4.1	86.8	4.3	55.7	22.7	7.1	65.7	31.8	278.2

Source: National Black Spot Program database

Project data

The BITRE evaluation is based on 1599 projects, which is 62% of the 2578 projects in scope. State and territory road agencies were unable to provide the detailed data needed on many of the projects approved and completed in their jurisdictions. Furthermore, many of the projects with data supplied had to be excluded for various reasons.

First, the project had to be in scope, that is, approved for funding under the National Black Spot Program during the years 1996–97 to 2002–03 inclusive. The project also had to have been completed. Projects with no start date and completion date were excluded because there is no way to be certain when to finish counting pre-treatment crashes and when to start counting post-treatment crashes.

Instances were found where two or three projects had been implemented at the same site at different times. This can happen when the first treatment fails to adequately reduce crashes at the site and a further attempt is made. In principle, the methodology of the evaluation is able to deal with such cases, but the projects were excluded due to the complexities involved in adapting the procedures to cater for them.

Projects were excluded if crash data were unavailable for the whole or any of the three time periods:

- prior to application for federal funding
- between application and commencement of the project
- after completion of the project

Other projects had to be excluded because of missing data for variables included in the regression analysis.

Table 3.3 lists the project data fields that were used in the evaluation. Data from both NBSP and state and territory sources were combined in the database. Where there were inconsistencies, judgments had to be made about which alternative was more likely to be correct. For example, state sources were considered more likely to be correct about start and completion dates of project works.

BITRE asked for data from state and territory road agencies on traffic levels, proportions of heavy vehicles and speed limits at black spot sites, which would have been desirable to better model the effectiveness of treatments. However, the data were not available for many projects. Rather than exclude large numbers of projects that were missing these data items, it was decided to drop the explanatory variables.

T3.3 Fields in project database

Field name	Explanation	Source	Use in evaluation
Federal reference	Australian Government reference code	NBSP	project identifier
State	State/Territory name	Both	*,†, report results by jurisdiction, cost under-reporting adjustment
State reference	State/Territory reference code	State	crosscheck national and state databases
Program year	financial year for which funding approved	NBSP	determine whether project is in scope
Urban/Rural	urban or rural	NBSP	*,†, results by urban/rural
State/Local	project implemented by state or local government	both	*,†
LGA	Local Government Area	both	crosscheck national and state databases
District	locality or suburb	State	crosscheck national and state databases
Site description	length or intersection and other details	NBSP	treatment classification
Spot or length	spot / length	State	treatment classification
Primary road	primary road on which the treatment occurs	both	crash assignment, crosscheck national and state databases
Secondary road	Intersecting or nearby road	both	crash assignment, crosscheck national and state databases
GIS coordinate longitude	location of site	both	crash assignment
GIS coordinate longitude	location of site	both	crash assignment
BCRorRSA	whether the site was approved on a BCR or RSA basis	NBSP	*
Treatment description	description of treatment(s)	both	treatment classification
Australian Government treatment code	Australian Government treatment code	NBSP	treatment classification

continued

* used in the Poisson regression of crash counts
† used in the regression of construction costs (see chapter 8)

T3.3 Fields in project database (continued)

Field name	Explanation	Source	Use in evaluation
BITRE primary treatment code	see chapter 6	BITRE	*,†
BITRE secondary treatment codes (six fields)	see chapter 6	BITRE	*,†
Date application received	date application received by Australian Government	NBSP	* (test for regression to the mean)
Construction start date	start date for implementation of treatment	both	*,†
Construction end date	completion date for implementation of treatment	both	*,†, confirm project completed, report results by implementation year
Problem	description of crashes that are a concern	both	identify primary treatment
Target DCA code	code for crash type the treatment is primarily aimed at reducing	both	identify primary treatment
Non-target DCA codes	other crash types the treatment aims to reduce	both	identify primary treatment
Australian Government cost	funding approved by Australian Government adjusted for variations	NBSP	component of total cost, adjustment for under-reporting
State cost	additional funding by state/ territory governments	both	component of total cost, adjustment for under-reporting
Local government cost	additional funding by local governments	both	component of total cost, adjustment for under-reporting
Other cost	additional funding from other sources	both	component of total cost, adjustment for under-reporting
Total cost	sum of all costs	calculated	†, CBA, adjustment for under-reporting

* used in the Poisson regression of crash counts
† used in the regression of construction costs (see chapter 8)

Explanatory variables

The Poisson regression analysis expresses the average annual crash rate at each project site as a function of a set of explanatory variables. In doing so, the model estimates the effectiveness of the different treatment types at reducing crashes and indicates whether the effectiveness varies with factors such as location, implementation year, and time of day.

The following is the list of explanatory variables before creating interaction terms:

- a dummy variable for each project or site
- crash treatment status (indicates when the crash took place in relation to implementation of Black Spot project, for example, pre- or post-treatment)
- time of day of crashes (day or night)
- treatment implementation year
- jurisdiction
- urban/rural
- local/state road type
- BCA/RSA (method of selection: benefit–cost analysis or road safety audit)
- treatment type

Characteristics of individual sites

Each individual site treated under the Program has its own unique characteristics that will affect the crash rate.

Some sites are intersections and others are lengths of road. Intersections have different numbers of arms and the roads may join at different angles. They may or may not have turning lanes, slip lanes or signals before the black spot project. Curvatures, gradients, superelevation, road width, skid resistance, roughness, sight distances, signage, and legal speed limits are some of the many factors that can affect crash rates at individual sites. In the regression analysis, these factors are taken account of by the site-specific dummy variables.

In the model, each site has its own unique explanatory variable from which can be derived an estimate of the pre-treatment crash rate at the site. There is an implicit assumption that, apart from the black spot project and the general trend in crashes, which is included in the model, there are no changes to individual sites that would affect the crash rate over the period covered by the analysis.

In road safety literature, the term 'exposure' refers to the number of opportunities at which crashes can occur (BTCE 1995, p. 41). Exposure at a location is usually measured as the number of vehicles passing through the site per period of time — more vehicles tends to be associated with more crashes, though not necessarily in proportion. Differences in traffic levels between sites imply differences in crash exposure. Crash rates will also be affected by the mix of vehicles (proportions of trucks of various types), the directional split of traffic, and for intersections, proportions of turning traffic.

As already noted, it was only possible to obtain data on traffic levels and proportions of heavy vehicles for a limited number of sites in the database. As well as allowing for differences in the physical characteristics of sites, the site-specific terms in the regression analysis also take account of the differences in exposure between sites arising from different traffic levels, vehicle mixes, directional splits and proportions of turning vehicles.

The multiplicative nature of the model deals with the relationship between effects of treatments and exposure. Comparing two identical sites with identical treatments, one site with twice the traffic and twice the number of crashes as the other, the proportional reduction in crashes from the treatment is assumed to be the same.

This is appropriate if crash numbers are proportional to traffic levels, which is probably approximately correct over a broad medium range of traffic levels. At low traffic levels, there is less likelihood of vehicles encountering other vehicles, though drivers may be less attentive. At higher traffic levels, congestion slows vehicles down, which may reduce crash probabilities and severity levels.

Fixed versus random effects models

To give each site its own specific parameter to handle the variation in crash rates between different sites is to assume 'fixed effects'. Each site has its own intercept for the regression equation. The intercept parameter is effectively the pre-treatment crash rate for the site. The site parameters are estimated together with all the other parameters and, as such, are maximum likelihood estimates.

The alternative 'random effects' approach assumes that, while some site-specific features might be predictable via some site variables, the remaining between-site variation is essentially random and is best modelled as coming from a distribution. The parameters of this distribution are estimated together with the other parameters.

Each approach has advantages and disadvantages. The fixed effects model ignores the fact that some of the apparent variation between sites is random. The random effects model has to assume that the variation follows some distributional form, without, in this case, any good argument as to what this should be and there is a risk of biases if it is wrong. The fixed effects model is computationally simpler. The random effects model can give some information on the structure of the differences between sites, but this is not relevant to the evaluation.

In this study, initial investigative models were fitted by both methods. The resulting differences in the relevant parameters — those measuring the effect of black spot treatments — were found to be small. Hence, the decision was made to use the fixed effect models, because the lower computational demands of fixed effect models enabled more complex models — models with more interactions — to be fitted.

Interaction terms

Adding 'interaction terms' enables the regression analysis to discern different factors that alter the effectiveness of black spot treatments.

Only the site dummy variables were used directly. The others were combined with crash treatment status to create interaction variables. Whether crash rates are different at black spot sites in different jurisdictions or in rural compared with urban areas or at sites with different treatment types is not of interest for this study. These effects are left to be picked up by the site specific dummy variables. It is the interactions between these variables and crash treatment status that are relevant to the present study, for example, whether the effectiveness of treatments varies between jurisdictions, and between rural and urban areas.

An interaction variable is obtained by multiplying two or more explanatory variables together. To determine how a variable affects treatment effectiveness, the variable is multiplied by the crash treatment status dummy variable, which indicates whether the crash occurred at a time before the treatment was commenced (0) or after the treatment was completed (1).

The resultant interaction dummy variable would be zero for time periods prior to treatment, and one for time periods after treatment. Hence, for a project that involved sealing/resealing together with line marking on a state road in rural Queensland, the five interaction variables created for the (1) sealing/resealing treatment type, (2) the line marking treatment type, (3) Queensland, (4) rural, and (5) state road would all change from zero to one for crash counts in time periods after treatment.

Writing the regression equation out in exponentiated form, the annual crash rate (m) at a given site between 1 and n is

$$m = \left(\alpha_1^{x_1}, \alpha_2^{x_2}, \cdots, \alpha_n^{x_n}\right)\left(\beta_1^{t_1} \quad \beta_2^{t_2}, \beta_3^{t_3}, \cdots\right)\left(\gamma_1^{y_1}, \gamma_2^{y_2}, \gamma_3^{y_3}, \cdots\right)$$

where, the α's are site coefficients, the β's are treatment type coefficients and the γ's are other interaction coefficients.

- The x's are site dummy variables. For each observation, only one of the site dummy variables can be set to one — all the others must equal zero.
- The t's are treatment dummy variables and the y's are interaction dummy variables. All the t's and y's are zero for observations during pre-treatment time periods. During post-treatment time periods the particular t's and y's relevant to the project are set to one.
- The estimated crash rate at site i before treatment is α_i.

Say the y's represent jurisdictions, Victoria, set as the base, is omitted and site i is in Victoria. Then, if treatment 2 was implemented at site i, the estimated post-treatment crash rate would be $\alpha_i\beta_2$ obtained by setting dummy variables x_i and t_2 to one and all the others to zero. If y_1 is the interaction term for South Australia, then for site j in South Australia, the pre-treatment crash rate would be α_j and the post-treatment crash rate for treatment 2 would be $\alpha_i\beta_2\gamma_1$.

For any site, if the equation for the post-treatment crash rate is divided by the equation for the pre-treatment crash rate, the site term, α, cancels out. As an average for all Victorian sites, the treatment effectiveness index (TEI) for treatment 2 is β_2. For South Australia, the average TEI for treatment 2 is $\beta_2\gamma_1$.

Note that the choice of the base is arbitrary. Had, South Australia been used as the base, the β's would be TEIs for South Australia, and the Victorian TEIs would be derived by multiplying the South Australian TEIs by the Victorian interaction term.

The full list of two-way interaction terms derived by multiplying an explanatory variable by crash treatment status is set out below:

- treatment type
- treatment implementation year
- jurisdiction
- urban/rural
- state/local road
- BCA/RSA

Three-way interaction variables are as follows:

- treatment type × treatment implementation year
- treatment type × jurisdiction
- treatment type × urban/rural
- BCR/RSA × urban/rural
- treatment type × treatment type (for sites with multiple treatments)
- treatment type × time of day

These are explained in chapters 5 and 6 when presenting the regression results, except for time of day which is discussed here as it relates to sites.

Day and night treatment impacts

Some treatment types are expected to have different safety impacts depending on lighting conditions.

Installation of street lighting is the most obvious example. It would be expected to reduce crashes at night only. During the day, street lights should have no effect on crashes unless cars collide with the posts. Modifications to traffic signals, line marking and installation of signs could also have different impacts during the day and night.

For each site with treatments expected to have different day–night impacts, the time-of-day variable (a dummy variable set to zero for daytime crashes (6:00AM to 6:00PM) and one for night-time crashes (6:00PM to 6:00AM)) was multiplied by the site's dummy variable to create a site-specific time-of-day interaction term.

The effect is to estimate different daytime and night-time pre-treatment crash rates for the sites. The night-time pre-treatment crash rate for a given site is obtained by multiplying the daytime crash rate by the exponentiated coefficient for the time-of-day interaction term for the particular site.

A three-way interaction term is created between crash treatment status, treatment type and time of day. This variable is set to one only for post-treatment crashes that occurred during the night at a site with a treatment believed to have differing day–night effects.

The variable's exponentiated coefficient is the ratio of night-time TEI to the daytime TEI for the particular treatment type. For example, if the daytime TEI for street lighting was 1.0 (no impact on crashes during the day) and the exponentiated coefficient for the night-term interaction term was 0.8, then the night-time TEI for street lighting would be $1.0 \times 0.8 = 0.8$, which is a 20% reduction in crashes.

End note

With a database of 1599 projects, the sample size is quite large compared with other evaluations of this type. A larger sample size means that more reliable results can be obtained for the more common treatment types. Furthermore, statistically significant results may be obtained for less common treatment types and for factors affecting treatment effectiveness that might not be significant with smaller samples.

CHAPTER 4
The dependent variable: crash counts

Summary

The regression analysis used data for crashes within plus or minus seven years of the each project's implementation time. Crash data outside the seven year periods were not used because the further the time periods are extended, the greater the likelihood that changes will have occurred to the site unrelated to the black spot project or in the volume of traffic using the site. Such changes could materially affect crash rates.

Separate regression models were developed for crashes grouped by severity — fatal, serious injury, minor injury and property damage only (PDO). Models were also developed for injury crashes as NSW data do not distinguish between serious and minor injury crashes. Models were also developed for casualty crashes as reduction of casualty crashes is a stated aim of the NBSP and facilitates comparison of crash reduction factor estimates with other studies.

Crash counts were grouped by calendar years, which averages out weekly and seasonal variations in crash rates that are not relevant to the analysis.

The general downward time trend in crash rates due to improving road safety was accounted for by adding variables for total injury crashes in each jurisdiction during each year. Without this, the regression could attribute general changes in crash rates to black spot treatments.

Crashes during project implementation periods were omitted.

For some sites, there was uncertainty about the time the observation period began. To begin the data for a site on the date when the first crash occurred would upwardly bias the estimated pre-treatment crash rate for the site. The solution is to remove the first crash from the data, assuming observations commenced on the day after the first crash. Similarly, where there is uncertainty about the end date, the last crash was removed from the data.

Under-reporting of crashes is significant at the low end of the severity spectrum — minor injury crashes and particularly for PDO crashes. However, the less severe crashes are of less concern from a road safety viewpoint, and much less costly when estimating program benefits for the CBA.

Crash data

Each project is associated with a series of crashes that occurred at the site of the project or very close to it.

BITRE requested data for crashes within plus or minus seven years of the implementation time of the treatment. For more recent treatments, where the seven-year post-treatment period extended beyond the time of the latest available crash data, jurisdictions were asked to provide what they could. In many cases, jurisdictions provided data well beyond the plus or minus seven-year periods requested for each treatment.

However, BITRE did not use crash data outside the seven year periods because the further the time periods are extended, the greater the likelihood that changes will have occurred to the site or in the volume of traffic using the site that could materially affect the crash rate.

Table 4.1 shows the main fields in the crash database assembled for the study with their uses.

T4.1 Fields in crash database

Field name	Use in evaluation
Australian Government reference for black spot project	link to project database
State and/or police reference number	identifier
Date	*, assign calendar year, calculation of number of days observed during each calendar year
Day of week	not used
Time of day	*, assign time of day period
Location (several fields: primary road, secondary road, GIS coordinates)	assign crash to black spot project
Numbers of fatalities, serious injuries, minor injuries (several fields)	assign crash severity
Crash severity level	*, grouping crashes for regression models
Number of vehicles involved	not used
Crash type (Road User Movement (RUM) code and/or Definitions for Classifying Accidents (DCA) code)	not used
Road surface condition (wet/dry)	not used
Weather (fine/light rain/heavy rain)	not used
Road surface type (bitumen/concrete/gravel)	not used
Light conditions (a code applied by the relevant jurisdiction).	not used

* used in Poisson regression of crash counts.

Crash severity versus crash type

Crashes are classified by severity according to the most severe casualty outcome. The classification levels are:

- fatal — a death occurring as the result of injuries sustained in a road crash within 30 days of the crash
- serious — injury (fracture, concussion, severe cuts or other injury) requiring medical treatment or removal to and retention in hospital — persons admitted to hospital for one day or more
- minor — injury that is not 'serious' but requires first aid, or which causes discomfort or pain to the person injured — persons treated at hospital for less than one day or treated by a general practitioner or who did not seek assistance for their injuries
- property damage only (PDO) — no injury

A 'casualty crash' is defined as being any crash in which at least one person is killed or injured. All crashes in the fatal, serious and minor injury categories are casualty crashes.

Crash categorisation by type is based on vehicle movements prior to the crash, for example head on or off-carriageway. The Definitions for Classifying Accidents (DCA) has 10 categories each of which has up to 10 subcategories (see BTE 2001, pp. 162–3 for details).

The first Bureau evaluation, BTCE (1995), used both the crash severity and crash type approaches and discussed their relative merits (pp. 94–6). The crash type approach was considered superior for two reasons.

First, the crash-type approach is likely lead to more reliable estimates of cost savings from the program. Fatal and serious injury crashes occur with much lower frequencies than minor injury and PDO crashes but have vastly greater costs. The low frequency for the high-severity crashes leads to higher standard errors in estimates of crash rates and treatment effectiveness compared to low-severity crashes.

For CBA purposes, it is desirable that the standard errors for the estimated numbers of fatal and serious injury crashes avoided be as small as possible because they account for most of the cost savings. In other words, with the crash severity method, there tends to be an undesirable positive correlation across the different severity levels between the standard errors of estimates and unit crash costs.

Grouping the crashes by type, to a certain extent, breaks the nexus between numbers of crashes in each group and unit crash cost. BTCE (1995, pp. 90–1) cites evidence that the injury profiles for different types of crashes tend to be fairly stable.

A counter-argument is that the level of under-reporting of crashes is inversely correlated with crash severity. For CBA purposes, it is better to have the high levels of under-reporting concentrated in groups of crashes with low unit costs, where the resultant under-estimation of benefits has less serious consequences.

Victoria, the jurisdiction that contributed the most data in terms of project numbers, was unable to provide any PDO crash data. Another drawback of the crash type approach is that, since the number of crash types is considerably larger than the number of severity levels, the data for some types can be very thin.

The second advantage of the crash type approach is that it facilitates target crashes, that is the crash types that the treatment is aimed at reducing or eliminating, being distinguished from non-target crashes, that is crash types the treatment does not affect. The problem of inability to distinguish between target and non-target crashes is discussed in detail in chapter 7. In short, the presence of non-target crashes will reduce the estimated crash reduction factors, but is not expected to materially affect the estimated number of crashes avoided.

The commissioned report by ARRB Group (Turner et al. 2008), reproduced in volume 3, provides estimates of crash reduction factors by type and treatment derived from the BITRE database.

The present study uses the crash severity approach only. The Austroads unit costs of crashes used in the CBA are available only by crash severity. It would therefore not be possible to derive benefit estimates for crashes avoided by type.

Effects of treatments on crash mix by severity

Black spot projects are expected to reduce the average level of crash severity as well as the number of casualty crashes. In other words, it is expected that the percentage reduction in fatal crashes would be higher than for serious injury crashes, and that the percentage reduction in serious injury crashes would be higher than for minor injury crashes. For some black spot treatments such as installation of signals and roundabouts, the lower severity levels for casualty crashes could come at the expense of increased numbers of PDO rear-end crashes.

A regression model has only one dependent variable, which can be crashes for a single severity level or the sum of crashes for a combination of severity levels. Examples of combinations are casualty crashes (fatal, serious injury and minor injury), injury crashes (serious and minor) and all crashes. Since one of the stated aims of the NBSP in the Notes on Administration is 'to reduce the social and economic costs of road trauma by the identification and cost effective treatment of locations with a record of *casualty crashes* …' (italics added), it is incumbent to undertake a regression of casualty crash numbers.

For the CBA, numbers of crashes avoided need to be multiplied by unit crash costs. The standard unit costs used throughout Australia and updated regularly are from Austroads (2008). These are published by jurisdiction for four severity levels: fatal, serious injury, minor injury and PDO, except for NSW. For NSW, which does not distinguish between serious and minor injury crashes, Austroads publishes an injury crash unit cost. Having a regression model for each severity level to estimate crashes avoided by the black spot program obviates the need to make assumptions about weights to calculate weighted average unit costs. Regression models were developed for each severity level including injury crashes to allow for NSW, and for casualty crashes, though the latter was not used for the CBA.[5]

Different definitions of crash severities between jurisdictions

All jurisdictions define a fatal crash as occurring where one or more persons involved die within 30 days of crash as a result of their injuries. For injury crashes, there are no common definitions of serious and minor injury crashes (BITRE 2009, p. 2).

For example, Queensland groups a non-fatal casualty injury as either hospitalised, medically treated or minor. New South Wales simply reports the casualty as injured. Also, the propensity for injured people to seek hospital treatment varies between jurisdictions. ABS (2003, p.5) reported that 'Nationally, 9% of persons reporting a recent injury attended hospital, although injured Victorians were less likely to take this action when compared to most Australians (5% of injured Victorians)'.

Provided the definitions are the same before and after implementation of black spot projects, they should not affect the estimated proportional changes in crashes due to the projects. Biases could conceivably be introduced where treatments alter the severity of injuries.

For example, a treatment that reduced the severity of injuries at the lower end of the scale could be seen to reduce minor injury crashes and increase PDO crashes in one jurisdiction and have no effect in another jurisdiction where the boundary between minor injury and PDO occurs at a lower level of injury severity.

The jurisdictional terms in the regression models may separate out impacts on treatment effectiveness levels caused by differing definitions of crash severities. For the CBA, crashes avoided in each jurisdiction were costed at the Austroads unit crash cost for the particular jurisdiction. The Austroads unit crash costs vary between jurisdictions for each severity level, which would reflect, among other things, the different definitions of severity levels.

5 Another approach is to model casualty or injury or total crashes with Poisson regression, and then to use a logit or multinomial logit model to split up the totals into severity level components. The logit and multinomial logit models are another form of generalised linear model for a dependent variable that follows a multinomial distribution and uses a logit link function. This contrasts with the Poisson distribution that uses a log link function. Since the probability of a crash occurring in a short time period is very small, the binomial and Poisson distributions are very similar and the logit function is a good approximation to the log function in this region. Hence, crash predictions can be expected to be very similar using either approach. The logit approach was not followed for two reasons. First, for the less frequent class of crashes, that is, fatal crashes, the model may not be able to produce statistically significant estimates of critical parameters, or very imprecise estimates that are not credible. The only solution would be to merge classes but this, to some extent, defeats the purpose of the exercise and assumes that classes merged have similar parameters. Second, the multinomial model assumes that classification by crash severity is categorical when it is really ordinal. The correct model for explaining shifts of crashes between categories could be quite different from that for numbers of crashes in each category considered in isolation. Use of the multinomial logit model is associated with a risk that the wrong model will be selected, particularly given the sparse data for fatal crashes.

Choice of time period

Crash data can be aggregated into any time period — days, months, years — provided the explanatory variables can be modelled. Calendar years were used in the present study.

A shorter time period than a year would be needed in order to include cyclical factors that affect crash rates within a year such as season (in so far as it affects weather), holiday periods, day of week, and time of day. The purpose of the analysis is not to model crash numbers, but the change in crash numbers following black spot treatments. These cyclical factors are the same before and after black spot treatments. So omitting them should not bias the estimates of the effectiveness of black spot treatments.

It is not always possible to have the data fitting neatly into calendar years. Implementation of black spot projects rarely commences on 1 January and finishes on 31 December. Nor do the observation periods for individual sites always commence on 1 January and finish on 31 December.

In generalised linear modelling, the standard and most effective way to account for differences in time periods is to specify an 'offset' variable. Exposure is assumed to be proportional to the time period of the observation. If a project commenced on 11 April and was completed on 15 June, the calendar year would be split into three observations in the regression data:

- pre-treatment: 1 January to 10 April, offset term = 100 days
- implementation: 11 April to 15 June, offset term = 65 days[6]
- post-treatment: 16 June to 31 December offset term = 200 days

Observations for complete non-leap years have 365 days as the offset.

The logarithm of the offset variable is added to the explanatory variables with a coefficient constrained to one. Letting z be the exposure variable, the model becomes

$$\log\left[\frac{E(Y)}{z}\right] = \log\left[E(Y)\right] - \log(z) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n$$

$$\log\left[E(Y)\right] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n + \log(z)$$

Longer-term factors affecting crash rates in general

There has been a substantial reduction in the number of road crash fatalities since the 1970s, when the wearing of seatbelts was made compulsory, and drink driving restrictions were first introduced. Steady improvements in road infrastructure, vehicle safety features, driver education, enforcement and regulations have all contributed to the downward trend. The downward trend has occurred despite increases in population and traffic levels.

If crash rates were falling generally during the evaluation period, failure to adjust for the time trend would lead to over-estimation of the effectiveness of black spot treatments because the general crash reductions would be wrongly attributed to the black spot treatments.

6 As explained below, observations for implementation periods were removed from the database.

For example, say a black spot treatment reduced the crash rate at a site by 30%. Around the same time that the treatment was carried out, speed limits were reduced leading to 10% reduction in the general crash rate. A simple before and after comparison of crash rates at the site would produce a result that reflects the two effects combined — an expected reduction in crashes of 37%, $(1 - 0.3) \times (1 - 0.1) = (1 - 0.37)$. If the impact of the reduction in speed limits is ignored, the entire 37% reduction would be attributed to the black spot treatment.

Ideally, factors that produce long-term effects on general crash rates would be included among the explanatory variables in the regression analysis. However, there are many potential factors and they are difficult to identify and quantify. After careful consideration of the alternatives, it was decided to use total crashes in each state or territory as an explanatory variable. Although crashes at black spot locations are included in the totals, they are overwhelmingly crashes at non-black spot sites. Hence, the approach is approximately equivalent to using the rest of the state or territory as a control site.

For each regression model, total numbers of crashes of the nearest possible severity level for each year were included as an offset term. The natural logarithm of the variable is made an explanatory variable with a parameter constrained to one. Hence, the crash rate at each site in each year is assumed to be proportional to total number of crashes in the jurisdiction.

Ideally, the crashes used for this control variable would be the same severity as that being modelled. While the number of fatal crashes was available for each state and territory over the relevant time period, it was not possible to obtain consistent information across all jurisdictions for the whole time period for any other crash severity level. Hence, for the fatal crash model, the total number of fatal crashes was used, but for all other models a single measure was used for each jurisdiction. For some jurisdictions the only measure available was the number of persons injured in crashes, while for others it was the number of serious injury crashes.

The measure used for each jurisdiction is set out below:

- ACT total persons injured (estimated for calendar years from financial year data)
- NSW total persons injured
- NT total serious injury crashes
- QLD total persons injured
- SA total serious injury crashes
- TAS total serious injury crashes
- VIC total serious injury crashes
- WA total serious injury crashes

Non-trend factors affecting crash rates

Having addressed influences on crash rates that change in regular cycles and the long-term trend, there remain non-trend factors such as weather, and one-off events such as the Olympic Games in Sydney or rerouting of traffic due to road works.

Weather conditions at the times of crashes could not be included as an explanatory variable because the data are lacking for many crashes in the database. Data on temporary traffic fluctuations at sites is not available. Hence, allowances could not be made in this study for one-off events having temporary effects on crash rates at individual or at groups of sites. As there are a large number of sites in the study, and one-off events can have positive or negative effects on crash rates and can occur either before or after treatment, failure to allow for them is not expected to bias the overall results. They could however, increase the standard errors of the results. By adding to the variances of crash numbers at individual sites without increasing the means, they would increase the overdispersion factor discussed below.

Crashes during implementation of treatments

Crashes that occur during the period when the treatment works are being carried out need to be distinguished from pre- and post-treatment crashes. The site will be physically different during the implementation period, traffic may divert to alternative routes, and there could be temporary lower speed limits in place. The choice is either to leave out altogether crashes occurring during implementation periods, or to include a separate indicator for them.

It would be desirable to include in the cost–benefit analysis the benefit of any reduction in crashes or the cost of any increase during implementation periods because cost–benefit analysis aims to be as comprehensive as possible. Furthermore, if road safety was found to be worse during project construction, program implementation might be improved by addressing safety deficiencies in the way traffic is managed when the works are carried out. However, to the extent that traffic diverts to alternative routes, there could be significant migration of crashes to other locations, which would not be observable in crash data from treatment sites. For this reason, it was decided to leave out all crashes during implementation of treatments.

Uncertain observation periods

BITRE asked road agencies to provide crash data within plus and minus seven years of implementation of each project, or up to the most recent date possible where the implementation occurred too recently for there to be a full seven years of data.

For most jurisdictions, there was a clear start date and end-date for crash data across all sites. For individual sites, data outside the plus or minus seven-year period were omitted because the longer the observation period before and after the treatment, the greater the chance that the characteristics of the site will have changed in ways that affect crashes.

The data were expanded by adding observations with zero crash counts between the start of the seven-year pre-treatment period and the year of the first crash. Similarly, zero crash count periods were added from the year of the last crash to end of the seven year post-treatment period or the end date of the crash data for the particular jurisdiction.

For some sites in some jurisdictions, it was not possible to establish clear start and end dates for the observation periods.

The date of the first crash at a site occurs well after the start of the seven-year pre-treatment period. On the basis of the crash rate during the period between the time of the first crash and commencement of the project, the probability of zero crashes between the start of the seven-year period and the date of the first crash is too small for zero crashes to be credible. More likely the data were missing. It would be distorting to complete the data with observations of zero crashes.

To obtain unbiased estimates of crash rates, it is essential to know when the observations start and finish.

Bias will occur if the observation period is assumed to start at the time when the first crash occurs. Say one observes a site for 100 days during which five crashes occur. The maximum likelihood estimate of the daily crash rate is 0.05 = 5/100. If instead, observations were deemed on commence on the day of the first crash, and the first crash occurred on day 21, the crash rate would be taken as 0.0625 = 5/80. Having observations commence on the day the first crash occurs leads to over-estimation of the crash rate because the denominator in the crash rate is too small.

To show this formally, say one observes a series of time periods in which the probability of a crash is Poisson distributed. Observations commence, but no record is made of them until there is a period in which one or more crashes occur. What is the expected number of crashes in the first recorded period?

The probabilities of all the possible outcomes — crash counts from one to infinity — must sum to one. But since at least one crash must occur for the period to be recorded, the probabilities of all possible outcomes sum to one minus the probability of zero crashes, that is

$$1-\frac{e^{-m}m^{0}}{0!}=1-e^{-m}\ .$$

So the probabilities from the Poisson distribution need to be scaled up by a factor of $1/\left(1-e^{-m}\right)$ to make them sum to one.

Letting x be the number of recorded crashes that can range from one to infinity, the expected number of crashes in the first recorded period is then:

$$E(x)=\frac{1}{\left(1-e^{-m}\right)}\sum_{x=1}^{\infty}x\frac{e^{-m}m^{x}}{x!}=\frac{m}{\left(1-e^{-m}\right)}\sum_{x=1}^{\infty}\frac{e^{-m}m^{x-1}}{(x-1)!}=\frac{m}{\left(1-e^{-m}\right)}$$

Since $e^{-m}<1, E(x)>m$, the crash rate will be over-estimated. As more time periods are observed and used together with the first observation to estimate the crash rate, the bias will reduce, but will only approach zero as the number of observed periods approaches infinity.

The solution is simply to omit the period containing the first crash or crashes. Effectively, the first crash is used to mark the date on which we can be certain that observations have been provided. This only has to be done for whole data set for a site comprising crashes of all severity levels, not for each severity level separately.

Intuitively, omitting the period with the first crash might be seen to introduce a bias towards under-estimation of the true crash rate, because the time periods immediately following the first crash could be expected to have zero crashes. However, this is a misconception. A fundamental assumption of a Poisson process is that it is 'memoryless'. The assumption that each crash is statistically independent of the others means that the probability distribution for crashes in one time period is not in any way affected by whether or not a crash has occurred in any other time period.

Similarly, where the end-date of the post-treatment period was uncertain, the last crash had to be omitted with observations deemed to finish in the preceding time period.

Unreported crashes

In 1995, BTCE surveyed the evidence available at the time on under-reporting of crashes and found it to be considerable. Studies of under-reporting of crashes invariably find that there is an inverse relationship between the level of under-reporting and crash severity. Only in exceptional circumstances would a fatal crash go unreported. A large proportion of PDO crashes are not reported. From the point of view of the CBA, having the under-reporting concentrated on the less costly crashes is less distorting than having it spread uniformly across all severity categories.

Provided the proportion of unreported crashes remains constant over time, before and after treatment, there will be no effect on the proportional reductions in crashes attributed by the regressions to black spot treatments. The smaller number of total crashes will reduce the estimated numbers of crashes avoided.

The Austroads (2008) unit crash costs for minor injuries used in the CBA in chapter 9 already include an allowance for under-reporting. The Austroads values were derived from the BTE (2000) estimate of total road crash costs for Australia. BTE (2000, p. 18) states:

> *'ATSB [the Australian Transport Safety Bureau] collects statistics concerning fatalities and serious injuries, and its estimates were used for these injury levels. Estimation of uninjured persons and those sustaining minor injury requires a number of assumptions, as there is no central organisation that compiles such numbers. The number of minor injuries was determined using a ratio relating hospital admissions to emergency department attendances and to presentations to general practitioners. This ratio is 1:3.53:3.88 …'*

Hence, assuming there is no under-reporting for the fatal and serious injury categories, and that the unit costs for minor injuries include an upward adjustment for under-reporting, the results of the CBA for casualty crashes should not be understated due to under-reporting. However, the estimated numbers of minor injury and PDO crashes avoided in chapter 8, and the benefits for the PDO estimates reported in chapter 9 will be under-estimated.

The recent 2009 BITRE crash cost study made allowances for unreported crashes. It used a different classification for injury crashes from the 2000 BTE study, hospitalised and unhospitalised.

Around 30% of people admitted to hospital are discharged on the same day and so would be counted as minor injuries under the traditional severity categorisation. From unpublished estimates made during preparation of BITRE (2009), ratios of under-reported to reported crashes are zero for fatal, 0.08 for hospitalised, 3.84 for non-hospitalised, 2.48 for PDO and 2.44 for all crashes.

If it is assumed that 30% of hospitalised injury crashes are minor injury crashes and that all unreported hospitalised crashes are minor injury crashes, then the ratio of unreported to reported crashes is zero for serious injury and 3.28 for minor injury crashes. This ratio and the 2.48 ratio for PDO crashes are used for a sensitivity test of predicted numbers of crashes avoided in chapter 7.

Crash migration

There is a hypothesis, called 'crash migration' in the road safety literature, that treatment of a black spot site reduces crashes at the treated site, but at the expense of increased crashes in the vicinity of the site.

One of the possible causes is 'risk compensation' by drivers. If a road is made safer, some of the benefit may be appropriated by drivers in the form of increased performance such as greater speed rather than less risk of crashes. The safety benefit could also be appropriated by drivers in the form of a lower level of attentiveness.

Another potential cause of crash migration is redistributions of vehicle and pedestrian traffic caused by the treatment, for example, using alternative routes to avoid waiting at signals.

A proper assessment of crash migration would require analysis of data on sites in the neighbourhood of each treated site, which is beyond the scope of the present study. For an extensive discussion of crash migration, see BTCE (1995, pp. 81 and 251–264).

End note

The analysis is able to address some of the issues arising from the crash data that could distort the results. For example, the possibility of exaggerating treatment effectiveness by attributing the general declining trend in crashes to the NSBP is countered by including a crash trend variable in the regression model.

Upward biases in pre- or post-treatment crash rate estimates due to uncertain observation periods were eliminated by removing the first or last crash from the data where necessary. Fluctuations of crash rates that occur with weekly or annual cycles are averaged out by undertaking the analysis on a yearly basis.

Some difficulties are less tractable. Differences in definitions of crash severities between jurisdictions will to some extent be separated out in the jurisdictional regression coefficients. There is widespread under-reporting of minor injury and PDO crashes.

The unit cost for minor injury crashes used in the cost–benefit analysis includes an allowance for unreported crashes, so the estimated benefits of casualty crashes avoided should not be underestimated due to omitted unreported crashes. Estimates of the numbers of minor injury and PDO the crashes avoided and benefits from PDO crashes avoided will be affected. Chapters 7 and 9 report results of sensitivity tests undertaken using ratios of unreported to reported crashes from BITRE (2009).

Discussion of another crash data issue, the presence of non-target crashes in the data, is deferred to chapter 7 where it is addressed in the context of predicted crashes avoided due to the NBSP.

CHAPTER 5

Regression analysis

Summary

Six regression models were estimated for crashes grouped by severity level — fatal, serious injury, minor injury, injury, casualty and property damage only (PDO). The amount of data available for each model varies considerably. As fatal and serious injury crashes occur relatively infrequently, these models are supported by considerably smaller numbers of projects and crashes.

Over-dispersion occurs when the variance of count data exceeds the mean. In Poisson regression models, it can occur where the model omits essential explanatory factors, is not precisely fitting the data, or there is lack of statistical independence in the data. Some over-dispersion was found in four of the six models necessitating scaling up of the standard errors of the estimated coefficients by factors ranging from 1.3 to 1.5.

Sites are selected for black spot projects because of past high crash rates. In some cases, the high crash rates are due to chance rather than an underlying road safety problem. Without any project being undertaken, the high crash rate is likely to be lower (regress to the mean) in subsequent periods. An ex-post black spot evaluation could attribute crash reduction caused by regression to the mean to treatments rather than to chance leading to an exaggerated estimate of effectiveness.

The crash rate during the interval of time between the date on which the funding application was submitted to the Government, and the date on which work on the project commenced, provides an estimate of the pre-treatment crash rate uncontaminated by selection bias (selecting projects due to a chance high crash rate).

Pre-application crash rates were found to be higher than post-application crash rates by statistically significant amounts in four of the six models — 25% for fatal crashes, 17% for serious injury crashes, 6% for injury and 7% for casualty crashes.

The reported crash reduction factors in this chapter compare post-treatment with post-application crash rates and so are free of selection bias.

Black spot treatments were found to be becoming more effective over time by 4% to 6% per annum.[7]

7 The treatment effectiveness index (TEI) (post-treatment crash rate / pre-treatment crash rate) falls by 4 to 6% each year, implying the crash reduction factor (1 – TEI) increases. All percentage changes in treatment effects given here refer to percentage changes to TEIs. To say that treatments are *x*% less effective implies TEIs are *x*% higher. To say that treatments are *x*% more effective implies TEIs are *x*% lower.

Significant variations exist in treatment effectiveness between jurisdictions for some models. Much of the variation can be attributed to differences between jurisdictions in the way crashes are assigned to sites and in the crash reporting requirements for PDO crashes. The ACT has considerably more effective treatments than the other jurisdictions, but with only 13 projects in the database, there is a small-sample-size issue.

Treatments are more effective in non-metropolitan areas compared with metropolitan areas — 13% for serious injuries, 27% for minor injuries and 17% to 19% for injury, casualty and PDO crashes — probably due to the higher speed environments in rural areas. Due to the smaller data set, no statistically significant difference was discernible for fatal crashes.

Treatments are less effective on state roads compared with local roads — 20% for minor injuries, 14% for injury and casualty and 29% for PDO crashes. The explanation might relate to the way state and local governments select and implement black spot projects or to the different characteristics of state and local roads. Due to the smaller data set, no statistically significant difference was discernible for fatal crashes.

Only the PDO crash model had a statistically significant effect for project selection by road safety audit (RSA) compared with crash history and benefit–cost ratio (BCR). Treatments in projects selected by RSA are 25% less effective compared with BCR-selected projects.

Regression models estimated

The Poisson regression modelling was undertaken by a firm of statistical consultants, Data Analysis Australia. Their report, reproduced in full in volume 3, contains a detailed description of the methodology with the outputs of the regression model for each crash severity level. This chapter presents the results for explanatory variables that apply equally to all treatment types.

Six regression models were estimated for different crash severity classifications:

- fatal crashes
- serious injury crashes (excludes NSW)
- minor injury crashes (excludes NSW)
- injury crashes (combines serious and minor injury crashes with NSW injury crashes)
- casualty crashes (combines injury and fatal crashes)
- property damage only crashes (excludes Victoria)

Tables 5.1 and 5.2 respectively show the numbers of projects and crashes for each regression model by jurisdiction. Combining the casualty and property damage only (PDO) crash totals, there are 71 824 crashes altogether in the database.

For each regression model, it was necessary to remove sites from the analysis where there were no crashes at all of the particular severity level. Hence, none of the individual regression models included all 1599 projects. The largest regression models in terms of numbers of projects, injury and casualty crashes, each with 1578 projects, excluded 21 projects that had only PDO crashes.

Fatal crashes are relatively infrequent. The majority of sites had to be excluded from the fatal crash regression because they had no fatal crashes.

The NSW RTA does not distinguish between serious and minor injury crashes, combining them into a single 'injury' class. The serious and minor injury crash regression models therefore exclude all NSW projects. All jurisdictions are represented in the injury crash regression model.

Since all sites with fatal crashes also had injury crashes, the set of projects for the casualty crash regression is identical with that for the injury crash regression. The fatal and injury crashes were combined for the casualty crash regression.

Vicroads was unable to supply any data on PDO crashes. WA has an exceptionally high average rate of PDO crashes per site. During the time the statistics were collected, WA traffic regulations specified an unusually low monetary threshold above which PDO crashes had to be reported to police. By contrast, for NSW and SA, drivers involved in a PDO crash are only obliged to report crashes where one of the vehicles needs to be towed or carried away.

Crash data collected for BITRE (2009) for estimating the overall cost of crashes in Australia showed that, for 2006, the ratio of PDO to casualty crashes was 4.22 for WA compared with 1.45 for all jurisdictions excluding Victoria.

T5.1 Numbers of projects in regression models

Jurisdiction	Fatal	Serious	Minor	Injury	Casualty	PDO[a]	Total
ACT	3	11	12	13	13	13	13
NSW	70	NA	NA	349	349	345	353
NT	11	24	26	26	26	26	26
QLD	45	199	220	229	229	211	233
SA	26	80	95	99	99	90	103
TAS	12	27	39	39	39	39	41
VIC	168	481	512	513	513	NA	513
WA	59	271	301	310	310	316	317
TOTAL	394	1 093	1 205	1 578	1 578	1 040	1 599

a. Property damage only

T5.2 Numbers of crashes in regression models

Jurisdiction	Fatal	Serious	Minor	Injury	Casualty	PDO	Total
ACT	3	34	84	118	121	2 161	2 282
NSW	122	NA	NA	4 064	4 186	5 423	9 609
NT	26	176	314	490	516	1 252	1 768
QLD	59	916	2 442	3 358	3 417	2 631	6 048
SA	36	305	2 250	2 555	2 591	7 287	9 878
TAS	18	87	341	428	446	885	1 331
VIC	301	3 685	9 279	12 964	13 265	NA	13 265
WA	110	1 398	5 472	310	6 980	20 663	27 643
TOTAL	675	6 601	20 182	1 578	31 522	40 302	71 824

Over-dispersion

As discussed in chapter 2, the mean and variance of the Poisson distribution are equal. The technical term for situations where the variance is greater than the mean is 'over-dispersion'. If the variance is less than the mean, the term is 'under-dispersion'.

It is straightforward to check whether the mean and variance of crash counts per period of time are similar. Differences between the mean and variance of count data would arise if there was dependency between the events being counted or if other assumptions of the Poisson distribution do not hold.

In the case of a Poisson regression model, each set of values for the explanatory variables gives rise to a different predicted mean. In a limitless number of independent realisations of the same set of values for the explanatory variables, the mean of the dependent variable (crash counts) will the same as the variance. The random error around the mean is introduced by the Poisson process itself (Berk and Macdonald 2008).

The deviance, being a measure of goodness of fit for a Poisson model, indicates how the residual variances compare with the means. As noted in chapter 2, the deviance is expected to have a chi-square distribution with degrees of freedom given by the number of observations minus the number of parameters. The mean of the chi-square distribution is the number of degrees of freedom. However, in practice, it is not unusual for the deviance to exceed the number of degrees of freedom (DAA 2009).

There are several reasons:

- The model may be omitting one or more factors that are needed to explain the data. These may be additional variables, interactions between existing variables or different encodings of existing variables. Hence more detailed models may be required.
- The model specification is not precisely correct and the lack of fit appears as additional variance. It could be that the functional forms specified are not correct or there is random variation in the predicted means (in addition to the Poisson variation around the means).
- There is a dependency between events being counted (crashes), which inflates the variance. This is inconsistent with the basic assumption of the Poisson distribution (DAA 2009, pp. 11–12; Berk and Macdonald 2008).

The first two of these possible causes are generally manageable provided that the relevant data are available. They suggest that efforts be made to improve a poorly fitting model.

The third reason is true over-dispersion and is a real departure from the Poisson model. Sometimes it might be due to unknown and unobserved factors that influence multiple events. However, since these are unobserved, they may as well be considered random.

A common solution to over-dispersed Poisson models is to use the negative binomial distribution instead. This approach was not followed here because there is no reason to believe that such a distribution is likely to better fit the data and it creates significant computational issues.

True over-dispersion rarely leads to biased estimates provided that the mechanism causing over-dispersion is not related to the factors in the model. However, it does lead to an under-statement of the standard errors associated with the estimates, giving false levels of significance for parameter estimates. To obtain realistic values for these standard errors, a dispersion parameter $\hat{c}$ is calculated as

$$\hat{c} = \sqrt{\frac{D}{n-p}}$$

where D is the deviance, n is the total number of observations and p is the number of parameters in the model. This factor gives an approximate representation of the amount of over-dispersion and is used to adjust the standard errors. The standard errors for all the coefficients are multiplied by reducing the statistical significance of the coefficients. This raises the hurdle for coefficients to be found statistically significant.

Adjustments for over-dispersion had to be made for four of the six models:

- serious injury crashes: $\hat{c}$ = 1.27
- injury crashes: $\hat{c}$ = 1.31
- casualty crashes: $\hat{c}$ = 1.32
- property damage only crashes: $\hat{c}$ = 1.49

Interpretation of results

The regression equation is estimated in logarithmic form. For ease of interpretation, the results presented throughout the report have been converted into percentage 'effects', that is, percentage changes relative to a baseline level.

Effect % = [exp(coefficient) – 1] × 100

A regression coefficient of –1.0 for a treatment type implies that the treatment effectiveness index (TEI) is exp(–1.0) = 0.368. The post-treatment crash rate is 36.8% of the pre-treatment rate. The 'effect' or crash reduction factor is –62.3% = (0.368 – 1) × 100. The regression coefficient and the effect always have the same sign. A negative value for the coefficient and effect implies the treatment reduces the crash rate. If the regression coefficient is zero, the effect is zero. A positive regression coefficient and effect implies the treatment increases crashes.

Interaction terms have also been converted to effects. Take serious injury crashes in South Australia as an example. The estimated effect of the jurisdiction interaction term is about –30%.

This means that, in South Australia, the estimated TEI will be 70% of the TEI for the same treatment in Victoria, the base jurisdiction for the serious injury model. For example, if in Victoria, roundabouts were estimated to reduce crashes by 70%, a TEI of 0.3, then the TEI for roundabouts in South Australia will be 0.3 × 0.7 ≈ 0.2. Hence, roundabout treatments in South Australia reduce crashes by 80% compared with 70% in Victoria.

The tables in this chapter and in chapter 6 feature 95% confidence intervals converted to percentage effects, and p-values.

The p-value is the probability of obtaining a result at least as extreme as the one obtained, assuming that the true value of the coefficient is zero. It is the minimum level of significance at which the coefficient would be considered statistically significant.

To pass the standard significance test at the 0.05 level, the p-value has to be less than 0.05. The p-values for pre-application bias are for a one-sided test because pre-application bias can only lead to a higher pre-application crash rate. For all other parameters shown in the tables, the p-value is for a two-sided test.

In the results tables throughout this report, coefficients statistically significant at 0.1, 0.05 and 0.01 levels are marked with one, two and three stars respectively.

Where a coefficient is found to be not statistically significant, there are two alternative interpretations: either there is no effect, or there is an effect but there are too few observations in the data to be reasonably certain about it. The number of significant variables in the different models is related to the amount of data. The model with the smallest amount of data, fatal crashes, had only four statistically significant coefficients at the 0.1 level for treatment type categories and no significant interaction terms other than for night-time crashes. The model with the largest data set, PDO crashes, obtained significant results for the largest number of terms.

Regression to the mean (selection bias)

Explanation

Black spot sites are chosen for treatment primarily on the basis of their high recent crash record. The criteria for selection set out in the current Program Notes on Administration (DIT 2009a, p. 9) are as follows:

> *Project proposals … should be able to demonstrate a benefit to cost ratio (BCR) of at least 2. …*
>
> *For discrete sites (e.g. an intersection, mid-block or short road section), the minimum eligibility criterion will be a history of at least three casualty crashes over a five-year period.*
>
> *For road lengths the minimum eligibility criterion is an average of 0.2 casualty crashes per kilometre per annum over the length in question measured over five years or the length must be amongst the top 10% of locations identified in each state which have an identified higher crash rate than other roads.*
>
> *Notes: Measures of casualty crashes should be provided from the most recently available 5 year period.*

Prior to the 2002–03 program year, the BCR criterion was the same but the other criteria were:

> *For discrete sites (e.g., an intersection, mid-block or short road section), the minimum eligibility criterion will be a history of at least 3 casualty crashes in any one year; or 3 casualty crashes over a three-year period; 4 over a four-year period; 5 over a five-year period, etc.*
>
> *For road lengths, the minimum eligibility criterion is an average of 3 casualty crashes per kilometre of the length in question, measured over 5 years; OR the length to be treated must be amongst the top 10% of sites identified in each state which have a demonstrably higher crash rate than other roads in a region.*
>
> *Note: Measures of casualty crashes should be provided for a period commencing not earlier than 1 January 1991 (BTE 2001, p. 138).*

The second set of criteria applied for all but the last year of the black spot projects within the scope of the present evaluation.

From a statistical point of view, a high number of crashes at a given site over a period of time could arise from either a high mean crash rate or a random fluctuation above a low mean crash rate. The problem is telling them apart. A black spot project may be warranted at a site with a high mean crash rate. At a site where a random fluctuation above a low mean crash rate occurs, it is highly likely that the crash rate will be lower (regress to the mean) in subsequent periods without any black spot project.

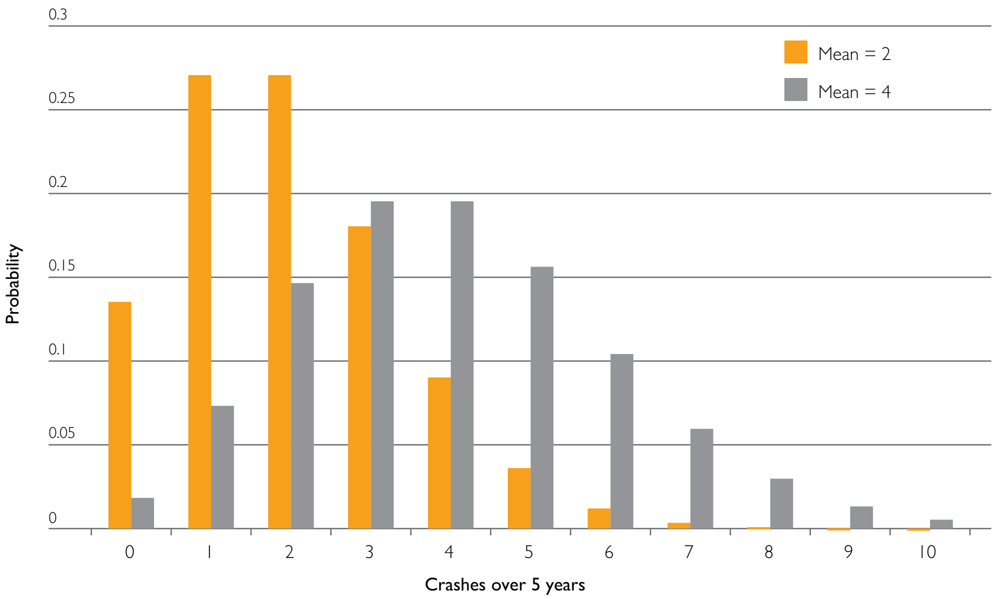
Figure 5.1 shows two Poisson probability distributions, one with a mean of 2.0 and the other with a mean of 4.0. Say the crash counts along the horizontal axis are for casualty crashes at a given site over a period of five years.

At the site, say there were four crashes observed during the most recent five year period. The site would qualify as a black spot under the current program criteria. However, the mean number of crashes and hence the underlying probability distribution are unknown. If the probability distribution had a mean of four, there would be a 76% probability of three or more crashes occurring in future five-year periods without treatment (the sum of the heights of bars for three crashes and above in figure 5.1).

If the mean was two, the probability of three or more crashes in future five-year periods is 32%. During the next five-year period, and subsequent five year periods, there is a 68% probability that there will be zero, one or two crashes without treatment.

If the mean was two, it is highly probable that the number of crashes would be lower in the next period and that the site would not qualify as a black spot. Thus, regression to the mean increases the risk of making wrong decisions when implementing a black spot program.

F5.1 Poisson distributed crash probabilities



In an ex-post evaluation of a black spot program, regression to mean increases the risk of over-estimating program effectiveness. If the site was treated because it qualified as a black spot, having four crashes in five years, and there was a significant reduction in the number of crashes following treatment, two interpretations are possible.

The first is that the treatment has been effective in reducing the mean crash rate. The second is that the treatment has been ineffective — the mean has not changed — the reduction in crashes occurred by chance.

Referring to figure 5.1, where four crashes occurred over the five-year pre-treatment period, if the average was four crashes every five years and the treatment was ineffective, there would be a 43% probability that the number of crashes would be three or less in the five years after treatment. If the average was two and the treatment was ineffective, there would be an 86% probability of fewer crashes in the following five years. Hence, if a site was selected for treatment due to a random fluctuation rather than a genuine high mean, there is a greater risk of wrongly concluding that an ineffective treatment was effective.

In the words of BTCE (1995, p.76), regression to the mean '… refers to the simple notion that when some condition is extreme or abnormal, it is likely to be less extreme (or closer to normal) in a subsequent period. For example, a scorching summer day is more likely to be followed by a cooler day than an even warmer day.' The phenomenon is also called 'selection bias'.

A proportion of the black spot sites selected for treatment are likely to have qualified because of random fluctuations in crashes. Even if the treatments were ineffective, there is a strong likelihood of reductions in crashes being observed at these sites after treatment.

The result of an analysis of the effectiveness of the black spot program could be biased towards exaggerating the effectiveness of treatments because of the way in which the sites have been selected.

Implications for project selection

In a well-funded black spot program, a certain amount of regression to the mean in project selection is inevitable. Raising the hurdle crash rate or benefit–cost ratio (BCR) will lower the probability of investing in a black spot project that would not be considered worthwhile on the basis of its true underlying crash rate.[8] In statistical parlance, it reduces the probability of type 1 error — observing a difference when in truth there is none.

The downside is that the higher the hurdle is set, the greater the probability of failing to treat a site that would be warranted on the basis of its true underlying crash rate because it has a crash rate below the hurdle rate at the time it is being observed. This is a type 2 error, failing to observe a difference when in truth there is one.

Both errors lead to poorer road safety outcomes — type 1 errors divert program funds away more beneficial projects and type 2 errors leave sites with high crash rates untreated until such time in the future when the requisite number of crashes has occurred.

Investment decisions are best made on the basis of expected values of benefits and costs because, in the long-term, making many decisions, the average net benefit is likely to be highest. It can be shown that, for a single site with a constant mean crash rate *m* over time, the maximum likelihood estimate of the mean is simply $\hat{m} = \sum k_i / Y$ where k_i is the number of crashes in each observed time period *i* and *Y* is the number of time periods.[9]

The critical crash rate at which the BCR equals the hurdle value could be reached after any number of observation periods. For example, if the critical crash rate was 1.9 casualty crashes per year, the project would be considered warranted on the basis of one year of crash data if there were two or more casualty crashes in the that year. If there was only one crash in the year, the investment would be considered warranted after two years if there was three or more casualty crashes in the second year. So the number of observation years can be variable.

It makes sense to set a maximum number of years of continuous data because the longer the observation period for a site, the greater the possibility of the underlying crash rate changing over the period due to changes in traffic levels or road infrastructure.

The qualifying criteria for black spot projects, whether based on crash rates or CBA or a combination of both, control the level of selection bias in the program. However, it is neither possible, nor desirable to eliminate it altogether. The question for the present ex-post evaluation is whether the amount of selection bias present is sufficient to affect the estimates of treatment effectiveness, and if so, by how much.

8 For CBA, a cut-off BCR above 1.0 is a capital rationing device. When available investment funds are insufficient to pay for all projects with benefits greater than costs (BCR > 1.0), projects should be ranked in descending order of BCR and the cut-off BCR is the BCR of the last project that fits within the budget. Since the estimated road safety benefit from a black spot project is proportional to the estimated without-treatment crash rate, raising the cut-off BCR has a similar effect to raising the cut-off crash rate. However, it will not be exactly the same because the BCR depends on other factors, in particular, project capital and maintenance costs, project life, and the crash reduction factor associated with the treatment.

9 The variance of is given by $\sum k_i / Y^2 = \hat{m}/Y$. Hence, the variance of the estimated mean falls as the number of observation periods increases. However, the variance is not relevant to the decision.

Testing for selection bias

A test exists to determine the significance of selection bias. The crash history of a treated black-spot site can be divided into three periods:

- before the site was identified as a black spot
- the lag period between identification as a black spot and commencement of the treatment
- after treatment (BTE 2001, p. 84)

The crash rate during the lag period is insulated from both the effects of the treatment and from selection bias. The statistical hypothesis can be tested that the crash rate prior to the application date, which may be affected by selection bias, is above the crash rate during the lag period, which is free from selection bias. Although, for most sites, the lag period is fairly short, with a large number of sites, a statistically robust test may be possible.

In the Poisson regression models, a dummy variable was introduced, called 'pre-application bias', set to one for pre-application observation periods and to zero for post-application periods — both pre- and post-treatment. A statistically significant positive coefficient indicates the extent to which crash rates are higher during pre-application periods because of selection bias. The estimated crash reduction factors are free from selection bias because as they compare post-treatment crashes with crashes during the lag period.

Regression results for pre-application bias

Pre-application bias results are shown in table 5.3. The coefficients for pre-application bias are strongly significant for three of the models and weakly so for two others. The levels are quite large for fatal and serious injury crashes. For fatal crashes, pre-application crash rates averaged 25% higher than post-application rates. For serious injury crashes, pre-application crash rates were 17% higher than post-application rates.

The models are suggesting that a significant part of the apparent drop in fatal and serious injury crashes, and smaller amounts for other severity levels were due to the selection process for black spot sites.

The high fatality and serious injury rates that led to some sites being selected were due to chance and the crash rates would have fallen in subsequent periods without treatment. Given that fatal crashes, and to a lesser extent serious injury crashes, are relatively rare and would carry greater weight in the selection process than minor injury and PDO crashes, it is not surprising that selection bias would be greater for fatal and serious injury crashes.

T5.3 Effects for pre-application bias

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	24.7	(-3.6, 61.3)	0.046	**
Serious injury	16.9	(7.8, 26.7)	0.000	***
Minor injury	2.8	(-3.1, 9.1)	0.183	ns
Injury	6.1	(0.8, 11.6)	0.012	**
Casualty	6.7	(1.4, 12.3)	0.006	***
PDO	3.7	(-1.4, 9.1)	0.080	*

Notes: Effect = exp(coefficient) – 1

p-value is the minimum significance level expressed as a probability at which the coefficient is significant. A value of 0.000 means less than 0.0005. For pre-application bias, the p-value is for a one-sided test. For all other p-values in the report, the test is two-sided.

95% CI = the lower and upper limits of the 95% confidence interval for the effect

*** = significant at 0.01 level, ** significant at 0.05 level, * significant at 0.1 level, ns = not significant at 0.1 level.

Effects of publicity given to black spots

The Notes on Administration for the National Black Spot Program requires erection of a sign at black spot sites, 'FEDERALLY FUNDED BLACK SPOT PROJECT', which is to remain in place for at least two years following completion of the treatment, for treatments costing more than $100 000. For projects costing less than $100 000, a temporary sign must be erected while the works are being carried out.

Drivers seeing these signs may exercise greater caution regardless of the treatment leading to a reduction in crashes. This was tested by adding an additional dummy variable to the regression that changes two years after completion of each treatment costing above $100 000. The hypothesis to test was whether a statistically significant reduction in treatment effectiveness occurs two years following the completion of the treatment when the sign is removed. The regression analyses found no significant changes.

Changing effectiveness of new treatments over time

Road agencies might be expected to give the worst black spots highest priority. They would, naturally, address the worst black spots during the early years of the Program. As time went on, less serious black spots would receive attention (Geurts and Wets 2003, p. 24).

The qualifying criteria in the Notes on Administration have been less stringent since 2002–03. Expansion of the road network and growth in traffic levels would give rise to new black spots, though for new roads, designers might have learned the lessons of the past and created fewer new black spots than their predecessors. Hence, the hypothesis that the effectiveness of black spot treatments is declining over time is worth testing.

On the other hand, the test needs to be two sided because effectiveness could have increased due to improvements in selection of sites and treatments and in implementation.

The possibility of changing effectiveness of treatments over time was not considered by the previous Bureau evaluations because they were looking at the program over three-year periods — not long enough for changes in effectiveness of the program to become apparent. The present evaluation covers treatments implemented over a longer period and so is in a better position detect any change over time.

To test whether the effectiveness of treatments is changing over time, an interaction term (one variable multiplied with another) was included in the regressions between the calendar year in which the treatment was commenced (1995 set to zero) and the treatment indicator.

Treatment implementation year was dropped from the fatal and serious injury models because of lack of significance. For the other four models, table 5.4 shows that treatment effectiveness has been increasing over time.

T5.4 Effects for treatment implementation year

Model	Effect (%)	95% CI (%)	p-value	Significance
Minor injury	-6.0	(-8.1, -3.8)	0.000	***
Injury	-3.8	(-5.6, -2.0)	0.000	***
Casualty	-3.7	(-5.5, -1.9)	0.000	***
PDO	-4.1	(-6.0, -2.2)	0.000	***

For minor injury crashes, on average, black spot treatments have become 6% more effective at reducing minor injury crashes each year since 1996.

To illustrate, for a given treatment type implemented in 2001, the TEI for minor injuries would be 27% = $[1 - (1 - 0.06)^5] \times 100$ less than the TEI for the same treatment type implemented in 1996, five years earlier. This suggests that administration of the National Black Spot Program has improved over the years.

Three-way interaction terms between implementation year and individual treatment types did not have significant coefficients, so it was not possible to discern different rates of change in effectiveness over time for different treatment types.

As with other explanatory variables, lack of statistical significance of treatment implementation year in the fatal and serious injury models does not necessarily imply that there has been no improvement in effectiveness for fatal and serious injury crashes. Rather, the smaller numbers of sites and crashes in the data sets for these models have made it impossible to discern a relationship if one exists.

Jurisdictions

Jurisdiction interaction terms were dropped from the fatal crash model as not significant. Results for the other five models are shown in table 5.5. Victoria is the base jurisdiction for the serious and minor injury models and NSW for the others.

Treatments in the ACT could be more effective than for the other jurisdictions, however, the ACT results are based on relatively few sites. There may be some specific conditions present at those sites causing the result.

The way in which crashes are assigned to sites in each jurisdiction, in so far as it affects the proportions of non-target crashes, may explain much of the variation between jurisdictions. As the evidence relates to the relationship between jurisdiction effects and predicted crashes avoided per site, discussion of this issue is deferred to chapter 7.

Different definitions of crash severity levels and levels of unreported crashes between jurisdictions could also influence the jurisdictional effect terms. In particular, for PDO crashes, the different reporting requirements may be material. The lower effectiveness of treatments in reducing PDO crashes in WA may be associated with the much higher level of reporting of PDO crashes in WA mentioned in chapter 4. Some black spot treatments reduce more serious crashes at a cost of increased PDO crashes. This could be more so when very minor PDO crashes are included.

Three-way interaction terms between jurisdictions and individual treatment types did not have significant coefficients.

T5.5 Effects for Jurisdictions

	ACT	NT	Qld	SA	Tas	Vic	WA
Serious injury							
Effect (%)	-36.0	29.9	-1.6	-30.6	-32.2	base	11.5
95% CI (%)	(-72.6, 49.7)	(-8.8, 85.1)	(-16.6, 16.1)	(-47.4, -8.3)	(-60.1, 15.4)		(-3, 28.1)
p-value	0.303	0.147	0.848	0.010	0.152		0.126
Significance	ns	ns	ns	**	ns		ns
Minor injury							
Effect (%)	-64.4	16.6	7.5	5.6	3.3	base	20.3
95% CI (%)	(-83.3, -23.9)	(-19.6, 69.1)	(-6.3, 23.5)	(-8.9, 22.4)	(-27, 46.1)		(7.9, 34.2)
p-value	0.008	0.418	0.302	0.472	0.854		0.001
Significance	***	ns	ns	ns	ns		***
Injury							
Effect (%)	-61.9	25.1	-6.5	-8.8	-11.5	-11.1	7.9
95% CI (%)	(-80, -27.5)	(-7.5, 69.1)	(-18, 6.6)	(-21.4, 5.9)	(-35.4, 21.1)	(-19.2, -2.2)	(-3.5, 20.6)
p-value	0.003	0.146	0.315	0.226	0.445	0.016	0.180
Significance	***	ns	ns	ns	ns	**	ns
Casualty							
Effect (%)	-59.2	23.9	-7.3	-8.3	-12.3	-10.4	7.7
95% CI (%)	(-78.3, -23.3)	(-7.9, 66.8)	(-18.6, 5.6)	(-21, 6.4)	(-35.7, 19.7)	(-18.5, -1.5)	(-3.6, 20.3)
p-value	0.005	0.156	0.254	0.253	0.409	0.023	0.191
Significance	***	ns	ns	ns	ns	**	ns
PDO							
Effect (%)	-32.8	19.2	-25.2	-10.4	37.9	na	31.8
95% CI (%)	(-48, -13.2)	(-7.4, 53.3)	(-36.1, -12.4)	(-21, 1.6)	(6.6, 78.4)		(19.2, 45.8)
p-value	0.002	0.173	0.000	0.086	0.014		0.000
Significance	***	ns	***	*	**		***

Note: NSW was omitted from the table altogether because it does not feature in the serious and minor injury models and is the base jurisdiction for the other three models.

Urban and rural areas

The NBSP Notes on Administration states

> *'… approximately 50 per cent of black spot funds in each state (other than Tasmania, the Australian Capital Territory and the Northern Territory) will be reserved for projects in non-metropolitan areas. For the purpose of this provision, metropolitan areas are defined, on the basis of Australian Bureau of Statistics statistical divisions, as cities and towns with a population in excess of 100,000. The urban–rural criterion is not applied to Tasmania, the Northern Territory and the Australian Capital Territory.'*

The definition of whether a project is urban or rural, therefore, does not relate to whether or not the site is in a built-up area. Being in a built-up area is likely to affect crash rates and treatment effectiveness because of the difference in vehicle speeds. A legal speed limit of less than 80 km/h would be a good indicator of whether a site is in a built-up area. Unfortunately, speed limit data were unavailable for most sites.

The NBSP Notes on Administration imposes quotas on the proportions of funds for rural projects in all jurisdictions except ACT, Northern Territory and Tasmania. So it is possible that, to meet the quota, less warranted projects may be accepted in rural areas. However, the coefficients will also be affected by the different speed environments of many, though not all, roads in non-metropolitan areas.

Table 5.6 shows the quantities of urban and rural site data used in the regression models. While there are generally more urban than rural data, the balance is good, which helps to ensure reliable estimates of any differences in treatment effectiveness between the two categories.

T5.6 Urban and rural data in regression models

	Fatal	Serious	Minor	Injury	Casualty	PDO	Total
Projects							
Urban	199	657	716	857	857	531	860
Rural	195	436	489	721	721	509	739
Total	394	1 093	1 205	1 578	1 578	1 040	1 599
Treatments							
Urban	303	944	1 021	1 208	1 208	720	1 211
Rural	341	728	802	1 178	1 178	848	1 213
Total	644	1 672	1 823	2 386	2 386	1 568	2 424
Crashes							
Urban	327	4 462	15 492	857	22 037	29 415	51 452
Rural	348	2 139	4 690	721	9 485	10 887	20 372
Total	675	6 601	20 182	1 578	31 522	40 302	71 824

An interaction term between the rural and after-treatment variables was created for all treatments together with a further 20 interaction terms between the rural variable and each of the 20 treatment type variables. The former captures the overall difference between urban and rural treatment effects and the latter for individual treatment types where they differ from the overall effect.

The full rural effect for a given treatment type is obtained by combining the coefficient for the general rural term and the specific treatment rural term. The effects set out in table 5.7 are weighted averages of the combined terms for all treatment types. The weights are the numbers of each treatment type in the data (all 1599 projects). The weighted averaging methodology is explained in the chapter 6.

The rural variables were dropped from the fatal model due to lack of significance. For the other models, treatments were found to be considerably more effective in rural areas compared with urban areas, –13% for serious injuries, –27% for minor injuries and just under –20% for the injury, casualty and PDO categories. This suggests that the bias towards rural projects in the program is not leading to selection of projects with less effective treatments, but the higher-speed environments in rural areas may have led to treatments being more effective.

T5.7 Weighted average rural effects compared with urban

Model	Effect (%)	95% CI (%)	p-value	Significance
Serious	-12.5	(-23.2, -0.4)	0.043	**
Minor	-27.4	(-37.1, -16.2)	0.000	***
Injury	-18.4	(-26.1, -9.9)	0.000	***
Casualty	-19.3	(-26.9, -11.0)	0.000	***
PDO	-17.5	(-26.8, -7.1)	0.001	***

Local and state roads

A field in the data indicates whether the site is on a local or state road and so points to the level of government most likely to have been responsible for the project. Table 5.8 shows that the proportions of data on local and state roads are well balanced between the two categories.

T5.8 Local road and state road data in regression models

	Fatal	Serious	Minor	Injury	Casualty	PDO	Total
Projects							
Local road	138	535	613	815	815	600	826
State road	256	558	592	763	763	440	773
Total	394	1 093	1 205	1 578	1 578	1 040	1 599
Treatments							
Local road	228	787	884	1 166	1 166	856	1 186
State road	416	885	939	1 220	1 220	712	1 238
Total	644	1 672	1 823	2 386	2 386	1 568	2 424
Crashes							
Local road	196	2 710	8 849	815	13 354	20 088	33 442
State road	479	3 891	11 333	763	18 168	20 214	38 382
Total	675	6 601	20 182	1 578	31 522	40 302	71 824

The state road interaction term was not significant in the fatal and serious injury models. Table 5.9 shows the results for the other four models with local roads as the base. In all four, black spot projects are less effective on state roads compared with local roads.

It does not necessarily follow that that local governments are better at selecting or implementing black spot projects than state governments. Sometimes local governments nominate and/or deliver on behalf of state road agencies black spot projects on state roads. The explanation could lie in the different characteristics of local and state government roads.

T5.9 Effects for state roads

Model	Effect (%)	95% CI (%)	p-value	Significance
Minor injury	19.7	(9.9, 30.4)	0.000	***
Injury	15.3	(7.3, 24.0)	0.000	***
Casualty	14.6	(6.6, 23.1)	0.000	***
PDO	29.1	(19.3, 39.8)	0.000	***

Method of project selection

The Notes on Administration specifies an alternative decision criterion to the combination of a minimum number of casualty crashes and a minimum BCR.

Projects may be recommended on the basis of an official road safety audit (RSA) report. Over the period of the evaluation, up to 20% of Program funding was available for sites selected by RSA. In the 2009 Notes on Administration, the maximum percentage of funds was raised to 30%.

The data show that the number of sites selected on the basis of an RSA was small over the evaluation period. The limited number of RSA projects in the regression data (see table 5.10), makes it difficult to ascertain whether the RSA method of selection is more or less effective than the crash history/BCR method.

T5.10 Decision criteria data in regression models

	Fatal	Serious	Minor	Injury	Casualty	PDO	Total
Projects							
BCR	363	1 036	1 136	1 478	1 478	943	1 492
RSA	31	57	69	100	100	97	107
Total	394	1 093	1 205	1 578	1 578	1 040	1 599
Treatments							
BCR	596	1 583	1 713	2 235	2 235	1 416	2 261
RSA	48	89	110	151	151	152	163
Total	644	1 672	1 823	2 386	2 386	1 568	2 424
Crashes							
BCR	604	6 383	19 198	1 478	29 454	36 012	65 466
RSA	71	218	984	100	2 068	4 290	6 358
Total	675	6 601	20 182	1 578	31 522	40 302	71 824

Note: BCR = benefit–cost ratio, RSA = road safety audit

The BCA/RCA interaction term was significant only for the PDO model.

The effect term was 25.0% (95% confidence interval: 11.0% to 40.7%) with a p-value of 0.000. The implication is that projects selected by road safety audit are less effective at reducing PDO crashes compared with projects selected by the combination of crash history and BCR. The most obvious explanation is that the RSA methodology is a less effective decision tool for investments in black spot projects compared with crash history and BCR, but there is insufficient data to demonstrate this for the casualty crash models. An alternative explanation is that the RSA methodology is targeted at reducing casualty crashes, not PDO crashes.

Three-way interaction terms between BCA/RSA and urban/rural did not have significant coefficients.

End note

Some interesting findings have emerged from the regression analysis, in particular, regarding regression to the mean and changing treatment effectiveness over time.

Regression to the mean is significant, more so for the higher crash severity categories. It is inevitable that a certain proportion of black spot projects will be chosen because the recent crash rate is high due to chance rather than an underlying road safety problem. The crash reduction factor estimates reported in the next chapter are free from bias due to regression from the mean.

It was expected that, with the worst black spots having been treated in the early years of the program, treatments would become less effective over time. However, the analysis has found the opposite — they are becoming more effective over time.

CHAPTER 6
Treatment effectiveness

Summary

BITRE developed a classification system for black spot treatments suitable for analysing effectiveness via Poisson regression. There are 29 first-level categories. After eliminating two categories that do not occur in the NBSP and combining eight that occur infrequently into an 'unspecified' category, the number reduces to 20 categories.

The most common treatments in the data are T01 roundabouts, T04 modify existing traffic signals, T19 line marking, T07 turning lanes and T10 sealing/resealing. Altogether, there were 2454 treatments identified.

With six crash severity regression models, 20 treatment types of which five have separate daytime and night-time effects, eight jurisdictions, and urban/rural and local/state road interaction terms, the number of derivable effect terms is huge. All are listed in appendix D in volume 2.

To draw out the main findings, weighted average effects were calculated for each regression model and treatment type, averaged across jurisdictions, urban/rural and local/state road. The weights come from the numbers of treatments in the database as a whole. Variances for the weighted averages were calculated from the variance–covariance matrix. This enabled confidence intervals to be estimated and statistical significance tests to be undertaken for the weighted average terms.

The major findings for individual treatment types are set out below:

- T01 roundabouts are generally the most effective treatment, reducing casualty crashes by over 70% and PDO crashes by about 50%.
- T03 new signals during the day and T22 alter traffic flow direction are the next most effective treatments across most severity levels, reducing crashes by more than 50%.
- Statistically significant crash reduction factors for other treatment types lie mostly in the 20% to 50% range.
- No treatments were found to systematically increase crashes.
- T18 warning signs and T20 priority signs may have little effect at night.

The relative infrequency of fatal and serious crashes limited the number of reliable treatment effect estimates derivable from the regression models for those crash severities.

38% of projects in the database consisted of multiple treatments undertaken together, in three cases, as many as six treatments. Analysis of the frequencies with which different treatments occur together showed the most commonly occurring pairs to be T10 sealing/resealing–T19 line marking, T04 modify existing signals–T07 turning lane, and T18 warning signs–T19 line marking.

In all, 21 pairs of treatments were identified as occurring with sufficient frequency to include in the regression models. The group of pair variables had to be dropped from the fatal and serious injury models. For the other models, the interaction terms between treatment pairs show:

- diminishing returns, that is, the combined impact less than the sum of the impacts of the treatments implemented separately, from T07 turning lanes combined with any of T02 medians, T04 modify signals and other turning lane treatments
- synergies, that is, the combined impact greater than the sum of the impacts of the treatments implemented separately, between the pairs T10 sealing/resealing–T19 line marking, T12 alter road width–T15 realign road width, T02 medians–T20 priority signs, and T10 sealing/resealing–T15 realign road length, and between pairs of T04 modify signals treatments.

Classification system

One of the aims of the study is to provide information on the effectiveness of different types of treatments. A large range of treatment types is represented in the database. To reduce the number of different possible treatments to a level suitable for analysis, a classification system is required.

BTE (2001) used the existing Australian Government classification system (see BTE 2001, p. 157 for definitions). While the existing system is satisfactory for the program administration task, BITRE considered that it can be improved upon for the purpose of assessing the effectiveness of different types of treatment. BITRE, with input from road safety experts from ARRB Group, developed an alternative classification system better suited to the purpose at hand.

The system has 29 first-level categories. The full system with subcategories is detailed in appendix A. Treatments were classified using the BITRE system for all 1599 projects in the database based on the Australian Government categorisation and the descriptions provided. The treatment T29 'Other' was used for treatments in the database that could not be categorised due to insufficient detail being provided. The regression analysis is based on first level categories. As perusal of the second and third levels of categorisation in appendix A shows, there is considerable variation within many of the first-level categories.

Treatment data

Primary treatment frequencies

For each multiple-treatment project, a primary treatment was chosen on the basis that it is likely to be the most important treatment in addressing the particular safety problem at the site identified in the 'problem' field of the NPSP database, and in reducing the main crash types that occurred at the site prior to treatment. The primary treatment from a road safety viewpoint need not be the most costly to implement.

Table 6.1 shows counts of projects with primary treatments in each category sorted in descending order of frequency. Roundabouts are the most common primary treatment in the database, accounting for almost a fifth the total. Then follow modification of existing traffic signals, turning lanes and sealing and resealing.

Three categories are empty. T23 camera and T24 speed limit treatments are too inexpensive to warrant funding under the NBSP. T27 grade separation is too costly to qualify for black spot funding and is normally undertaken more for traffic flow than safety reasons. There are two instances of speed limit treatments in the database occurring as secondary treatments. Because no instances of T23 cameras and T27 grade separation occur in the data, they are omitted from all further tables in the report.

T6.1 Projects by primary treatment

Code	Description	Project count	Percentage
T01	Roundabout	303	18.9
T04	Modify existing signals	224	14.0
T07	Turning lane	152	9.5
T10	Sealing/resealing	152	9.5
T03	New signals	123	7.7
T02	Medians	108	6.8
T14	Barriers/guardrails	66	4.1
T16	Realign intersection	53	3.3
T19	Line marking	53	3.3
T08	Pedestrian treatments	50	3.1
T11	Non-skid treatment	50	3.1
T12	Alter road width	47	2.9
T15	Realign road length	45	2.8
T06	Lighting treatments	28	1.8
T20	Priority sign treatments	28	1.8
T22	Alter traffic flow direction	26	1.6
T17	Clear obstacles/hazards	20	1.3
T18	Warning signs	20	1.3
T05	Traffic calming	17	1.1
T28	Channelisation	13	0.8
T21	Ban turns	5	0.3
T29	Other	5	0.3
T09	Cycling treatments	4	0.3
T13	Overtaking lane/s	3	0.2
T25	Parking	3	0.2
T26	Railway crossing modification	1	0.1
Total		1599	100

All treatment frequencies

There are two ways to count treatment frequency for multiple-treatment projects:

- the total number of treatments of a given type that occur in the database (treatment count), and
- the total number of projects in the database that involve a given type of treatment (project count).

These two definitions would be equivalent if the same treatment type could occur only once for a single project. For 88 projects, the same category of treatment occurs twice, and for two projects, three times. In no cases are the treatments identical at the sub-category level. An example is installation of a right turn lane (T07.1) and a left turn lane (T07.2) at the same site, which counts as two T07 turning lane treatments.

Table 6.2 shows treatment frequencies under both definitions sorted in descending order for the treatment count definition. In total, there are 2424 treatments in the database. The main change in the order of frequencies compared with primary treatments is that T19 line marking treatments has moved from ninth to third place, indicating that they are an important secondary treatment. T16 realignment of intersections has moved significantly down the list, from 8th to 12th place indicating that it is more commonly a primary treatment than a secondary treatment.

T6.2 Treatment frequencies

Code	Description	Treatment count	Percentage	Project count	Percentage
T01	Roundabout	307	12.7	307	13.2
T04	Modify existing signals	269	11.1	246	10.5
T19	Line marking	237	9.8	218	9.3
T07	Turning lane	227	9.4	209	9.0
T10	Sealing/resealing	211	8.7	207	8.9
T02	Medians	154	6.4	153	6.6
T03	New signals	124	5.1	124	5.3
T08	Pedestrian treatments	96	4.0	87	3.7
T12	Alter road width	93	3.8	89	3.8
T14	Barriers/guardrails	91	3.8	88	3.8
T11	Non-skid treatment	81	3.3	81	3.5
T15	Realign road length	71	2.9	64	2.7
T17	Clear obstacles/hazards	69	2.8	67	2.9
T16	Realign intersection	68	2.8	68	2.9
T18	Warning signs	68	2.8	67	2.9
T20	Priority sign treatments	59	2.4	59	2.5
T06	Lighting treatments	59	2.4	58	2.5
T05	Traffic calming	36	1.5	36	1.5
T22	Alter traffic flow direction	27	1.1	27	1.2
T28	Channelisation	27	1.1	27	1.2
T25	Parking	13	0.5	13	0.6
T29	Other	13	0.5	13	0.6
T21	Ban turns	12	0.5	12	0.5
T09	Cycling treatments	6	0.2	6	0.3
T13	Overtaking lane/s	3	0.1	3	0.1
T24	Speed limits	2	0.1	2	0.1
T26	Railway crossing modification	1	0.0	1	0.0
Total		2 424	100	2 332	100

The unspecified category

The last seven treatments (T25 parking and below), with frequencies of between 1 and 13, do not occur often enough to derive meaningful results for their effectiveness. They were combined into an 'unspecified' category for analysis.

The channelisation treatment (T28) was added to the unspecified category because it is a generic category covering projects that ought to be categorised elsewhere including medians, line marking, and turning lanes, but the person recording the information chose not to be specific. The database includes 77 unspecified treatments comprised of:

- T09 cycling treatments
- T13 overtaking lane/s
- T21 ban turns
- T24 speed limits
- T25 parking
- T26 railway crossing modification
- T28 channelisation
- T29 other

With T23 cameras and T27 grade separation omitted and with eight categories grouped together as unspecified, the 29 treatment categories reduces to 20 treatment categories (including unspecified), for the purpose of the regression analysis.

Treatments by jurisdiction

Numbers of projects and crashes in the data for each jurisdiction were provided previously in tables 5.1 and 5.2. Table 6.3 shows numbers of treatments by jurisdiction. The ACT is not well represented in the data, followed by Northern Territory and Tasmania. Victoria was able provide the most data in terms of numbers of projects and treatments.

T6.3 Numbers of treatments in regression models by jurisdiction

	Fatal	Serious	Minor	Injury	Casualty	PDO
ACT	5	17	16	19	19	19
NSW	130	0	0	518	518	515
NT	16	35	39	39	39	39
Qld	70	316	343	359	359	333
SA	41	128	149	157	157	147
Tas	19	46	60	60	60	62
Vic	282	741	786	789	789	0
WA	81	389	430	445	445	453
Total	644	1 672	1 823	2 386	2 386	1 568

Treatments and crashes by treatment in regression models

Tables 6.4 and 6.5 show numbers of treatments and crashes respectively in each regression model by treatment type. When a project involves multiple treatments, the treatments and crashes have been counted for each treatment. The tables help to explain why the regression models were unable to derive significant coefficients for some treatment types, in particular, for the fatal and serious injury crash models.

T6.4 Numbers of treatments in regression models by treatment type

Treatment	Fatal	Serious	Minor	Injury	Casualty	PDO
T01 Rndabout	30	159	194	305	305	222
T02 Medians	28	105	118	152	152	109
T03 New sigs	31	86	94	124	124	86
T04 Mod sigs	57	215	231	269	269	154
T05 Traf calm	3	20	20	36	36	20
T06 Lighting	21	47	54	59	59	41
T07 Turn lane	47	171	184	221	221	167
T08 Ped trmts	23	63	68	95	95	63
T10 Sealing	98	166	175	205	205	97
T11 Non-skid	18	65	69	78	78	53
T12 Alt width	31	61	62	90	90	68
T14 Barriers	43	41	49	86	86	67
T15 Realign len	26	25	25	69	69	53
T16 Realign int	13	49	54	68	68	40
T17 Clear obs	20	46	50	67	67	44
T18 Wrn sgns	26	49	51	67	67	36
T19 Lines	104	191	200	234	234	127
T20 Prty sgns	9	37	42	59	59	43
T22 Alt dir	5	17	21	27	27	23
Unspecified	11	59	62	75	75	55
Total	644	1 672	1 823	2 386	2 386	1 568

T6.5 Numbers of crashes in regression models by treatment type

Treatment	Fatal	Serious	Minor	Injury	Casualty	PDO
T01 Rndabout	34	444	1 472	2 727	2 761	4 087
T02 Medians	40	507	1 771	2 515	2 555	4 411
T03 New sigs	35	408	1 420	2 140	2 175	2 927
T04 Mod sigs	57	1 257	4 734	6 551	6 608	7 729
T05 Traf calm	4	82	200	402	406	185
T06 Lighting	46	504	1 453	2 027	2 073	2 467
T07 Turn lane	52	844	3 502	4 697	4 749	8 802
T08 Ped trmts	27	370	1 190	1 908	1 935	4 557
T10 Sealing	179	1 109	2 282	3 724	3 903	2 141
T11 Non-skid	33	415	1 574	2 127	2 160	3 078
T12 Alt width	46	286	611	1 213	1 259	1 004
T14 Barriers	96	330	697	1 909	2 005	1 763
T15 Realign len	31	195	303	753	784	452
T16 Realign int	13	222	905	1 219	1 232	2 613
T17 Clear obs	40	284	569	946	986	794
T18 Wrn sgns	48	323	733	1 445	1 493	2 492
T19 Lines	203	1 429	3 012	4 786	4 989	5 138
T20 Prty sgns	21	135	426	825	846	1 137
T22 Alt dir	6	57	174	305	311	439
Unspecified	13	348	1 024	1 502	1 515	1 962
Total	1 024	9 549	28 052	43 721	44 745	58 178

Effects for single treatments

Combining terms

The coefficient for an interaction term represents the effect of the interacted variable compared with the main effect term, not the base line.

To illustrate, in the injury crash regression model, the estimated 46% crash reduction factor for T03 new signals applies during the day, which is the base. At night, there is an increase of 32% compared with the daytime TEI, resulting in a night-time crash reduction factor of 29%.

The calculation can be performed by adding the two coefficients. The T03 daytime base coefficient –0.621 plus the T03 night-time interaction coefficient 0.279 equals the T03 night coefficient –0.342, from which the night-time effect can be obtained, exp(–0.342) – 1 = 0.710 – 1 = –29.0%. Alternatively, one could exponentiate the coefficients first and then multiply together the resultant treatment effectiveness indexes, exp(–0.621) × exp(0.279) = 0.537 × 1.322 = 0.710.

To obtain the standard error of the calculated term, one has to combine the variances using the formula

$$Var\left(\sum_{i=1}^{n} X_i\right) = \sum_{i=1}^{n} Var\left(X_i\right) + 2\sum_{i<j}^{n} Cov\left(X_i, X_j\right)$$

For the injury regression model, the base is NSW–urban. To obtain the coefficient for the T03 at night in South Australia in a rural area, there would be a further three coefficients to add — South Australia, rural and T03-rural. To obtain the variance of the derived coefficient, the variances of the five coefficients and ten covariances need to be combined.

From the consultant's regression results, BITRE derived the coefficients and variances for all possible combinations of treatments types and interaction terms for day–night, jurisdiction, urban–rural and local–state roads. Terms were combined regardless of whether or not they are statistically significant. The significance test is applied to the combined term after adjusting the combined standard error for over-dispersion.

As noted earlier, the bases selected are arbitrary. The derived coefficients and standard errors are independent of the base. In other words, if different bases had been used for the model, the derived values would be the same.

For example, in the injury crash regression, the base is NSW–day–urban–local road–implementation year 1995. In coding the input data for the regression model, all these variables were set to zero. The coefficients for treatment effectiveness therefore represent the estimated impacts on crash rates during the day of treatments implemented in NSW in 1995, in urban areas on local roads.

The treatment coefficients and their standard errors need to be combined with interaction terms to obtain the coefficients and standard errors for any other combination, for example, Queensland–night–rural–state road–implementation year 2000. Exactly the same coefficients and standard errors could be obtained by running the regression again with Queensland–night–rural–state road–implementation year 2000 as the base.

As the number of combined terms for treatment effectiveness is huge, they are provided in appendix D in volume 2. To summarise the results for the present chapter, weighted average coefficients were calculated by combining coefficients for jurisdictions, urban-rural and local-state road. The weights were derived from counts of treatments in the entire database, not for the projects included in each model. Ideally, the weights would be for all projects within the scope of the study in to order to provide effectiveness measures representative of the entire program. It was only possible to include projects in the database because treatments for other in-scope projects were not categorised.

As the last columns of tables 5.6 and 5.8 show, the ratios of urban to rural treatment numbers and local road to state road treatment numbers are both approximately 50:50. So for each jurisdiction *j*, the four combinations urban-local (*ul*), rural-local (*rl*), urban-state (*us*) and rural-state (*rs*) each have a weight of about 0.25.[10] The jurisdiction weights (w_j) were obtained from the last column of table 6.3 and differ between models, omitting NSW for serious and minor injury and Victoria for PDO.

10 Precisely, the weights are urban-local 0.245, rural-local 0.244 urban-state 0.256 and rural-state 0.255.

Hence, the weighted average coefficient is calculated as

$$0.25\sum_{j} w_j \left(\beta_{jul} + \beta_{jrl} + \beta_{jus} + \beta_{jrs}\right)$$

Each coefficient is the sum of the base coefficient (urban–local) and the appropriate jurisdiction, rural and state interaction terms. The weighted average can be expressed as a weighted sum of the base coefficient and interaction coefficients. This enables a standard error for the weighted average coefficient to be calculated as a weighted sum of the variances and covariances for the component coefficients.

For the treatment implementation interaction term, the calendar year 1995 was set to zero as the base year. Thus the coefficients for treatment types in models that include treatment implementation year represent the effectiveness for projects commenced in 1995. The treatment effect levels reported in this chapter have been updated to 2000, the average, and also the median commencement year for all projects in the database.

The average year was chosen for reporting because the purpose is to show how the program as a whole has performed. Choosing the average year also ensures that the crash reduction factors shown for models that include implementation year are comparable with the crash reduction factors from the fatal and serious injury models from which the treatment implementation year term was dropped.

T01 Roundabouts

Roundabouts are the most effective of all the treatment types, consistently reducing crashes by 70% to 80% for all casualty models. The effect for PDO crashes is less, at about 50%, probably because of the way roundabouts reduce crash severity by altering the angles and speeds at which vehicles collide. Roundabouts are the most common treatment in the database, which helps to ensure highly significant results.

Turner et al. (2008, p. 18) reported that the typical crash reductions for roundabouts found in the literature range from 55% to 70% depending on the number of legs and the previous type of traffic control. 'High severity and fatal crashes could be expected to reduce by a greater amount than lower severity crashes'.

T6.T01 Treatment effectiveness: T01 Roundabouts

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-79.2	(-93.0, -38.5)	0.005	***
Serious injury	-72.3	(-78.7, -64.1)	0.000	***
Minor injury	-74.6	(-79.1, -69.2)	0.000	***
Injury	-70.7	(-74.5, -66.3)	0.000	***
Casualty	-70.7	(-74.5, -66.4)	0.000	***
PDO	-51.6	(-57.2, -45.2)	0.000	***

T02 Medians

The fatal crash and serious injury models did not provide significant results for medians. For the other crash models, the effects are consistently in the –40% to –50% range. According to Turner et al. (2008, p 19), 'Reductions in crash numbers of around 35% can be expected from the installation of splitter islands at intersections in rural areas, with a 40% reduction at urban intersections. Reductions from the installation of median islands on the through road at intersections are less, at around 25%'.

T6.T02 Treatment effectiveness: T02 Medians

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-10.8	(-59.5, 96.4)	0.777	ns
Serious injury	-7.1	(-24.9, 14.9)	0.496	ns
Minor injury	-44.7	(-55.3, -31.7)	0.000	***
Injury	-42.6	(-51.9, -31.5)	0.000	***
Casualty	-42.8	(-52.1, -31.8)	0.000	***
PDO	-48.6	(-57.0, -38.5)	0.000	***

T03 New signals

New signals was one of the five treatment types for which the models distinguished between daytime and night-time crashes. During the day, new signals reduce fatal crashes by about 90% and other types of crashes by about 50%. New signals appear to be less effective during the night.

For fatal crashes during the night, there is a large positive effect term but it is not statistically significant. In the data for the fatal crash regression model, there are nine projects with new signals treatments and night-time fatal crashes. For four of the projects, there is one night-time fatal crash before treatment and zero after treatment suggesting the treatment reduces night-time fatal crashes. For the other five projects, there are zero night-time crashes before treatment and one after treatment suggesting the treatment increases night-time fatal crashes. The majority of one project showing an increase has caused the effect term to be positive but not statistically significant. In contrast, there are 22 traffic signal projects with daytime fatal crashes in the data. In all but one case, there are zero daytime fatal crashes after treatment.

Turner et al. (2008, p. 19) reported, 'Reductions of between 35% and 50% in all crashes can be expected from the introduction new traffic signals'. This range combines daytime and night-time crashes.

T6.T03 Treatment effectiveness: T03 New signals

Model	TOD[a]	Effect (%)	95% CI (%)	p-value	Significance
Fatal	day	-93.1	(-99.1, -46.9)	0.010	**
Serious injury	day	-59.1	(-69.4, -45.4)	0.000	***
Minor injury	day	-52.6	(-61.5, -41.6)	0.000	***
Injury	day	-51.2	(-58.8, -42.3)	0.000	***
Casualty	day	-51.6	(-59.1, -42.8)	0.000	***
PDO	day	-48.4	(-55.7, -39.9)	0.000	***
Fatal	night	173.1	(-38.0, 1103.4)	0.184	ns
Serious injury	night	-18.0	(-45.8, 24)	0.347	ns
Minor injury	night	-44.6	(-60.4, -22.5)	0.001	***
Injury	night	-35.5	(-50.9, -15.3)	0.002	***
Casualty	night	-33.7	(-49.4, -13.1)	0.003	***
PDO	night	-24.1	(-43.0, 1.0)	0.059	*

a. Time of day

T04 Modify existing signals

Modification of existing traffic signals consistently reduces crashes by around 30% to 40%, though the result from the fatal crash model is not statistically significant at the 0.1 level.

According to Turner et al. (2008, p. 20), 'Re-modeling of existing signals (including controlling right turns with the use of arrows) can … provide large safety benefits of around 30–45%'.

T6.T04 Treatment effectiveness: T04 Modify existing signals

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-34.0	(-65.9, 27.5)	0.216	ns
Serious injury	-33.7	(-43.2, -22.6)	0.000	***
Minor injury	-41.6	(-51.7, -29.3)	0.000	***
Injury	-35.7	(-44.8, -25.0)	0.000	***
Casualty	-35.7	(-44.9, -25.1)	0.000	***
PDO	-30.8	(-41.0, -18.9)	0.000	***

T05 Traffic calming

Due to the small number of projects in the data with traffic calming treatments and casualty crashes of those sites, it was not possible to obtain reliable results for serious and minor injury crashes. Having only four fatal crashes at sites with traffic calming treatments made it impossible to obtain any meaningful result for the fatal model.

The results for the injury and casualty crash models are almost identical because, with only four fatal crashes in the database at sites with traffic calming treatments, the data for this treatment in the two models is almost identical. Traffic calming treatments are estimated to reduce injury crashes by about 30% and PDO crashes by about 55%.

Turner's (2008, p. 21) discussion of traffic calming treatments concluded that 'Little reliable crash reduction information exists for Australian conditions, although overseas experience shows that, when correctly used, significant reductions can be obtained (up to 60% based on the UK experience, although the extent of use and concentration of population is less in Australia, so lower figures could be expected)'.

T6.T05 Treatment effectiveness: T05 Traffic calming

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	na	na	na	na
Serious injury	-14.3	(-48.0, 41.4)	0.546	ns
Minor injury	-34.8	(-64.2, 19.0)	0.164	ns
Injury	-33.3	(-53.9, -3.5)	0.032	**
Casualty	-33.7	(-54.3, -4.0)	0.029	**
PDO	-55.1	(-73.8, -23.0)	0.004	***

T06 Lighting treatments

During the day time, lighting treatments were found to reduce injury and PDO crashes by about 20%, which is difficult to understand.

The explanation appears to lie with application of the project implementation time factor for five years. It was reported in chapter 5 that treatment effectiveness, across all treatment types, was found to be increasing over time in the minor injury, injury, casualty and PDO models with effects ranging from –3.7% to –6.0% per annum (see table 5.4).

The weighted average treatment effects reported in the present chapter for those four models are as at year 2000 and so allow for five years of improvement in effectiveness. For T06 lighting treatments implemented in 1995, the base year for implementation time in the regression models, the weighted average coefficients for daytime crashes are not statistically significant even at the 0.1 level for minor injury, injury, casualty and PDO crashes.

The p-values are above 0.5 in all four cases. As the growth factors are applied, in order to obtain effect terms for lighting treatments implemented in each successive year after 1995, the p-values fall. The effect terms are significant at the 0.05 level for lighting treatments during the day implemented after 1999 for minor injury crashes, 1998 for injury and casualty crashes and 1997 for PDO crashes.

Ideally, there would be different implementation time growth factors for different treatment types, in which case, a smaller growth factor may have been obtained for lighting treatments. Then repeated application of the growth factor over successive years might not have lead to unrealistic significant estimates for lighting treatments during the day. However, as noted in chapter 5, the three-way interaction terms between implementation year and individual treatment types did not have significant coefficients.

For night-time minor injury and general injury crashes, lighting treatments are estimated to have a crash reduction factor close to 30%. The statistically insignificant PDO effect is the result of its being a weighted average of positive and negative effects, some of which are statistically significant. The significant positive effects for PDO crashes could be the result of vehicles colliding with light poles.

The present study finds effectiveness levels for T06 lighting treatments at night to be below the range reported elsewhere. Turner et al. (2008, p 21) states:

> *'Crash reductions of between 30% and 50% in night-time crashes can be expected with the introduction of new street lighting. Improvements are greatest at intersections (up to 50%), while lower reductions can be expected for midblock sections (up to 40%). Reductions are lower in rural areas for intersections (up to 40%) and midblock sections (up to 30%) although there is less reliable data available in this environment.*
>
> *Reductions in crashes from an improvement in street lighting can also be expected, and depending on the level of improvement may be similar to the installation of street lighting where none existed previously (30 to 40%, with the higher figure seen at intersections).'*

T6.T06 Treatment effectiveness: T06 Lighting treatments

Model	TOD	Effect (%)	95% CI (%)	p-value	Significance
Fatal	day	16.2	(-59.5, 233.1)	0.780	ns
Serious injury	day	1.8	(-21.1, 31.3)	0.891	ns
Minor injury	day	-21.5	(-36.2, -3.3)	0.023	**
Injury	day	-21.6	(-34.6, -6.0)	0.008	***
Casualty	day	-21.6	(-34.5, -6.1)	0.008	***
PDO	day	-22.8	(-35.1, -8.2)	0.003	***
Fatal	night	61.9	(-30.0, 274.4)	0.260	ns
Serious injury	night	-9.4	(-33.0, 22.4)	0.519	ns
Minor injury	night	-28.7	(-47.2, -3.8)	0.027	**
Injury	night	-28.3	(-43.8, -8.7)	0.007	***
Casualty	night	-27.4	(-42.8, -7.8)	0.009	***
PDO	night	-13.8	(-35.6, 15.2)	0.315	ns

T07 Turning lanes

Turning lane treatments reduce injury and PDO crashes by about 20% to 30%. The impact on fatal crashes, of about 60%, is much larger but has a larger confidence interval around it.

Turner et al. (2008, p. 21) reports 'Left turn lanes provide a crash reduction benefit of up to 30%, while right turn lanes provide around a 30% reduction for urban intersections and up to a 35% reduction for rural intersections'.

T6.T07 Treatment effectiveness: T07 Turning lanes

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-60.4	(-82.2, -11.6)	0.024	**
Serious injury	-12.6	(-26.3, 3.5)	0.118	ns
Minor injury	-30.8	(-43.3, -15.5)	0.000	***
Injury	-25.1	(-35.5, -13.1)	0.000	***
Casualty	-25.6	(-35.8, -13.7)	0.000	***
PDO	-29.6	(-39.1, -18.6)	0.000	***

T08 Pedestrian treatments

Pedestrian treatments reduce injury and PDO crashes by some 20% to 30%. The fatal result did not miss out on being statistically significant at the 0.1 level by a great deal, which is suggestive that there may be some effect not due to chance.

Turner et al. (2008, p. 22) comments: 'Little is known about the crash reduction effectiveness of various pedestrian treatments in the Australian context, although reductions of up to 35% in pedestrian related crashes can be expected from the use of pedestrian refuge islands'.

T6.T08 Treatment effectiveness: T08 Pedestrian treatments

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-58.6	(-86.6, 27.7)	0.125	ns
Serious injury	-10.4	(-29.9, 14.5)	0.380	ns
Minor injury	-31.1	(-47.8, -9.2)	0.008	***
Injury	-24.4	(-38.2, -7.6)	0.006	***
Casualty	-25.4	(-38.9, -8.9)	0.004	***
PDO	-19.6	(-34.3, -1.7)	0.033	**

T10 Sealing/resealing

Sealing or resealing reduces injury crashes by roughly 20%. Examination of the individual effect terms that comprise the weighted averages in table 6.T10 shows that, for the injury crash models, for most jurisdictions, sealing or resealing has no significant effect on urban crashes but a highly significant effect for rural crashes.

The fatal crash effect has a p-value not greatly above 0.1 and its magnitude is close to those of the injury models.

The PDO effect, which is not significant, is a weighted average of positive and negative effects, many of which are statistically significant. The overall finding as to its effect is therefore inconclusive. While all the significant rural PDO effects are negative, there are some significant positive urban effects. It could be surmised that sealing/resealing is reducing the severity of crashes urban areas, transforming injury crashes into PDO crashes.

Turner et al. (2008, p. 23) wrote, 'Crash reduction of around 10% could be expected from shoulder widening, while a reduction of 30% could be expected from shoulder sealing'.

T6.T10 Treatment effectiveness: T10 Sealing/resealing

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-25.5	(-49.8, 10.7)	0.145	ns
Serious injury	-21.3	(-32.8, -7.9)	0.003	***
Minor injury	-18.9	(-31.5, -3.9)	0.015	**
Injury	-15.8	(-26.8, -3.2)	0.015	**
Casualty	-17.1	(-27.8, -4.9)	0.007	***
PDO	-12.4	(-29.3, 8.4)	0.222	ns

T11 Non-skid treatment

Non-skid treatments had no significant effects for fatal and serious injury crashes. For minor injury and injury crashes in general, non-skid treatments produce a reduction of about 20% to 30%. The weighted average PDO result is inconclusive due to a mixture of positive and negative effects. It is possible that non-skid treatments reduce crash severity, converting minor injury crashes into PDO crashes.

The significant amounts in table 6.T11 are less than others have found. Turner et al. (2008, p. 24) noted, 'Crash reductions of around 35% can be expected from the improvement of skid resistance'.

T6.T11 Treatment effectiveness: T11 Non-skid treatment

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	61.0	(-23.2, 237.6)	0.208	ns
Serious injury	-2.4	(-21.7, 21.6)	0.827	ns
Minor injury	-30.2	(-42.3, -15.4)	0.000	***
Injury	-23.5	(-35.1, -9.7)	0.002	***
Casualty	-23.0	(-34.6, -9.2)	0.002	***
PDO	-7.1	(-19.8, 7.6)	0.327	ns

T12 Alter road width

Altering the road width reduces minor injury, general injury and PDO crashes by around 40%.

This is markedly different from Turner et al. (2008, p. 24). 'Crash reductions of between 5 and 10% could be expected, depending on width added'. A contributing factor could be that 'There are some indications that vehicle speeds increase when roads are widened, possibly due to a perception of improved safety by drivers. Thus, lane widening should only be considered where crash records strongly indicate that lane width is a clear contributing factor.'

Application of the implementation time factor is not the explanation for the differences between the effects in table 6.T12 and in the literature as reported by Turner et al. For treatments implemented in 1995, the effects for the minor injury, injury, casualty and PDO models are reduced to 23% (ns), 27% (**), 28% (**) and 25% (*) respectively.

Possible explanations for the models' findings of high effectiveness of altering road widths could be prudent application of the treatment in Australia, or the fact that only crashes along or very near the road lengths actually widened were counted and not further along the roads.

T6.T12 Treatment effectiveness: T12 Alter road width

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-7.6	(-55.6, 92.0)	0.832	ns
Serious injury	-7.8	(-29.2, 20.3)	0.551	ns
Minor injury	-43.8	(-60.7, -19.7)	0.002	***
Injury	-40.0	(-54.3, -21.2)	0.000	***
Casualty	-40.4	(-54.6, -21.8)	0.000	***
PDO	-38.9	(-56.1, -14.9)	0.004	***

T14 Barriers/guardrails

The results for barriers and guardrails suggest that they reduce minor injury crashes and injury crashes in general by around 30% and PDO crashes by around 40%. The coefficients for the fatal and serious injury crash regression models are not significant.

The reduction levels for injury and PDO crashes are consistent with Turner's (2008, p. 25) summary of the literature.

> *'It should be noted that safety barriers are in themselves roadside hazards. While they are designed to protect motorists from other roadside hazards (and cross-median head-on crashes in the case of median barriers), they achieve this protection by providing something less aggressive for vehicles to collide with. Although the presence of a barrier is unlikely to reduce the number of crashes, if properly designed, safety barriers should reduce the severity of crashes involving errant vehicles, and therefore the number of crashes that result in injury. In terms of injury crashes, reductions of up to 40% could be expected.'*

T6.T14 Treatment effectiveness: T14 Barriers/guardrails

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-6.0	(-44.0, 57.9)	0.816	ns
Serious injury	12.7	(-13.2, 46.3)	0.370	ns
Minor injury	-34.6	(-57.2, -0.1)	0.050	**
Injury	-28.1	(-42.1, -10.7)	0.003	***
Casualty	-27.7	(-41.6, -10.6)	0.003	***
PDO	-41.5	(-56.0, -22.1)	0.000	***

T15 Realign road length

Realignment of road length was only found to have a significant impact in the injury and casualty models, at about 40%. This is below Turner's (2008, p. 25) indicative figure. 'Crash reduction of around 50% could be expected for a horizontal realignment'.

T6.T15 Treatment effectiveness: T15 Realign road length

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-20.0	(-66.9, 93.4)	0.620	ns
Serious injury	-13.3	(-39.0, 23.3)	0.427	ns
Minor injury	-46.9	(-79.4, 36.9)	0.190	ns
Injury	-40.3	(-61.8, -6.7)	0.024	**
Casualty	-40.8	(-61.7, -8.4)	0.018	**
PDO	-29.5	(-65.5, 44.1)	0.338	ns

T16 Realign intersection

The regression models suggest reductions greater than Turner et al. (2008, p. 26) for minor injury and general injury crashes and the same for PDO crashes. 'Crash reduction of around 30% can be expected from converting a X-intersection into a staggered intersection.' The fatal crash result, significant at the 0.1 level, is well above 30% but is less accurate as indicated by the large confidence interval.

T6.T16 Treatment effectiveness: T16 Realign intersection

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-74.6	(-94.9, 25.8)	0.093	*
Serious injury	-0.1	(-25.1, 33.0)	0.992	ns
Minor injury	-44.3	(-59.6, -23.2)	0.000	***
Injury	-38.6	(-51.2, -22.7)	0.000	***
Casualty	-39.7	(-52.0, -24.3)	0.000	***
PDO	-29.6	(-48.0, -4.6)	0.023	**

T17 Clear obstacles/hazards

Model results in the 25% to 40% reduction range are in line with Turner et al. (2008, p. 26). 'Crash reductions of up to 45% could be expected from increasing the clear zone by six metres on straight roads, while a 30% reduction from the same increase in clear zone could be expected on curves'.

T6.T17 Treatment effectiveness: T17 Clear obstacles/hazards

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	-14.4	(-60.2, 84.1)	0.690	ns
Serious injury	-25.3	(-43.1, -1.9)	0.036	**
Minor injury	-42.9	(-58.3, -22.0)	0.000	***
Injury	-41.2	(-54.0, -24.9)	0.000	***
Casualty	-41.7	(-54.2, -25.7)	0.000	***
PDO	-35.9	(-52.0, -14.4)	0.003	***

T18 Warning signs

For warning signs during daytime, significant weighted average results of just under 40% were obtained for the injury and casualty crash models and just under 30% for PDO crashes. During the night, the only significant result was a 47% reduction for PDO crashes. Turner et al. (2008, pp. 26–7) states:

> *'There is surprisingly little research on the effectiveness of many types of warning signs in terms of crash reduction. Typically reductions of 25–30% could be expected for curve warning signs. There are indications that reductions from intersection warning signs are less than this at between 5–10% reduction in all crashes. There is limited evidence to show that bridge warning signs reduce crashes by around 30%, and that animal warning signs reduce crashes by 5%. There is a lack of conclusive evidence on the effectiveness of other warning signs.'*

Our results for injury and casualty crashes — 40% during the day and zero at night — are broadly consistent with Turner's reduction of 25–30% for curve and bridge warning signs considering that Turner's reduction applies to both daytime and night-time crashes together.

T6.T18 Treatment effectiveness: T18 Warning signs

Model	TOD	Effect (%)	95% CI (%)	p-value	Significance
Fatal	day	41.7	(-39.8, 233.5)	0.425	ns
Serious injury	day	-9.5	(-36.4, 28.9)	0.580	ns
Minor injury	day	-26.2	(-52.5, 14.7)	0.177	ns
Injury	day	-37.0	(-54.6, -12.6)	0.006	***
Casualty	day	-38.9	(-55.8, -15.5)	0.003	***
PDO	day	-27.7	(-48.6, 1.7)	0.062	*
Fatal	night	-34.4	(-76.6, 84.3)	0.424	ns
Serious injury	night	3.0	(-31.7, 55.3)	0.888	ns
Minor injury	night	3.2	(-40.3, 78.5)	0.910	ns
Injury	night	-20.6	(-46.6, 18.1)	0.255	ns
Casualty	night	-26.0	(-49.8, 9.1)	0.129	ns
PDO	night	-46.8	(-65.2, -18.6)	0.004	***

T19 Line marking

Line marking reduces minor injury and general injury crashes by 20% to 30%, day and night. The night-time reductions are higher. Serious injury crashes are reduced by 20% at night, but the daytime estimate is not significant. The impact on PDO crashes is greater, a reduction of around 35%, day and night.

Turner's findings are similar.

> *'An average reduction of 30% in all crashes could be expected with the installation of new centreline markings. An improvement of currently substandard markings could also be expected to produce a reduction in crashes in the order of 5–10%. Crash reduction of about 20% can be expected with the introduction of edge lines. The reduction is greatest for run-off-road type crashes, where a reduction of up to 30% could be expected. In situations where the edge line markings are substandard, a reduction in crashes could be expected from re-marking. The installation of audible edgelines could be expected to provide an additional benefit of a further 20–25% reduction over standard edgelines.'*

T6.T19 Treatment effectiveness: T19 Line marking

Model	TOD	Effect (%)	95% CI (%)	p-value	Significance
Fatal	day	-20.1	(-48.9, 24.8)	0.324	ns
Serious injury	day	-12.5	(-25.8, 3.2)	0.112	ns
Minor injury	day	-27.0	(-39.1, -12.5)	0.001	***
Injury	day	-20.9	(-31.7, -8.4)	0.002	***
Casualty	day	-21.4	(-31.9, -9.2)	0.001	***
PDO	day	-36.7	(-46.7, -24.7)	0.000	***
Fatal	night	-13.9	(-49.6, 47.3)	0.586	ns
Serious injury	night	-21.0	(-35.2, -3.7)	0.020	**
Minor injury	night	-27.4	(-42.5, -8.4)	0.007	***
Injury	night	-26.3	(-38.5, -11.7)	0.001	***
Casualty	night	-26.3	(-38.2, -12.0)	0.001	***
PDO	night	-33.9	(-47.4, -16.8)	0.000	***

T20 Priority sign treatments

Priority sign treatments were not found to have significant effects during the night nor on fatal and PDO crashes during the day. The models suggest they reduce injury crashes by 30% to 50% during the day.

Turner's (2008, p. 27) report states:

> *'The benefits of installing Stop signs are greater for two-way Stop signs at a four legged cross intersections than for a one-way Stop sign at a T intersection (35% and 20% respectively). The crash reduction benefit of installing Give Way signs is unclear, although there is some US-based evidence to suggest there is a reduction in crashes.'*

T6.T20 Treatment effectiveness: T20 Priority sign treatments

Model	TOD	Effect (%)	95% CI (%)	p-value	Significance
Fatal	day	155.1	(-18.3, 696.7)	0.107	ns
Serious injury	day	-52.8	(-71.8, -20.8)	0.004	***
Minor injury	day	-47.0	(-71.3, -2.2)	0.042	**
Injury	day	-31.2	(-50.9, -3.7)	0.030	**
Casualty	day	-30.4	(-50.2, -2.8)	0.034	**
PDO	day	-20.0	(-41.3, 8.9)	0.156	ns
Fatal	night	-59.4	(-95.7, 285.8)	0.433	ns
Serious injury	night	-0.6	(-54.8, 118.8)	0.989	ns
Minor injury	night	-39.7	(-73.0, 34.9)	0.219	ns
Injury	night	-5.5	(-41.9, 53.8)	0.821	ns
Casualty	night	-10.1	(-44.5, 45.5)	0.664	ns
PDO	night	-25.5	(-52.8, 17.7)	0.207	ns

T22 Alter traffic flow direction

Altering traffic flow direction gives rise to crash reductions of the order of 50% to 80% for all models except the fatal crash model, where it is not significant. Turner et al. (2008, p. 28) states 'Typical crash reductions for street closure are a 30% reduction for closing one of the legs at a cross intersection, and a 65% reduction for closing the 'stem' of a T intersection'. Our findings are in line with the latter reduction.

T6.T22 Treatment effectiveness: T22 Alter traffic flow direction

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	20.7	(-79.6, 615.8)	0.836	ns
Serious injury	-77.8	(-89.8, -52.0)	0.000	***
Minor injury	-68.2	(-81.3, -45.9)	0.000	***
Injury	-58.8	(-71.3, -41.0)	0.000	***
Casualty	-58.3	(-70.8, -40.3)	0.000	***
PDO	-53.1	(-66.6, -34.2)	0.000	***

Unspecified treatments

The group of unspecified treatments reduces minor injury and general injury crashes by about 20% and PDO crashes by 27%. This is consistent with Turner's reported reductions, listed below, for most of the individual treatments included in the unspecified category.

- T09 cycling treatments: up to 30%
- T13 overtaking lane/s: 30%
- T21 ban turns: 20%
- T24 speed limits: 15%
- T25 parking: 10% to 20%
- T26 railway crossing modification: 25% to 70% (depending on the modification)
- T28 channelisation: 15% to 40% (depending on the treatment)

T6.T99 Treatment effectiveness: Unspecified

Model	Effect (%)	95% CI (%)	p-value	Significance
Fatal	65.9	(-52.0, 473.7)	0.424	ns
Serious injury	-2.4	(-22.7, 23.4)	0.842	ns
Minor injury	-23.6	(-37.2, -7.1)	0.007	***
Injury	-19.9	(-31.9, -5.8)	0.007	***
Casualty	-19.0	(-31.2, -4.8)	0.011	**
PDO	-27.0	(-41.2, -9.4)	0.004	***

Treatment effects summary

Table 6.6 summarises the foregoing weighted average treatment effect tables showing the statistically significant effects for all treatment types. Borderline insignificant effects have been added where the p-value is less than 0.3 and the effect is negative.

T01 roundabouts are generally the most effective treatment. T03 new signals during the day and T22 alter traffic flow direction are the next most highly effective treatments across most severity levels. There are no positive statistically significant weighted average effects, that is, there are no treatments found to systematically increase crashes. T18 warning signs and T20 priority signs may have little effect at night. The relative lack of frequency of fatal and serious crashes has prevented reliable effect estimates from being derived for many treatment types.

T6.6 Statistically significant and borderline insignificant weighted average treatment effects

Treatment	Day/night	Fatal	Serious	Minor	Injury	Casualty	PDO
T01 Rndabout	both	*** -79	*** -72	*** -75	*** -71	*** -71	*** -52
T02 Medians	both			*** -45	*** -43	*** -43	*** -49
T03 New sigs	day	** -93	*** -59	*** -53	*** -51	*** -52	*** -48
T03 New sigs	night			*** -45	*** -35	*** -34	* -24
T04 Mod sigs	both	-34	*** -34	*** -42	*** -36	*** -36	*** -31
T05 Traf calm	both			-35	** -33	** -34	*** -55
T06 Lighting	day			** -21	*** -22	*** -22	*** -23
T06 Lighting	night			** -29	*** -28	*** -27	
T07 Turn lane	both	** -60	-13	*** -31	*** -25	*** -26	*** -30
T08 Ped trmts	both	-59		*** -31	*** -24	*** -25	** -20
T10 Sealing	both	-25	*** -21	** -19	** -16	*** -17	-12
T11 Non-skid	both			*** -30	*** -23	*** -23	
T12 Alt width	both			*** -44	*** -40	*** -40	*** -39
T14 Barriers	both			** -35	*** -28	*** -28	*** -41
T15 Realign len	both			-47	** -40	** -41	
T16 Realign int	both	* -75		*** -44	*** -39	*** -40	** -30
T17 Clear obs	both		** -25	*** -43	*** -41	*** -42	*** -36
T18 Wrn sgns	day			-26	*** -37	*** -39	* -28
T18 Wrn sgns	night				-21	-26	*** -47
T19 Lines	day		-13	*** -27	*** -21	*** -21	*** -37
T19 Lines	night		** -21	*** -27	*** -26	*** -26	*** -34
T20 Prty sgns	day		*** -53	** -47	** -31	** -30	-20
T20 Prty sgns	night			-40			-25
T22 Alt dir	both		*** -78	*** -68	*** -59	*** -58	*** -53
Unspecified	both			*** -24	*** -20	** -19	*** -27

Multiple-treatment projects

Multiple treatments in the data

Of the 1599 projects in the database, 606 or 38% comprised more than one treatment, up to a maximum of six treatments.

Table 6.7 shows the number of projects with each number of treatments. Turner et al. (2008) cite overseas evidence of widespread under-reporting of multiple treatments. Data from New Zealand indicate that around 80% of treated sites use multiple treatments (Turner et al., Austroads 2009), well above the 38% in the BITRE database. It is not known to what extent there is under-reporting in the Australian data.

T6.7 Projects with each number of treatments

Number of treatments	Project count	Percentage
1	993	62.1
2	431	27.0
3	138	8.6
4	33	2.1
5	1	0.1
6	3	0.2
Total	1599	100.0

The crash reduction impact of a multiple-treatment project is expected to be the combined effect of each of the component treatments, together with any interaction effects between the treatments.

Distinguishing the effects of the different components of multiple treatment projects can be a problem for estimating the effectiveness of individual treatment types. The traditional approach taken in black spot program evaluation studies is to identify a single treatment, the 'primary treatment', for each multiple-treatment project based on road safety considerations. The remaining secondary treatments are ignored. The Poisson regression approach of the present evaluation treats all the component treatments in multiple-treatment projects equally, letting the regression analysis disentangle their respective effects.

The number of possible combinations of treatment types is immense, but most of them either never occur in the data or occur too infrequently for regression analysis to identify any statistically significant interactions between treatments. To enable the regression analysis to focus on combinations that could yield statistically significant interaction results, multiple treatment projects were examined to find out which treatments commonly occurred together.

Frequencies of treatment type pairs and triples in the data were obtained, including pairs and triples in projects with several treatments. For example, a project consisting of three treatments A, B and C, would give rise to three treatment pairs, AB, BC, and AC. Projects consisting of four, five and six treatments would give rise to 6, 10 and 15 pairs of treatments respectively.

Numbers of pairs will be smaller under the project count definition where the same project contains more than one treatment of the same type.

For example, if the project consisted of three treatments of types A, A and B, even though there would be three pairs in the treatment count, AA, AB, and AB, there would be two pairs in the project count, AA and AB.

After grouping the unspecified treatments together, there are 20 treatment types giving rise to 210 possible treatment type pairs in the database.[11] The number of pairs that *actually* occurs is 163.

11 20 × 19 / 2 = 190 pairs of different treatment types, plus 20 pairs of the same treatment type repeated.

Table 6.8 shows frequencies of pairs of treatments under both definitions sorted into descending order of treatment count down to a frequency of 10. T10 sealing/resealing combined with T19 line marking is the most common pair of treatments. The next most common is T04 modify existing traffic signals combined with T07 turning lanes. T19 line marking is often combined with other treatments. T01 roundabouts, the most common treatment in the database, are not often combined with other treatments.

The first 21 treatment pairs in the list, down to a count of 14, were included in the regression models to test whether there were significant interactions between the two treatments implemented together.

While a project with three treatments, two of which are of the same type, A, A and B, is different from a project with two treatments, A and B, as far as the regression models are concerned, unless the pair AA is included as a variable, the two projects are considered to be the same. Three of the pairs in the regression analysis have both components the same, T04 modify existing signals, T07 turning lane and T19 line marking. As noted previously, in all cases where pairs of identical treatment types occur in the same project, the treatments are different at the sub- category level.

T6.8 Treatment pair frequencies down to 10

Treatment 1	Treatment 2		Treatment count	Project count
T10 Sealing	T19 Lines	*	82	76
T04 Mod sigs	T07 Turn lane	*	47	40
T18 Warn sgns	T19 Lines	*	41	37
T12 Widen	T19 Lines	*	29	26
T02 Medians	T07 Turn lane	*	28	27
T12 Widen	T15 Realign	*	26	23
T14 Barriers	T19 Lines	*	24	22
T04 Mod sigs	T04 Mod sigs	*	23	23
T10 Sealing	T14 Barriers	*	23	23
T10 Sealing	T15 Realign	*	23	21
T02 Medians	T20 Prty sgns	*	21	21
T10 Sealing	T12 Widen	*	21	21
T19 Lines	T19 Lines	*	20	18
T02 Medians	T19 Lines	*	18	15
T07 Turn lane	T07 Turn lane	*	18	18
T10 Sealing	T17 Clearing	*	18	18
T15 Realign	T19 Lines	*	18	15
T07 Turn lane	T08 Ped trmts	*	17	16
T14 Barriers	T18 Warn sgns	*	16	15
T19 Lines	T20 Prty sgns	*	15	15
T17 Clearing	T19 Lines	*	14	14
T04 Mod sigs	T08 Ped trmts		13	11

continued

T6.8 Treatment pair frequencies down to 10 (continued)

Treatment 1	Treatment 2	Treatment count	Project count
T07 Turn lane	T12 Widen	13	12
T11 Non-skid	T19 Lines	13	13
T02 Medians	T05 Traf calm	12	12
T06 Lighting	T19 Lines	11	10
T10 Sealing	T11 Non-skid	11	11
T02 Medians	T08 Ped trmts	10	10
T07 Turn lane	T19 Lines	10	9
T06 Lighting	T08 Ped trmts	10	8
T15 Realign	T18 Warn sgns	10	8

* Treatment pair included in regression models.

Treatment triples in the database were identified and counted in the same manner as for pairs. The most common triple combination, T14 barriers/guardrails, T18 warning signs and T19 line marking occurred for 10 projects in the database. Next was T12 alter road width, T15 realign road length and T19 line marking that occurred for 7 projects. Since they are each represented by 10 or less projects in the database, treatment triples are highly unlikely to have statistically significant coefficients in the regression analysis for interactions over and above those already identified for their component pairs. No triples were therefore included in the regression analysis.

The report commissioned from ARRB Group as part of this evaluation (Turner et al. 2008) (reproduced in volume 3) contains an investigation of the impacts of multiple treatments using BITRE's data.

Effects of treatment pairs

Three-way interaction terms involving pairs of treatments are included in the minor injury, injury, casualty and PDO models.

The group was dropped from the fatal and serious injury models because of lack of significance. Tables 6.9 and 6.10 show effects derived from interaction coefficients for treatment pairs found to be statistically significant in the four models. For the treatment pairs in table 6.9, the treatment effectiveness index (TEI) of the two treatments implemented together is *greater* than the product of their TEIs.

In other words, there are diminishing returns — the whole is less than the sum of its parts. The effect terms are positive because the road safety outcome is less desirable. To illustrate, for the minor injury model with Victorian urban treatments as the base, T02 medians has a TEI of 0.79 and T07 turning lanes a TEI of 0.88. The adjustment for improving implementation over time is $0.94^{5\ \text{years}} = 0.73$. The interaction adjustment for the treatment pair is 1.45 = 1 + 0.45 (the effect term in table 6.9). Combining these terms, the TEI for the pair of treatments is 0.79 × 0.88 × 0.73 × 1.46 = 0.74. The effect is a 26% reduction in the crash rate (1 – 0.74), which is only statistically significant at the 0.1 level and is a worse outcome than either of the two treatments implemented singly.

For the weighted average of treatments across jurisdictions, urban/rural and local/state roads, the treatment pair medians and turning lanes is not statistically significant for any of the four models with treatment pair terms. This calls into question the efficacy of undertaking both treatments together from a road safety point of view.

The same conclusion applies to the other three treatment pairs in the table — it may be better to implement only one treatment at the site. However, the regression analysis relates only to road safety impacts. There may be traffic flow considerations that warrant construction of turning lanes together with medians and traffic lights at intersections.

T6.9 Interactions between treatment pairs: diminishing returns

Treatment 1	Treatment 2	Model	Effect (%)	95% CI (%)	p-value	Significance
T02 Medians	T07 Turn lane	Minor	44.9	(1.4, 107.1)	0.042	**
		Injury	37.1	(1.4, 85.3)	0.040	**
		Casualty	35.0	(-0.1, 82.5)	0.050	*
		PDO	86.8	(35.3, 157.9)	0.000	***
T07 Turn lane	T07 Turn lane	Injury	36.8	(-2.5, 92)	0.070	*
		Casualty	36.3	(-3.0, 91.3)	0.074	*
		PDO	35.9	(0.4, 83.9)	0.047	**
T04 Mod sig	T07 Turn lane	PDO	31.8	(3.3, 68.1)	0.026	**
T19 Lines	T19 Lines	PDO	38.8	(9.2, 76.5)	0.007	***

There are synergies between the treatment pairs in table 6.10 — the whole is greater than the sum of its parts. It is usually unavoidable to carry out T19 line marking after T10 sealing or resealing, and as evident in table 6.8, this is by far the most commonly occurring treatment pair in the database. T10 sealing or resealing is also inevitable when a road length is realigned, T15. But this does not explain why the road safety effect is greater for the treatment pairs than the combined effects of the component treatments.

It is difficult to generalise about why some treatment pairs have synergies and others have diminishing returns. One might expect to find diminishing returns from implementing a second treatment of the same type at a site as for two of the pairs in table 6.9. However, there is an exception in table 6.10 where pairs of T04 modify signals treatments have a significant synergy for PDO crashes. It is left to the road safety experts to explain the findings for interactions between treatments.

T6.10 Interactions between treatment pairs: synergies

Treatment 1	Treatment 2	Model	Effect (%)	95% CI (%)	p-value	Signif
T10 Sealing	T19 Line marking	Minor	-38.6	(-56.8, -12.7)	0.007	***
		Injury	-35.9	(-51.8, -14.9)	0.002	***
		Casualty	-37.0	(-52.4, -16.7)	0.001	***
T12 Alter road width	T15 Realign road length	Injury	-49.4	(-73.1, -4.9)	0.034	**
		Casualty	-47.5	(-71.7, -2.5)	0.041	**
T02 Medians	T20 Priority signs	Injury	-51.3	(-75.5, -3.2)	0.040	**
		Casualty	-46.4	(-72.5, 4.4)	0.067	*
T07 Turning lane	T08 Pedestrian treatments	Injury	-32.9	(-56.1, 2.7)	0.066	*
		Casualty	-30.9	(-54.9, 5.8)	0.089	*
T10 Sealing	T15 Realign road length	Injury	-49.5	(-72.3, -8.1)	0.025	**
		Casualty	-43.8	(-68.7, 1.0)	0.054	*
		PDO	-61.8	(-85.7, 1.7)	0.054	*
T04 Mod sigs	T04 Mod sigs	PDO	-55.8	(-70.9, -32.7)	0.000	***

The full list of effects for pairs of treatments included in the regression models is given in appendix D in volume 2. For the fatal and serious injury models from which the treatment pair interaction terms were dropped, the pair effects are derived by adding the coefficients for the two treatments without any interaction term.

The weighted average treatment pair effects are summarised in table 6.11 showing only the statistically significant effects and borderline insignificant effects where the p-value is less than 0.3 and the effect is negative. In each case, the effect of the pair needs to be compared with the effects of its two component treatments to see if one of the components is accounting for most or all of the effect, or if one treatment is detracting from the other.

T6.11 Statistically significant and borderline insignificant weighted average treatment pair effects

Treatment 1	Treatment 2	D/N	Fatal	Serious	Minor	Injury	Cas	PDO
T02 Medians	T07 Turn lane	both	* -65				-14	
T02 Medians	T19 Lines	day				-22	-22	*** -42
T02 Medians	T19 Lines	night		-20		* -27	* -27	** -40
T02 Medians	T20 Prty sgns	day		*** -52	** -56	*** -71	*** -68	* -37
T02 Medians	T20 Prty sgns	night			-50	*** -61	** -59	-41
T04 Mod sigs	T04 Mod sigs	both	-56	*** -52	*** -50	** -37	** -37	*** -73
T04 Mod sigs	T07 Turn lane	both	*** -74	*** -37	*** -30	** -24	** -24	* -17
T07 Turn lane	T07 Turn lane	both	** -84	-17				
T07 Turn lane	T08 Ped trmts	both	** -84	-15	** -43	*** -43	*** -43	*** -35
T10 Sealing	T12 Alt width	both		-21	-38			-21
T10 Sealing	T14 Barriers	both			* -27	-21	-22	-23
T10 Sealing	T15 Realign len	both		-25	*** -69	*** -62	*** -59	** -69
T10 Sealing	T17 Clear obs	both	-36	*** -36		-26	-25	
T10 Sealing	T19 Lines	day	* -41	*** -25	*** -42	*** -36	*** -39	*** -57
T10 Sealing	T19 Lines	night	-36	*** -32	*** -42	*** -41	*** -43	** -55
T12 Alt width	T15 Realign len	both			** -64	*** -73	*** -72	*** -72
T12 Alt width	T19 Lines	day			*** -54	*** -50	*** -49	** -55
T12 Alt width	T19 Lines	night		-20	*** -54	*** -53	*** -52	** -53
T14 Barriers	T18 Wrn sgns	day				** -33	* -29	
T14 Barriers	T18 Wrn sgns	night						-35
T14 Barriers	T19 Lines	day					-21	** -48
T14 Barriers	T19 Lines	night					-26	** -45
T15 Realign len	T19 Lines	day			* -50	-34	-33	
T15 Realign len	T19 Lines	night		-25	* -50	* -38	* -37	
T17 Clear obs	T19 Lines	day		** -29	** -62	** -55	** -55	
T17 Clear obs	T19 Lines	night		*** -36	** -62	*** -58	*** -57	
T18 Wrn sgns	T19 Lines	day			-21	* -22	* -22	-17
T18 Wrn sgns	T19 Lines	night						** -36
T19 Lines	T19 Lines	day		-16				* -28
T19 Lines	T19 Lines	night		* -32				-21
T19 Lines	T20 Prty sgns	day		*** -55	-24	-24	-22	
T19 Lines	T20 Prty sgns	night						

End note

The crash reduction factors for individual treatment types estimated by the regression models are generally consistent with factors reported in the literature as summarised in the survey by Turner et al. (2008) commissioned by BITRE.

Exceptions are:

- T12 alter road width — considerably more effective
- T01 roundabouts, T02 medians, and T16 realign intersections — slightly more effective
- T06 lighting treatments at night, T11 non-skid treatments and T15 realign road length — less effective

The large database enabled the regression analysis to shed light on interactions between frequently occurring pairs of treatment types implemented together. Instances were found where the effect of a pair of treatment types is greater than or less the sum of its parts by statistically significant amounts. Multiple-treatment projects are becoming increasingly common, as shown in chapter 8. The regression results for pairs of treatments may have lessons for the development of multiple treatment projects in the future.

CHAPTER 7
Predicted crashes avoided

Summary

The predicted number of crashes avoided at a site in a year is the difference between the predicted without-treatment and the predicted with-treatment crash rates at the site for the year.

The regression models were used to predict the without-treatment and with-treatment crash rates for all sites from the time of implementation up to 2036, the last year of the range covered by the cost–benefit analysis (CBA).

In forecasting beyond the range of the data, crash rates in each jurisdiction were assumed to grow in line with projected population growth for that jurisdiction reduced by one percentage point per year to account for the general decreasing trend in crash numbers due to system-wide improvements in road safety.

Results are reported in this chapter for the year 2006 because it is the first year in which all projects in the database had been completed. The average number of reported crashes avoided per project in the database (not in each model) was 1.7 crashes. For individual severity levels, average reported crashes avoided per project were 0.01 fatal, 0.11 serious injury, 0.55 minor injury, 0.61 injury, 0.62 casualty and 1.1 PDO.

The 0.01 rate for fatal crashes implies that one fatal crash is avoided per year for every 100 projects completed. Making indicative adjustments for unreported minor injury and PDO crashes, there could be as many as 6.0 crashes avoided per year of which 2.3 is a casualty crash and 3.7 a PDO crash.

Extrapolating across the entire program, the 2578 projects approved between 1996–97 and 2002–03 and completed are estimated to be saving over 4000 crashes per annum of which about 1550 are casualty crashes and almost 30 are fatal crashes.

On average, there are 1.1 deaths per fatal crash, so the 2578 projects are estimated to be saving approximately 30 lives per year or one life per year for every 84 projects completed. The indicative under-reporting adjustments for minor injury and PDO crashes increase the total number of crashes avoided to 14 500 of which 5700 are casualty crashes.

The ratio of predicted crashes avoided to total predicted crashes without treatments provides an average crash reduction factor for the program as a whole. The program is estimated to reduce crashes at treated sites by about 30% for all severity levels except for serious injury crashes where the reduction is 23% and PDO crashes where it is 26%.

Black spot project databases identify target crash types that each project is aiming to prevent or reduce. In preparing the database for regression analysis, no attempt was made to remove non-target crashes from the data because there was considered to be insufficient information do so with confidence.

Non-target crashes, by definition, are not affected by treatments. The presence of non-target crashes in the data will reduce estimated crash reduction factors, but will not affect predicted numbers of crashes avoided. The rules for assigning crashes to sites differ between jurisdictions, so the proportions of non-target crashes in the data are likely to vary between jurisdictions. The regression coefficients for jurisdictions may have absorbed some of the differences in proportions of non-target crashes in the data between jurisdictions.

Methodology and assumptions

The regression models were used to predict numbers of crashes avoided at each site as a result of the program from the time of implementation up to 2036, the last year of the period covered by the CBA.

Annual crash rates were forecast without and with the treatment at each site, for each crash severity level. The difference between crash rates without and with treatment is an estimate of the average annual number of crashes avoided as a result of the treatment.

In forecasting, crash rates at all sites in each jurisdiction were assumed to grow in line with projected population growth for that jurisdiction reduced by one percentage point per year to account for the general decreasing trend in crash numbers due to improvements in vehicle safety, driver education and enforcement.

The adjustment is not intended to cover the contribution of improvements in road infrastructure to the general downward trend. Such improvements are location specific. The only road improvements that affect crash rates at individual black spot sites are the black spot treatments themselves, which are fully accounted for by the models.

The population projections were the Australian Bureau of Statistics Series B projections — the middle set between Series A (high) and C (low). The annual rates of forecast population increase range from –0.8% for Tasmania in the 2030s to 1.4% for Queensland from 2004 to 2006. In years when the forecast population growth was less than 1% per annum, crashes had negative growth rates.

The growth factors were applied for each jurisdiction to the year after the last year of the crash data used for the model. For the CBA reported in chapter 9, a sensitivity test was undertaken assuming constant crash rates over time.

As noted in chapter 4, sensitivity tests are undertaken for the effect of adjusting for unreported crashes. The assumed ratios of unreported to reported crashes are zero for fatal and serious injury crashes, 3.28 for minor injury crashes, and 2.48 for PDO crashes. Hence, estimated minor injury and PDO crashes avoided are multiplied by 4.28 and 3.48 respectively.

The sensitivity tests are undertaken only for the totals, not for each jurisdiction. The ratios are indicative only. The information from which they were derived was not considered sufficiently accurate to estimate ratios of individual jurisdictions.

Estimates for 2006

Table 7.1 shows the estimated numbers of crashes avoided at the 1599 sites in the database for the year 2006 as predicted by regression models. The number of crashes avoided each year increases rapidly after 1996 as more of the projects in the database are completed until the last-completed project in the data is finished in 2005. The year 2006 was selected because it is the first year in which all projects in the database had been completed.

The sums of predicted serious and minor injury crashes avoided do not equal predicted injury crashes avoided because the results were obtained from different regression models using different data. The injury model includes NSW sites.

Since the 1599 total is a subset of all the projects in scope, the totals are not very meaningful. The numbers of crashes avoided per site in table 7.2 were derived by dividing the totals in table 7.1 by the total numbers of sites in the data (the last column of table 5.1, repeated as the first column of table 7.2), not the number of sites in each model.

For example, even though there were only 394 projects in the fatal crashes regression model, the estimate of 16.3 fatal crashes avoided was divided by 1599, the total number of projects in the database to allow for the fact that most treated sites have a zero fatal crash rate.

There is considerable variation in numbers of crashes avoided per project across jurisdictions in table 7.2. This is due to a number of factors including the jurisdictional coefficients in the regression equations (see table 5.5) and different project characteristics such as the mixes of treatment types across jurisdictions. The site-specific coefficients (the without-treatment crash rates at the sites in each regression model) also play a role. They are influenced by traffic levels.

Smaller jurisdictions in terms of numbers of projects, the ACT, the NT and Tasmania, show greater variability compared with the totals in the bottom row of the table partly because there is less averaging across projects.

The NT has the lowest rates for predicted crashes avoided per project and a negative value for serious injury crashes suggesting that the NBSP has lead an increase in serious injury crashes. The jurisdictional regression effect terms for the NT shown in table 5.5 are highly unfavourable in all the models, both in absolute terms and compared to the other jurisdictions. These would be the main cause for the low, and for one model negative, predicted numbers of crashes avoided. However, due to the small sample size, none of the the NT's jurisdictional effect terms in table 5.5 are statistically significant. The poor performance of the NT projects in terms of crashes avoided correctly mirrors the data however, we cannot be confident that this is typical of the NT sites and not due to chance. The estimated treatment effect terms for serious injury crashes in the NT (see appendix D) show that most of the limited number that are statistically significant are negative, that is, they reduce crashes, not increase them.

In table 7.3, estimated numbers of crashes avoided as a result of all completed NBSP projects approved between 1996–97 and 2002–03 inclusive were obtained by multiplying the rates per site in table 7.2 by the numbers of approved and competed projects in the first column of table 7.3.

As there are no NSW serious or minor injury crashes and no Victorian PDO crashes in the data, the estimated numbers avoided for these three cells in table 7.3 are estimates based on the predictions for the other states. As such, these estimates are indicative only, particularly for PDO crashes in Victoria, given the differences in reporting levels between jurisdictions.

Assuming that the estimated rates of crashes avoided for the 1599 projects in the database are the same as for the other projects in each jurisdiction, the program as a whole — 2578 projects approved between 1996–97 and 2002–03 and completed — is estimated to be saving over 4000 crashes per annum, of which about 1550 are casualty crashes and almost 30 are fatal crashes.[12]

After adjusting for unreported minor injury and PDO crashes, the total number of crashes avoided could be as high as 14 500, of which 5700 are casualty crashes. Note that the adjustment factors are indicative only.

From the 'total' row of table 7.2, on average, a single project is estimated to save 1.7 crashes per annum comprised of 0.01 of a fatal crash, 0.61 of an injury crash (or alternatively 0.11 of a serious injury crash and 0.55 of a minor injury crash) and 1.07 PDO crashes. The 0.01 rate for fatal crashes implies that one fatal crash is avoided per year for every 100 projects completed.

A fatal crash involves one or more deaths. On average, there are 1.1 deaths per fatal crash (BITRE 2009).[13] So the 2578 projects are estimated to be saving about 30 lives per year or one life per year for every 84 projects completed.

After adjusting for unreported minor injury and PDO crashes, there could be as many as 6.0 crashes per year avoided for each project undertaken on average, of which 2.3 is a casualty crash and 3.7 a PDO crash.

T7.1 Predicted crashes avoided for projects in regression models: 2006 calendar year

	Estimated from regression model					Casualty[a]	Casualty[a]
Jurisdiction	Fatal	Serious injury	Minor injury	Injury	PDO	Fatal + serious + minor	Fatal + injury
ACT	0.7	4.1	19.6	23.4	206.7	24.4	24.1
NSW	3.4	na	na	144.5	201.1	na	147.9
NT	0.1	-0.5	7.9	8.0	34.3	7.4	8.0
Qld	1.5	36.4	131.2	169.5	202.6	169.2	171.0
SA	1.3	14.2	80.8	89.9	283.1	96.4	91.2
Tas	1.1	3.7	12.6	16.2	7.3	17.4	17.2
Vic	5.9	59.2	262.5	343.8	na	327.6	349.7
WA	2.3	25.1	165.2	185.3	222.1	192.6	187.6
Total	16.3	na	na	980.5	na	na	996.7

a. Obtained by summing columns to the left, not from the casualty regression model.

12 The estimates were made for each jurisdiction separately. The totals in table 7.3 are the sums of the rows above. The extrapolation to the entire 2578 projects in scope therefore adjusts for differences in the proportions of projects by jurisdiction in the 1599 projects in the evaluation and the 2578 projects in scope and for differences in crashes avoided per site between jurisdictions. It was not possible to adjust for differences in the mixes of treatment types between the evaluation database and all projects in scope because the treatments for the other 979 = 2578 – 1599 projects in scope were not classified.

13 In 2006, 1602 people were killed in 1455 crashes, a rate of 1.101 persons per crash (BITRE 2009, pp. 10 and 13).

T7.2 Predicted crashes avoided per project completed: 2006 calendar year[a]

	Projects	Fatal	Serious injury	Minor injury	Injury	PDO	Fatal + serious + minor	Fatal + injury
ACT	13	0.05	0.32	1.51	1.80	15.90	1.88	1.85
NSW	353	0.01	na	na	0.41	0.57	na	0.42
NT	26	0.00	-0.02	0.30	0.31	1.32	0.29	0.31
Qld	233	0.01	0.16	0.56	0.73	0.87	0.73	0.73
SA	103	0.01	0.14	0.78	0.87	2.75	0.94	0.89
Tas	41	0.03	0.09	0.31	0.39	0.18	0.42	0.42
Vic	513	0.01	0.12	0.51	0.67	na	0.64	0.68
WA	317	0.01	0.08	0.52	0.58	0.70	0.61	0.59
Total	1599	0.01	0.11	0.55	0.61	1.07	na	0.62
Adjusted total[b]		0.01	0.11	2.34	2.28	3.70	na	2.29

a. Estimates in table 7.1 divided by the number of projects in the database, as shown in the first column of table 7.2.

b. Sensitivity test factoring up minor injury and PDO crashes for estimated unreported crashes.

T7.3 Predicted crashes avoided in 2006 due to all completed projects approved from 1996–97 to 2002–03[a]

	Projects	Fatal	Serious injury	Minor injury	Injury	PDO	Fatal + serious + minor[e]	Fatal + injury[e]
ACT	21	1	7	32	38	334	39	39
NSW	688	7	49[b]	233[b]	282	392	288	288
NT	40	0	-1	12	12	53	11	12
Qld	430	3	67	242	313	374	312	316
SA	189	2	26	148	165	519	177	167
Tas	179	5	16	55	71	32	76	75
Vic	617	7	71	316	413	547[c]	394	421
WA	414	3	33	216	242	290	252	245
Total[d]	2 578	28	268	1 254	1 535	2 540	1 550	1 563
Adjusted total[f]		28	268	5 363	5 681	8 776	5 658	5 709

a. Crashes per project in table 7.2 multiplied by total numbers of projects completed shown in first column of table 7.3, except for the totals (see note d below).

b. Estimated by splitting NSW injury crashes in the proportions for the totals estimated for the other jurisdictions.

c. Estimated for Victoria using the number of PDO crashes avoided per site for the other jurisdictions.

d. Totals are sums of estimates in the rows above for all jurisdictions.

e. Obtained by summing columns to the left, not multiplying total projects by crashes avoided per site.

f. Sensitivity test factoring up minor injury and PDO crashes for estimated unreported crashes.

Table 7.4 shows predicted crashes avoided divided by the predicted total crashes in the absence of black spot treatments for 2006. These ratios are average treatment crash reduction factors (effectiveness percentages without the negative signs).

For all jurisdictions together, the program is estimated to be reducing crashes at treated sites by about 30% except for serious injury crashes where the reduction is 23% and PDO crashes where it is 26%.

There is no sensitivity test for unreported crashes because, with the adjustment being made to the numerator and the denominator of the ratios for minor injury and PDO crashes, there is no effect.

T7.4 Ratio of predicted crashes avoided to total predicted crashes without treatments: 2006

(%)

	Fatal	Serious injury	Minor injury	Injury	PDO	Fatal + serious + minor	Fatal + injury
ACT	76	57	77	73	46	73	73
NSW	31	na	na	36	37	na	36
NT	5	-4	24	16	27	14	16
Qld	28	32	39	38	53	37	37
SA	41	43	33	33	36	35	33
Tas	60	56	48	49	13	51	51
Vic	28	19	30	29	na	27	29
WA	27	18	28	25	11	26	25
Total	31	23	32	31	26	30	31

Urban/rural analysis

Table 7.5 examines predicted crashes avoided per project completed split into urban and rural categories.

It was reported in chapter 5 that treatments were found to be more effective at sites in rural areas than in urban areas (see table 5.7) in all models except for the fatal crash model for which the rural coefficients were not statistically significant. The ratios of predicted crashes avoided to predicted crashes without treatment in the bottom part of table 7.5 bear this out. It was suggested that the explanation may lie with the higher speed environments in rural areas.

Despite the greater crash reduction factors in rural areas, the middle part of table 7.5 shows that the absolute numbers of predicted crashes avoided per site are higher in urban areas. The explanation can be found in the without-treatment predicted crash rates in the top part of the table. The smaller crash reduction factors in urban areas are being applied to much higher without-treatment crash rates in urban areas compared with rural areas. The higher absolute crash rates in urban areas are most likely a reflection of higher traffic levels, and consequent crash exposure levels in urban areas.

T7.5 Predicted crashes: urban/rural analysis: 2006

	Fatal	Serious injury	Minor injury	Injury	PDO	Fatal + Injury
Estimated without-treatment crash rates per project completed						
Urban	0.03	0.57	2.24	2.57	6.10	2.60
Rural	0.04	0.39	0.97	1.28	2.06	1.32
Total	0.03	0.50	1.71	1.97	4.08	2.01
Estimated crashes avoided per project completed						
Urban	0.01	0.12	0.66	0.74	1.62	0.75
Rural	0.01	0.10	0.38	0.46	0.51	0.47
Total	0.01	0.11	0.55	0.61	1.07	0.62
Ratio of predicted crashes avoided to total predicted crashes without treatments (%)						
Urban	34	21	30	29	27	29
Rural	28	26	40	36	25	36
Total	31	23	32	31	26	31

Note: Predicted without-treatment crashes and crashes avoided for all sites were divided by 860 projects for urban, 739 projects for rural and 1599 for the total (see table 5.6) for the fatal, injury and casualty models. Since the serious and minor injury models exclude NSW projects, the divisors for those columns are 724, 522, and 1246 for urban, rural and total respectively. Since the PDO model excludes Victorian projects, the divisors for the PDO column are 544, 542 and 1086 respectively.

Effect of non-target crashes in the data

It was remarked in chapter 5 that a possible contributor to differences in treatment effectiveness between jurisdictions could be the way in which crashes are assigned to sites in each jurisdiction, in so far as it affects the proportions of non-target crashes in the data.

Explanation of non-target crashes

Black spot project databases list Definitions for Classifying Accidents (DCA) codes for target crash types that each project is aiming to prevent or reduce. Hauer (1997, p.40) defines the target crashes of a treatment as being those crash types, 'the occurrence of which can be materially affected by the treatment'. The particular crash types targeted will affect the choice of treatments and detailed project design. Non-target DCA codes are also listed in many databases. These are crash types that occurred at each black spot site but were not targeted by the treatment type applied (BTE 2001, p. 167).

Knowing the target and non-target crash types for each black spot project and the type of each crash at the site may still not be sufficient to identify those crashes likely to be affected by the treatment. Many intersection treatments, such as fully controlled right turns and turning lanes, can be applied to any or all of the arms of an intersection. Treating one arm may have little or no affect on traffic using other arms or could even increase crashes on them. Traffic signal treatments, while reducing crashes within intersections could increase rear-end collisions on the arms.

No attempt has been made in this study to distinguish between target and non-target crashes except where it is related to time of day.

Some treatment types, such as street lighting, are clearly targeted at night-time crashes and the recorded time of the crash enables night-time and daytime crashes to be readily identified. The present evaluation is being carried out for an entire program. It would not be consistent with the macro level of this evaluation to undertake the detailed examination of individual sites and individual crashes necessary to distinguish between target and non-target crashes.

The number of non-target crashes in the data for a study of this type is affected by the way crashes are assigned to sites. Crashes were assigned to sites by the road agencies supplying data except for South Australia for which BITRE did the assignments.

One method is to use GIS coordinates to extract from the crash database for a region or jurisdiction, crashes that occurred within a specified radius of the precise physical location of each project. Choosing the size of the radius involves a degree of arbitrariness. For the South Australian data, BITRE used a 25 metre radius. The larger the radius, the greater the number of crashes associated with each site. The alternative method is to use road names for intersections, and road names with distances from landmarks for mid-block sites. For intersections, determining the distance along the arms for counting crashes deemed to occur at the intersection involves some subjectivity.

Impact on estimated treatment effects and predictions of crashes avoided

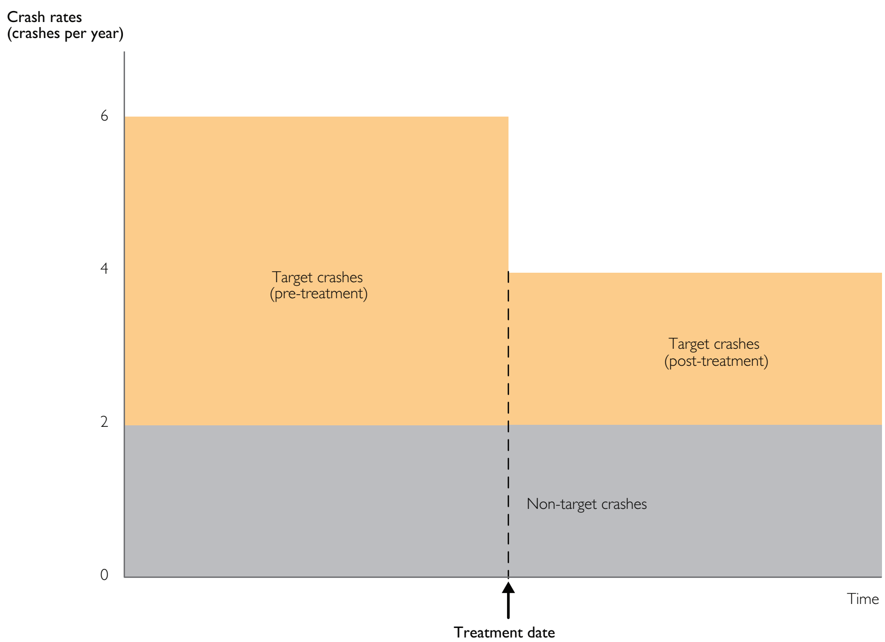
The presence of non-target crashes at treated sites in the data can alter the regression coefficients, reducing the estimated effectiveness of black spot projects and increasing the estimated mean crash rates at individual sites, both before and after treatment.

The basic problem is that non-target crashes are an addition to target crashes, while the Poisson model is multiplicative — the *sum* of target and non-target pre-treatment crash rates is multiplied by the treatment effectiveness index (TEI) to obtain the post-treatment crash rate, not just the target crash rate. A model that allows for additive non-target crashes could be fitted in theory, but would require assumptions to be made about the proportions of non-target crashes at individual sites. The information does not exist to support such assumptions being made.

As illustrated in figure 7.1, say site A had an average of four target crashes per year before treatment and two after treatment, the black spot project having achieved a 50% reduction in target crashes. An additional two non-target crashes occurred at site A each year, both before and after treatment. The pre-treatment crash rate would be six crashes per year and the post-treatment rate, four crashes per year. The presence of non-target crashes in the data reduces the estimated crash reduction factor from 50% to 33.3%. However, the estimated number of crashes avoided in absolute terms is not affected. The estimate of crashes avoided is the product of the pre-treatment crash rate and the crash reduction factor. In the absence of non-target crashes, the estimate of crashes avoided is $2 = 0.5 \times 4$. With non-target crashes, the estimate is the same, $2 = 0.333 \times 6$.

The reason is that the error introduced into the estimate of crashes avoided by applying the crash reduction factor to the non-target crashes, 0.667 = 0.333 × 2, is exactly offset by the error caused by applying a deflated crash reduction factor, 0.333 instead of 0.5, to the target crashes, 0.667 = (0.5 – 0.333) × 4.

F7.1 Effect of non-target crashes in data



This example refers to one site considered in isolation. The conclusion still applies when the crash reduction factor is estimated from a number of sites taken together, as is the case for a Poisson regression, when the non-target crash rate as a proportion of the target crash rate is the same for all sites.

Site i has a mean pre-treatment crash rate of m_i for target crashes. The post-treatment crash rate is θm_i where θ is the TEI. The predicted number of crashes avoided across all sites is $(1 - \theta)\sum m_i$.

There are $\rho \times m_i$ non-target crashes at each site i where ρ is the ratio of the non-target crash rate to the target crash rate. The pre-treatment total crash rate (target and non-target crashes together) at each site is then $m_i^* = (1 + \rho)m_i$. The post-treatment crash rate is $\theta^* m_i^*$ where the TEI with non-target crashes included is $\theta^* = (\theta + \rho)/(1 + \rho)$. For the numerical example of figure 7.1, where $\theta = 0.5$ and $\rho = 0.5$, this formula gives $\theta^* = 2/3$.

With uniform proportions of non-target crashes across all sites, the estimated number of crashes avoided is correct using total crash rates and the TEI based on total crashes.

$$(1 = \theta^*)\sum m_i^* = \left[1 - \frac{(\theta + \rho)}{(1 + \rho)}\right](1 + \rho)\sum m_i = (1 - \theta)\sum m_i$$

Proportions of non-target crashes are likely to be more uniform for sites with the same treatment type in the same jurisdiction, and to differ between them. Among sites with the same treatment type, there is likely to be less variability in site layouts and crash type mixes than between sites with different treatment types. Methods of assigning crashes to sites are likely to be more consistent within jurisdictions than between them. The regression models include treatment type and jurisdiction as explanatory variables. Differences in proportions of non-target crashes between treatment types and jurisdictions will be reflected in differences between the TEIs and so should not distort predictions of crashes avoided.

Appendix C contains a technical discussion of the effects of non-target crashes in the data on estimated crashes avoided.

Where proportions of non-target crashes vary across sites, the estimated number of crashes avoided will also be correct if the number of post-treatment observation periods is the same for all sites. This assumption will not hold in practice because fewer years of post-treatment crash data will be available for more recently treated sites. However, provided the numbers of post-treatment observation periods are randomly distributed across sites with different pre-treatment target crash rates and proportions of non-target crashes, the estimate of crashes avoided should not be greatly affected by non-target crashes.

There is no reason to expect there to be any correlation between numbers of years of post-treatment crash data and either target crash rates or proportions of non-target crashes. Since more recently treated sites have fewer years of post-treatment crash data, to have a correlation would require the program to be shifting focus over time to sites with higher or lower crash rates or a change in the way crashes are assigned to sites that alters the proportion of non-target crashes.

If the crash reduction factors estimated from a data set that contains non-target crashes are used to forecast crashes avoided from new black spot treatments elsewhere with different proportions of non-target crashes in the data, there may be errors.

Appendix C also considers the impact of non-target crashes on the variances and test statistics of the estimates of treatment effectiveness indexes. The presence of non-target crashes in the data is likely to reduce the statistical significance of a treatment effectiveness estimate.

Jurisdictional differences in proportions of non-target crashes

Other things being equal, if the effectiveness of treatment types at reducing target crashes was uniform across jurisdictions, the jurisdictional coefficients would be entirely a reflection of different proportions of non-target crashes in the data.

As explained just above, impacts of non-target crashes in the data on TEIs have no effect on predicted crashes avoided. Looking across jurisdictions, we would expect to see no correlation between jurisdictional coefficients and predicted crashes avoided per project.

At the other extreme, if the proportions of non-target crashes were the same for all jurisdictions but treatment effectiveness differs, we would expect to see a negative correlation between the jurisdictional coefficients and predicted crashes avoided per project. A jurisdiction with less effective treatments would have a higher jurisdictional coefficient leading to a smaller predicted number of crashes avoided per project, and conversely.

Table 7.6 shows predicted crashes avoided per project site in each model, that is, the crashes in table 7.1 divided by numbers of projects in each model from table 5.1.

Table 7.7 shows the exponentiated jurisdictional coefficients ($exp(\beta_j)$), which in table 5.5 are presented as percentage effects, $(1 - \beta_j) \times 100$). Table 7.8 shows correlation coefficients between the effects and crashes avoided per site. Considering all jurisdictions, the correlation coefficients clearly indicate negative relationships.

When the two outlier jurisdictions, the ACT and the Northern Territory, are omitted, the negative relationships are considerably reduced. It is eliminated altogether for the minor injury model and reduced to –0.21 for the injury model, which is the most comprehensive in data of the models shown. While the evidence is not conclusive, it is suggestive that the differences between the jurisdictional coefficients are partly a reflection of different proportions of non-target crashes in the data between jurisdictions.

Predicted numbers of crashes avoided per project in each jurisdiction are affected by a range of factors besides the jurisdictional coefficients, in particular, the mix of treatment types with different levels of effectiveness for each jurisdiction, the mix of site locations, urban/rural, state road/local road, and the absolute magnitudes of the without-treatment crash rates for target crashes at the sites in each jurisdiction, which are related to traffic levels.

T7.6 Predicted crashes avoided per project in models: 2006

	Fatal	Serious injury	Minor injury	Injury	PDO
ACT	0.232	0.374	1.633	1.799	15.899
NSW	0.049	na	na	0.414	0.583
NT	0.006	-0.023	0.304	0.306	1.319
Qld	0.034	0.183	0.597	0.740	0.960
SA	0.051	0.178	0.851	0.908	3.145
Tas	0.089	0.137	0.324	0.415	0.186
Vic	0.035	0.123	0.513	0.670	na
WA	0.039	0.093	0.549	0.598	0.703
Total	0.041	0.130	0.564	0.621	1.113

Note: The divisors are the numbers of completed projects in each model in each jurisdiction displayed in table 5.1, not the totals in the database as in table 7.2.

T7.7 Exponentiated jurisdiction regression coefficients

	Fatal	Serious injury	Minor injury	Injury	PDO
ACT	na	0.64	0.36	0.38	0.67
NSW	na	na	na	1.00	1.00
NT	na	1.30	1.17	1.25	1.19
Qld	na	0.98	1.08	0.94	0.75
SA	na	0.69	1.06	0.91	0.90
Tas	na	0.68	1.03	0.88	1.38
Vic	na	1.00	1.00	0.89	na
WA	na	1.11	1.20	1.08	1.32

T7.8 Correlation coefficients between exponentiated jurisdiction regression coefficients (table 7.7) and predicted crashes avoided per project (table 7.6) across jurisdictions

	Serious injury	Minor injury	Injury	PDO
All jurisdictions	-0.79	-0.90	-0.91	-0.63
Excluding outliers ACT and NT	-0.51	0.11	-0.21	-0.52

End note

The statistical analysis shows that the NBSP is effective in reducing crashes and hence loss of life, injuries and property damage. However, this information alone is not sufficient to determine the worth of the Program. The value of the lives, injuries and property damage saved is not infinite. If the value of life was infinite, society might abandon road transport altogether. The value of the savings needs to be compared with the value of the resources expended to obtain those savings, in order to determine whether the NBSP is a good use of society's resources.

CHAPTER 8

Project costs

Summary

The construction costs of black spot projects are essential data for the cost–benefit analysis (CBA). Data on project costs were assembled from both the National Black Spot program (NBSP) database and information provided by state and territory road agencies. Costs were inflated to 2007 dollars using the consumer price index (CPI). The total cost of the 1599 projects in the database in 2007 prices was $251 million, an average of $157 000 per project.

The Australian National Audit Office (ANAO) published a review of the NBSP in 2007 that raised concerns about under-reporting of contributions to project costs by state, territory and local governments. ANAO found that 50% of a sample of 255 projects had non-NBSP contributions. The NBSP funded 74% of the costs of these projects.

In the BITRE database, only 18% of projects had non-NBSP funding contributions, suggesting significant under-reporting. The NBSP contribution for these projects amounted to 67% of total costs, fairly consistent with the ANAO finding.

A regression analysis was undertaken of the inflation-adjusted costs of the 1599 projects in the database. The regression coefficient for implementation time indicated that project construction costs were rising by 4.7 per annum in real terms, much higher than the BITRE Road Construction and Maintenance Price Index, which rose at 0.6% per annum over the period after adjusting for CPI increases.

Project construction costs are considerably higher for work undertaken in the months of July, August and October. Costs are, on average, 55% higher in non-metropolitan areas than in metropolitan areas, and 35% higher on state roads compared with local roads. State and Territory coefficients are correlated with the percentage of projects with known non-NBSP funding contributions suggesting that different levels of under-reporting accounts for much of the cost differences between jurisdictions.

Treatments involving significant construction works — T01 roundabouts, T10 sealing/resealing, T12 widening, T14 barriers and guardrails, T15/T16 realigning, — and T03 new traffic signals, which involve electronic equipment and software programming, have significantly above-average costs. Treatments involving T18 warning signs, T20 priority signs and T19 line marking have below-average costs.

The proportion of multiple-treatment projects and the number of treatments per multiple-treatment project have been rising over time increasing the average construction costs of projects.

Adjustments were made to project costs to correct for under-reporting of non-NBSP contributions. No adjustments were made for the ACT, which has no local governments, and Queensland for which 45% of projects — close the ANAO's 50% — had known non-NBSP contributions. The other six jurisdictions had their costs adjusted upward on the assumption that 50% of projects have non-NBSP contributions. For those projects having their costs adjusted upwards, the NBSP was assumed to have contributed 70% of funds. South Australia, Victoria and Western Australia had the largest adjustments, increasing total project costs for those jurisdictions by 18% to 19%. The overall impact was a 10% increase to the cost of all projects to $277 million or $173 000 per project.

Data sources

Since CBA aims to measure costs and benefits to society as whole, the relevant project construction cost is the actual construction cost of the project regardless of who provides the funds.

The NBSP database contains:

- the initial approved amount of NBSP funding for each project along with the final amount after making approved variations, and
- contributions to project costs from other sources, mainly state, territory and local governments.

BITRE asked state and territory road agencies to also provide construction cost data. Most jurisdictions were able to do so. For many projects, the final approved NBSP costs were consistent with those provided by the road agency. But for others, there were missing data or inconsistencies.

In assigning costs to these projects, the following rules were broadly applied, exercising judgment as required on a case-by-case basis.

- Where no construction cost data were available from the state or territory road agency, the final approved amount of NBSP funding was used, plus any contribution from other sources recorded in the NBSP database in the 'other funds' field.
- Where the road agency indicated a cost greater than the final approved amount of NBSP funding, the agency's cost was accepted on the assumption that it included an additional contribution. Often, this was corroborated by the 'other funds' field in the NBSP database, and/or a breakdown of sources of funds provided by the road agency.
- Where the state or territory data indicated a lower cost than the final approved amount of NBSP spending, the NBSP amount was used.

Costs of individual projects in the database ranged from $305 for a 1998 project to raise pavement markers (T19 line marking treatment) to $1.89 million for a 2003 project to reconstruct the horizontal and vertical alignments of a length of road and widen two bridges (T15 realign road length combined with T12 alter road width). The total cost of all the 1599 projects in the database was $206 million, of which $182 million or 89% was contributed by the NBSP.

Inflation adjustment

The projects in the BITRE database were implemented over the calendar years 1996 to 2005. Since the CBA was undertaken using Austroads unit crash costs as at 30 June 2007, all project construction costs were adjusted to that date using the consumer price index.

The BITRE Road Construction and Maintenance Price Index (RCMPI) (BITRE 2007) was not used because it measures the combined effects of general inflation and the real increase in road construction and maintenance costs over time. Time trends for the CPI, RCMPI and black spot project costs are compared below.

For each project, the average CPI was estimated for the implementation period, which was used as the base for inflating to 30 June 2007 dollars. Implementation periods for projects in the database range from zero (started and completed on the same day) to 1115 days (three years and 20 days), with an average of 111 days.

Grouping by year of completion

For the purpose of examining how program benefits and costs have changed over time, projects were grouped by the calendar year that included the project's completion date, the day before benefits began to accrue.

The single project completed in 1996 was grouped with the 1997 projects. The 17 projects completed in 2004 and the single project completed in 2005 were grouped with the 2003 projects.

Grouping by calendar year produced more uniform group sizes than financial years. Having more uniform group sizes is desirable because it reduces the impacts of outlying observations on averages for small groups. Table 8.1 shows the numbers of projects in each year by jurisdiction.

T8.1 Numbers of projects in year groups

Year	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	0	45	6	17	18	9	71	20	186
1998	3	62	3	38	12	10	100	57	285
1999	1	28	4	45	17	13	71	43	222
2000	5	31	6	30	19	5	101	60	257
2001	0	75	3	44	24	3	61	70	280
2002	2	61	–	23	4	1	52	26	169
2003	2	51	4	36	9	0	57	41	200
Total	13	353	26	233	103	41	513	317	1599

Note: The first year group, 1997, contains one project completed in 1996. The last year group, 2003, includes 17 projects completed in 2004 and one in 2005.

Cost summary

Table 8.2 shows total project costs in real terms by year and jurisdiction. Table 8.3 shows these costs divided by numbers of projects from table 8.1. The cost per project varies considerably for the smaller jurisdictions because they have fewer projects in each year to average out individual projects with unusually high or low costs. The average project cost was $157 000 measured in 2007 prices. Costs per project across all jurisdictions show no time trend in real terms except for the last two year-groups, 2002 and 2003, for which the average costs are distinctly higher compared with the previous five year-groups. Explanations are offered below.

T8.2 Total costs in real terms by year and jurisdiction

($millions in 2007 prices)

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	–	8.74	1.33	3.10	3.02	0.67	8.31	4.72	29.89
1998	0.32	10.03	0.25	7.58	2.86	0.78	9.24	4.31	35.38
1999	0.90	7.37	0.36	9.65	2.13	2.23	10.74	3.09	36.47
2000	0.77	5.94	0.95	8.09	3.04	0.69	12.32	5.12	36.91
2001	–	10.71	0.57	8.82	4.40	1.48	7.84	5.68	39.51
2002	0.46	12.76	–	6.35	0.19	0.03	8.24	3.04	31.07
2003	1.51	12.64	0.57	9.45	1.11	–	11.56	4.99	41.83
Total	3.96	68.20	4.02	53.06	16.75	5.88	68.24	30.95	251.06

T8.3 Cost per project in real terms by year and jurisdiction

($'000 in 2007 prices)

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	–	194	221	183	168	75	117	236	161
1998	107	162	85	200	239	78	92	76	124
1999	904	263	89	214	125	171	151	72	164
2000	153	191	158	270	160	138	122	85	144
2001	–	143	189	201	183	493	129	81	141
2002	228	209	–	276	46	34	158	117	184
2003	756	248	142	263	123	–	203	122	209
Total	305	193	155	228	163	143	133	98	157

Missing costs

The construction cost estimates for the 1599 projects in the BITRE database are the best obtainable given the available data. There are still likely to be significant inaccuracies in both directions.

Of particular concern are contributions by other parties not recorded in the NBSP database and not provided to BITRE by road agencies. The other parties are mainly local governments and state and territory road agencies. Private sector developers and other government bodies such as the National Capital Authority in ACT have also contributed to project costs. Vicroads informed BITRE that it does not inform the Australian Government of additional costs it incurs to complete NBSP projects.

In 2007, the Australian National Audit Office reported on a performance audit of the Program (ANAO 2007). ANAO examined a sample of 273 projects in four states, all approved between 2002–03 and 2005–06. Some of ANAO's findings relate to the accuracy of construction cost data.

ANAO's analysis of the 255 projects for which the final cost could be substantiated found that the NBSP fully funded 127 projects. Of the 128 instances (50%) where the Program did not fully fund the project, on average, the NBSP funded 74% of project costs.

However, in the NBSP database, only 17 of the 128 projects were reported to have partner contributions. A further three projects reportedly had partner contributions but the NBSP fully funded the project (ANAO, p. 158).

Identifying all projects with partner contributions, and the amounts of these contributions, is particularly important in the ranking of projects by benefit–cost ratio (BCR) as part of the assessment and approval process. Excluding partnership contributions causes understatement of the project costs and overstatement of BCRs (ANAO 2007, pp. 34 and 159).

In our assignment of construction costs to projects, information from road agencies was used in addition to the NBSP database. So the costs in the BITRE database present a more complete picture than could be obtained from the NBSP database alone. However, there are still thought to be major shortfalls.

Table 8.4 shows numbers of projects and costs, comparing the total estimated costs with NBSP funding. For 292 projects (18% of 1599), total cost exceeded NBSP funding. This is well below the 50% of projects with non-Australian Government funds in ANAO's sample. Only for Queensland does the proportion of projects with non- Australian Government funds approach 50%. For Victoria, South Australia and Western Australia, jurisdictions with low proportions of projects with non-NBSP funding, BITRE had no cost information other than that in the NBSP database. This suggests the perceived proportion of projects with non-NBSP funds is related to the information that the jurisdiction is able to provide.[14]

14 Tasmania is recorded in Table 8.4 as having only three projects with non-NBSP funding contributions, but a relatively high percentage of non-NBSP funding in dollar terms. Two of the three projects had very large partner contributions, one from the Tasmanian Government and the other from a private road owner.

T8.4 Projects and costs by jurisdiction and funding source

Jurisdiction	Number of projects with non-NBSP funds	Number of projects	% projects with non-NBSP funds[a]	NBSP funding for all projects	All funding for all projects	% NBSP funding[a]
			(%)	($m)[b]	($m)[b]	(%)
ACT	3	13	23	2.8	4.0	70
NSW	124	353	35	59.4	68.2	87
NT	5	26	19	3.3	4.0	83
Qld	105	233	45	40.4	53.1	76
SA	6	103	6	16.5	16.8	98
Tas	3	41	7	4.2	5.9	71
Vic	25	513	5	66.0	68.2	97
WA	21	317	7	30.3	30.9	98
Total	292	1599	18	222.9	251.1	89

a. Ratio of figures in the two columns to the left × 100.
b. In 2007 prices.

For the 292 projects with non-NBSP funds (total cost $84 million), the proportion of NBSP funds (total $56 million) is 67% of the total, which is fairly consistent with the 74% proportion in the ANAO sample.

While lack of information on non-NBSP contributions to project costs leads to underestimation of costs, there are factors working in the opposite direction. As noted above, ANAO found three projects with incorrectly recorded non-NBSP contributions. ANAO also uncovered over-charging that would lead to over-estimation of costs. In 8% of cases in the ANAO sample, NBSP funds were used to undertake both the approved works and additional unapproved works (p 37). For 85 projects, 33% of ANAO's sample, more than the actual cost of the road safety work was claimed and paid for by the NBSP. Most of these instances occurred where local governments claimed the approved budget rather than the actual cost of the road works (p. 41).

Vicroads was adding a 3% administrative charge, which is not allowable under the Notes on Administration (p. 41). To the extent that some jurisdictions have included administration charges in costs and not others, the relative BCRs between jurisdictions will be distorted. Ideally, for CBA analysis purposes, only avoidable administration costs of projects should be included, that is, costs that would be avoided in the absence of the project, not an average for all construction works.

Instances were found of road agencies undertaking black spot works as parts of larger projects or broader programs of works and charging a disproportionate share of costs to the NBSP (pp. 41–2).

Hence there are factors working for both under- and over-estimation of construction costs. Omission of non-NBSP contributions leading to under-estimation is judged to be, by far, the most serious for the present evaluation. The regression analysis of cost data below provides further evidence of significant missing costs for some jurisdictions.

Regression analysis

Although the database was established for the purposes of regression analysis of crash numbers, the addition of project construction costs to the database makes it straightforward to undertake a regression analysis of construction costs. The regression analysis was undertaken to:

- check the data
- explain why costs have changed over time
- confirm that the 'under-reporting adjustment' (discussed below) is warranted, and
- obtain information on the relative costs of different treatments with which to estimate maintenance and replacement costs for multiple-treatment projects for the CBA.

Since the dependent variable, project cost, is continuous, unlike crash counts, the ordinary least squares method can be employed.

All 1599 projects in the database were included as observations. A large number of possible models was tested. The final model expresses the log of construction cost in 2007 prices as a linear function of:

- implementation time
- log of days construction time
- proportion of construction time in each month
- rural or urban dummy variable
- state road or local road dummy variable
- jurisdiction dummy variables
- treatment type dummy variables
- treatment type pair dummy variables
- a constant term

The model results are set out in table 8.5.

As the R-squared value indicates, the model is able to explain 44.6% of the variation in the log of costs. If costs are used instead of the log of costs, the R-squared term is reduced to 30.5%.

Implementation time

Implementation time is the time of construction defined as the month containing the midpoint in time between the start date and finish date of the project, numbering months from January 1996 as month 1. The implementation time variable in the database ranged from 6 (June 1996) to 110 (February 2005). A plot of the residuals against implementation time was inspected to check that the assumption of exponential growth fitted the data.

Project construction costs are estimated to be growing at 0.39% per month or 4.7% per annum in real terms.

Since the dependent variable is the logarithm of costs *in real terms*, the rising trend is on top of inflation as measured by the CPI. Over the years covered by the black spot project data, 1996–97 to 2003–04 inclusive, the BITRE Road Construction and Maintenance Price Index (RCMPI) had a rising trend of 3.5% per annum compared with a 2.8% per annum trend for the CPI.

Adjusting the RCMPI by the CPI and fitting a trend shows that road construction and maintenance costs rose in real terms by 0.6% per annum over the period. Hence, the annual real increase in construction costs for black spot projects has been about 4% per annum above than the general rise in road construction and maintenance costs.

One possible explanation is that black spot sites that are relatively less expensive to treat have been addressed earlier in the period, and progressively more expensive sites are being treated.

Log days construction time

The construction time for each project is the number of days between the start and finish dates.

Since the number of days was converted to a logarithm, the coefficient term is an elasticity. The values in the '%' and confidence interval columns shown in table 8.5 have not been converted to percentages. The coefficient implies that each 1% increase in the length of the construction period increases the project's cost by 0.17%.

Some treatment types will inevitably take longer to construct than others because of the nature of the works involved and the location, and some jurisdictions may be faster or slower than others. However, since treatment type, location in so far as it is either urban or rural, and jurisdiction have been included in the regression, the construction time coefficient relates more to delays in individual projects.

T8.5 Regression analysis of project construction costs

Dependent variable: Log (construction cost) R-squared = 0.4464

Number of observations = 1599 F_{crit} (63, 1535) = 19.64 Prob $F_{obs} > F_{crit}$ = 0.000

Independent variables	Coefficent	SE	t-stat	p-value	%[a]	95% CI (%)[b]	Significance[c]
Implementation time	0.0039	0.0011	3.60	0.000	0.39	(0.18, 0.6)	***
Log days construction time	0.1687	0.0272	6.20	0.000	0.17[d]	(0.12, 0.22)[d]	***
Proportion of construction time in month[e]							
January	0.0577	0.2945	0.20	0.845	6	(-41, 89)	ns
February	0.4614	0.2794	1.65	0.099	59	(-8, 174)	*
March	0.2655	0.2531	1.05	0.294	30	(-21, 114)	ns
April	0.4644	0.2546	1.82	0.068	59	(-3, 162)	*
May	0.4457	0.2463	1.81	0.071	56	(-4, 153)	*
June	0.4750	0.2444	1.94	0.052	61	(0, 160)	*
July	0.9417	0.2972	3.17	0.002	156	(43, 359)	***
August	1.0613	0.3756	2.83	0.005	189	(38, 504)	***
October	0.8665	0.3556	2.44	0.015	138	(18, 378)	**
November	0.2314	0.2928	0.79	0.429	26	(-29, 124)	ns
December	0.3048	0.3239	0.94	0.347	36	(-28, 156)	ns
Project location[f]							
Rural (not urban)	0.4392	0.0549	8.00	0.000	55	(39, 73)	***
State road (not local)	0.2994	0.0535	5.60	0.000	35	(21, 50)	***
ACT	1.2130	0.3104	3.91	0.000	236	(83, 518)	***
NSW	0.5106	0.1617	3.16	0.002	67	(21, 129)	***
NT	0.5682	0.2395	2.37	0.018	77	(10, 182)	**
Qld	0.8386	0.1670	5.02	0.000	131	(67, 221)	***
SA	0.3961	0.1845	2.15	0.032	49	(3, 113)	**
Vic	0.3893	0.1620	2.40	0.016	48	(7, 103)	**
WA	0.2325	0.1649	1.41	0.159	26	(-9, 74)	ns

a. '%' = [exp(coefficient) – 1] × 100

b. '95% CI' = lower and upper limits of 95% confidence interval

c. *** = significant at 0.01 level, ** = significant at 0.05 level, * = significant at 0.1 level, ns = not significant at 0.1 level

d. Values in the '%' and confidence interval columns not exponentiated and converted to percentages because the independent variable is the log of costs, not costs. The coefficient is therefore an elasticity.

e. One month had to be excluded to avoid linear dependence. September was chosen because it has the lowest costs, ensuring positive coefficients for all the other months.

f. One jurisdiction had to be excluded to avoid linear dependence. Tasmania was chosen because it has the lowest costs ensuring positive coefficients for all the other jurisdictions.

T8.5 Regression analysis of project construction costs (continued)

Variable	Coefficent	SE	t-stat	p-value	%	95% CI (%)	Significance
Treatment type							
T01 Rndabout	1.1373	0.0930	12.23	0.000	212	(160, 274)	***
T02 Medians	-0.0055	0.1113	-0.05	0.961	-1	(-20, 24)	ns
T03 New sigs	1.2388	0.1108	11.18	0.000	245	(178, 329)	***
T04 Mod sigs	-0.0257	0.0991	-0.26	0.795	-3	(-20, 18)	ns
T05 Traf calm	0.1831	0.1652	1.11	0.268	20	(-13, 66)	ns
T06 Lights	0.1584	0.1297	1.22	0.222	17	(-9, 51)	ns
T07 Turn lane	0.2917	0.1032	2.83	0.005	34	(9, 64)	***
T08 Ped trmts	0.2990	0.1226	2.44	0.015	35	(6, 72)	**
T10 Sealing	1.2721	0.1248	10.19	0.000	257	(179, 356)	***
T11 Non-skid	0.3309	0.1140	2.90	0.004	39	(11, 74)	***
T12 Alt width	0.6778	0.1543	4.39	0.000	97	(46, 167)	***
T14 Barriers	0.5647	0.1530	3.69	0.000	76	(30, 137)	***
T15 Realign len	1.1763	0.2106	5.59	0.000	224	(115, 390)	***
T16 Realign int	0.6800	0.1264	5.38	0.000	97	(54, 153)	***
T17 Clear obs	0.1830	0.1495	1.22	0.221	20	(-10, 61)	ns
T18 Wrn sgns	-0.7468	0.1846	-4.04	0.000	-53	(-67, -32)	***
T19 Lines	-0.3905	0.1294	-3.02	0.003	-32	(-48, -13)	***
T20 Prty sgns	-0.9792	0.1888	-5.19	0.000	-62	(-74, -46)	***
T22 Alt dir	0.1469	0.1923	0.76	0.445	16	(-21, 69)	ns
Unspec	0.2711	0.1154	2.35	0.019	31	(5, 64)	**
Treatment pairs							
T02T07	0.7141	0.2241	3.19	0.001	104	(32, 217)	***
T02T19	0.1569	0.2778	0.56	0.572	17	(-32, 102)	ns
T02T20	0.5288	0.2812	1.88	0.060	70	(-2, 195)	*
T04T04	0.0380	0.2065	0.18	0.854	4	(-31, 56)	ns
T04T07	0.7058	0.1892	3.73	0.000	103	(40, 194)	***
T07T07	0.5319	0.2329	2.28	0.023	70	(8, 169)	**
T07T08	-0.1288	0.2749	-0.47	0.640	-12	(-49, 51)	ns
T10T12	-0.7673	0.2553	-3.01	0.003	-54	(-72, -23)	***
T10T14	-0.5482	0.2619	-2.09	0.036	-42	(-65, -3)	**
T10T15	-1.2101	0.2825	-4.28	0.000	-70	(-83, -48)	***
T10T17	-0.3280	0.2805	-1.17	0.243	-28	(-58, 25)	ns
T10T19	0.3731	0.1771	2.11	0.035	45	(3, 106)	**
T12T15	-0.3966	0.2873	-1.38	0.168	-33	(-62, 18)	ns
T12T19	0.2728	0.2449	1.11	0.265	31	(-19, 112)	ns
T14T18	0.3621	0.3284	1.10	0.270	44	(-25, 174)	ns
T14T19	-0.0454	0.2792	-0.16	0.871	-4	(-45, 65)	ns
T15T19	0.3207	0.3035	1.06	0.291	38	(-24, 150)	ns
T17T19	0.0894	0.3046	0.29	0.769	9	(-40, 99)	ns

continued

T8.5 Regression analysis of project construction costs (continued)

Variable	Coefficent	SE	t-stat	p-value	%	95% CI (%)	Significance
T18T19	0.5004	0.2571	1.95	0.052	65	(0, 173)	*
T19T19	0.1415	0.2356	0.60	0.548	15	(-27, 83)	ns
T19T20	0.0543	0.3124	0.17	0.862	6	(-43, 95)	ns
Constant term							
constant	8.5278	0.3069	27.79	0.000	5053[g]	(2768, 9225)[g]	***

g. Values shown in '%' and confidence interval columns are exponentiated only, not multiplied by 100 to convert them to percentage increases.

Proportion of construction time in month

The proportion of the project construction time occurring in each calendar month of the year was calculated for each project. For example, if a project began and ended in July, it is assigned a one for July and a zero for all other months, whether it takes one day or all 31 days.

A project commenced on 17 July and completed on 15 August, a total of 30 days to implement, would have 15 implementation days in July and 15 in August. The project therefore would be counted as having 0.5 of its construction time in July and 0.5 in August. The month of September was dropped to avoid linear dependence. September was chosen because it has the lowest costs, ensuring positive coefficients for the remaining 11 months.

Although not all months had statistically significant coefficients, the group of all 11 months does make a statistically significant contribution to the model as a whole. The model suggests that costs are unusually high for construction work undertaken during the months of July, August and October.

Interactions between implementation months and jurisdictions were tested but found to be not significant.

Since seasonal climatic conditions vary between jurisdictions, the absence of significant interactions between months and jurisdictions suggests that the spikes in costs during July, August and October are not due to weather. The explanation, most likely, lies in accounting and budgeting factors, July being the start of a new financial year. Government organisations close their books for the financial year several days before the 30 June. Work undertaken during those days would be invoiced in the next financial year. Invoices intended to meet the deadline but not lodged in time would held over for the next financial year.

ANAO (2007, pp. 38 and 222–3) reports that state road agencies pressure local governments to complete projects by 30 June of the year of approval, warning that funding may be rescinded for projects not substantially completed by that date. ANAO mentions that this is not a requirement of the Notes on Administration. That there is a strong desire to complete projects by the end of the financial year is evidenced by the fact that 30% of the projects in the database were completed in the month of June. It could be that many of the projects continuing on into July or delayed to the point where they commenced in July involved unexpected technical difficulties giving rise to higher costs.

Rural or urban

The NBSP definitions of rural and urban were explained in chapter 6. According to the regression model, projects in rural areas cost, on average, 55% more than in urban areas. The greater distances that workers, equipment and materials have to travel to reach sites in rural areas would be a contributing factor.

State or local road

The regression analysis suggests that projects implemented on state roads cost, on average, 35% more than projects implemented on local roads. Part or all of the explanation could lie in under-reporting of funding contributions by local governments. It could also be the case that state roads, being more highly trafficked, are wider and built to higher standards causing the same treatments to cost more.

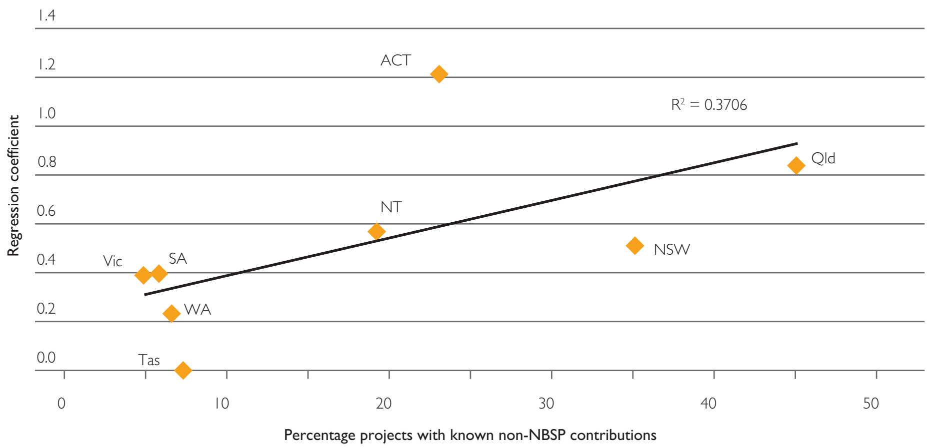
Jurisdiction

The coefficients showed some striking differences between jurisdictions. To avoid linear dependence, one jurisdiction had to be dropped. The lowest-cost jurisdiction, Tasmania, was chosen to ensure positive coefficients for the other jurisdictions. The coefficients expressed as percentages ranged from zero for Tasmania to 236% for the ACT. The ACT coefficient, however, is based on a sample of only 13 projects and has a very large confidence interval around it.

Under-reporting of the non-NBSP contributions appears to be a major source of the differences in coefficients between jurisdictions. Figure 8.1 shows a plot of the jurisdiction regression coefficients in table 8.5 against the percentage of projects with known non-NBSP funds from table 8.4 (fourth column). There is a clear positive relationship, shown by the regression line added to the chart.

The percentage of projects with known non-NBSP contributions in the project's jurisdiction cannot be added to the regression model as a variable without, at the same time, dropping at least one more jurisdiction due to linear dependence. The reason is that the variable takes on the same value for all projects in the same jurisdiction. If this variable is substituted for all of the jurisdiction variables, it is highly statistically significant with a t-statistic of 6.88. However, the model in table 8.5 is the better fitting model because there is additional variation between jurisdictions.

F8.1 Plot of regression coefficients against percentage of projects with known NBSP funds



Treatment type

The signs and sizes of the coefficients for treatments are not surprising. Treatments involving significant construction works — T01 roundabouts, T10 sealing/resealing, T12 widening, T14 barriers and guardrails, T15/T16 realigning, — and T03 new traffic signals, which involves electronic equipment and software programming, have significantly above-average costs. T18 warning signs, T19 line marking and T20 priority signs have below-average costs.

Although 12 of the 21 treatment pair variables are not significant at the 0.1 level, the group as a whole makes a statistically significant contribution to the model. There are cost savings from carrying out T10 sealing or resealing together with T12 widening, erecting T14 barriers or guardrails, and T15 realignment. This saving does not extend to T19 painting lines, which has a significant positive coefficient indicating that there are additional costs. T07 turning lanes combined with T02 medians or T04 signal modification costs more than if the treatments are carried out separately.

Changes in yearly average costs

It is important to understand why costs per project vary between the year groups to explain any changes in benefit–cost ratios over time. The last column in Table 8.3 showed that costs per project in each year manifested no general trend for the first five years, averaging $145 000 per project over the five years. Then the cost per project jumped to $184 000 in 2002 and to $209 000 in 2003, an average of $198 000 for the two years.

Higher costs per project in any year could result from:

- the steady 4.7% per annum upward trend
- longer construction times
- more work undertaken in June, July and October
- more rural projects
- more projects on state roads
- more projects in higher cost jurisdictions
- more high-cost treatment types
- more treatments per project

Tables 8.6 and 8.7 show indicators for these possibilities for projects grouped by calendar year.

T8.6 Indicators for factors affecting average project costs over time

Year	Average cost ($'000)	Average project construction time (days)	% construction time in high-cost months	% rural	% state road	Ratio of project numbers for high: low-cost jurisdictions	Ratio of numbers of high: medium: low-cost treatments
1997	161	82	27	58	51	37:63	48:16:35
1998	124	110	23	50	48	37:63	43:16:41
1999	164	121	22	47	49	35:65	38:20:43
2000	144	113	20	39	51	28:72	36:25:39
2001	141	120	15	44	39	44:56	43:17:40
2002	184	123	12	46	56	51:49	38:25:37
2003	209	106	21	42	51	47:54	40:18:42
Total	157	111	20	46	48	39:61	41:19:40

Average project construction time

The average project construction time was low for projects completed in 1997 because the program was new and there were no lengthy projects carried over from earlier years. Otherwise, there is no trend upward or downward.

Construction time in high-cost months

The percentage of total construction days occurring in July, August and October has declined for all but the last year. This is one factor offsetting the 4.9% per annum trend and then contributing to the cost increase in the final year.

Rural/urban

The percentage of projects in rural areas, which have higher costs, has declined. This too has offset the rising trend.

State roads/local roads

No trend is discernable in the proportion of projects on state roads, which have higher costs.

High-cost and low-cost jurisdictions

For the purpose of deriving the ratios, the ACT, NSW, the Northern Territory and Queensland were classed as high-cost jurisdictions. Low-cost jurisdictions were South Australia, Tasmania, Victoria and Western Australia. The ratio of numbers of projects in high to low cost jurisdictions was higher for the last two years. The adjustments to project costs, discussed in the next section, narrow the gap between high and low cost jurisdictions.

High-cost and low-cost treatments

For the purpose of deriving the ratios, high-cost treatments were defined as having costs greater than 70% above average (T01, T03, T10, T12, T14, T15, T16)(see results of regression analysis in table 8.5), medium-cost 30% to 40% above average (T07, T08, T11, T99), and low-cost 20% above average and below (T02, T04, T05, T06, T17, T18, T19, T20, T22). The low-cost category includes all the treatment types with non-significant and significant negative coefficients. There is no discernible change in the mix of treatments towards either the high-cost or low-cost ends.

Number of treatments per project

Table 8.7 shows there is trend towards greater numbers of treatments per project. This is the result of both increases in the proportion of multiple-treatment projects in each year and in the average number of component treatments in each multiple-treatment project. The jump in treatments per project in the last two years would be a major contributor to the higher costs per project in those years.

T8.7 Multiple-treatment projects by year

Year	Average cost ($'000)	Number of treatments per project	Percentage of projects with multiple treatments	Number of treatments per multiple treatment project
1997	161	1.31	30	2.16
1998	124	1.32	29	2.26
1999	164	1.45	36	2.36
2000	144	1.46	39	2.34
2001	141	1.45	36	2.37
2002	184	1.65	50	2.48
2003	209	1.66	50	2.48
Total	157	1.46	38	2.36

Findings on cost changes over time

Despite the 4.9% per annual increase in real project construction costs, there was no general trend in average cost per project over the first five years because of falling proportions of projects constructed in high-cost months and in rural areas for which costs are higher.

The cost per project is significantly higher for the last two years because of the rising general trend, a sudden increase in work undertaken in high-cost months for 2003, a higher proportion of projects in high-cost jurisdictions in the sample, and greater numbers of treatments per project.

Under-reporting adjustment

Three pieces of evidence point to significant under-reporting of non-NBSP contributions to project costs in the BITRE data. These are:

- ANAO (2007)
- the apparent relationship between the level of detail in the cost data provided by each jurisdiction to BITRE and the proportion of projects with known non-NBSP contributions (table 8.4), and
- the positive relationship between the proportion of projects with known non-NBPS contributions and the coefficients for costs between jurisdictions (figure 8.1).

To the extent that project costs are under-estimated, the CBA will over-estimate the net value of the program. To remove the bias, costs have been adjusted for likely under-reporting of non-NBSP contributions.

Costs for the ACT and Queensland were not adjusted. The ACT has no local government and the data provided on the 13 projects in the database is comprehensive about non-NBSP contributions. The Queensland Department of Main Roads provided good data on non-NBSP contributions. For Queensland, the ratio of projects with known non-NBSP contributions to all projects was 45% (see table 8.4), close to the 50% ratio in ANAO's sample.

For the other jurisdictions, adjustments were made assuming that:

- 50% of all projects for the jurisdiction (including those with known non-NBSP contributions) have non-NBSP contributions, based on ANAO's finding and the proportion for Queensland in table 8.4, and
- for the projects having their costs adjusted upwards, the proportion of NBSP funding is 70% (about midway between the 67% for the BITRE data and 74% for the ANAO sample).

Figure 8.2 explains the under-reporting adjustment formula. The total number of projects for a jurisdiction is first partitioned into two groups.

N_x projects known to have extra costs contributed by a non-NBSP source, total cost C_x, and

N_o projects with no known extra costs but which might have them, total known cost .

The N_o projects without known extra costs are further partitioned into two groups using the assumption of 50% of all projects with and 50% of all projects without extra costs:

$(N_o + N_x)/2$ projects (half of all projects) assumed to have no extra costs, and

$(N_o + N_x)/2 - N_x = (N_o - N_x)/2$ projects assumed to have extra costs.

It is not known which of the N_o projects without known extra costs actually have them, so the average cost of these projects (C_o/N_o) was used to estimate the total costs of each group.

The last group of $(N_o - N_x)/2$ projects has its costs adjusted upward by a factor of 100/70. Adding the adjusted cost of the last group to the unadjusted costs of the previous two other groups ($(N_o + N_x)/2$ and N_x projects) leads to the formula for adjusted total costs

$$\left(\frac{C_o}{14}\right)\left[17 - 3\left(\frac{N_x}{N_o}\right)\right] + C_x \, .$$

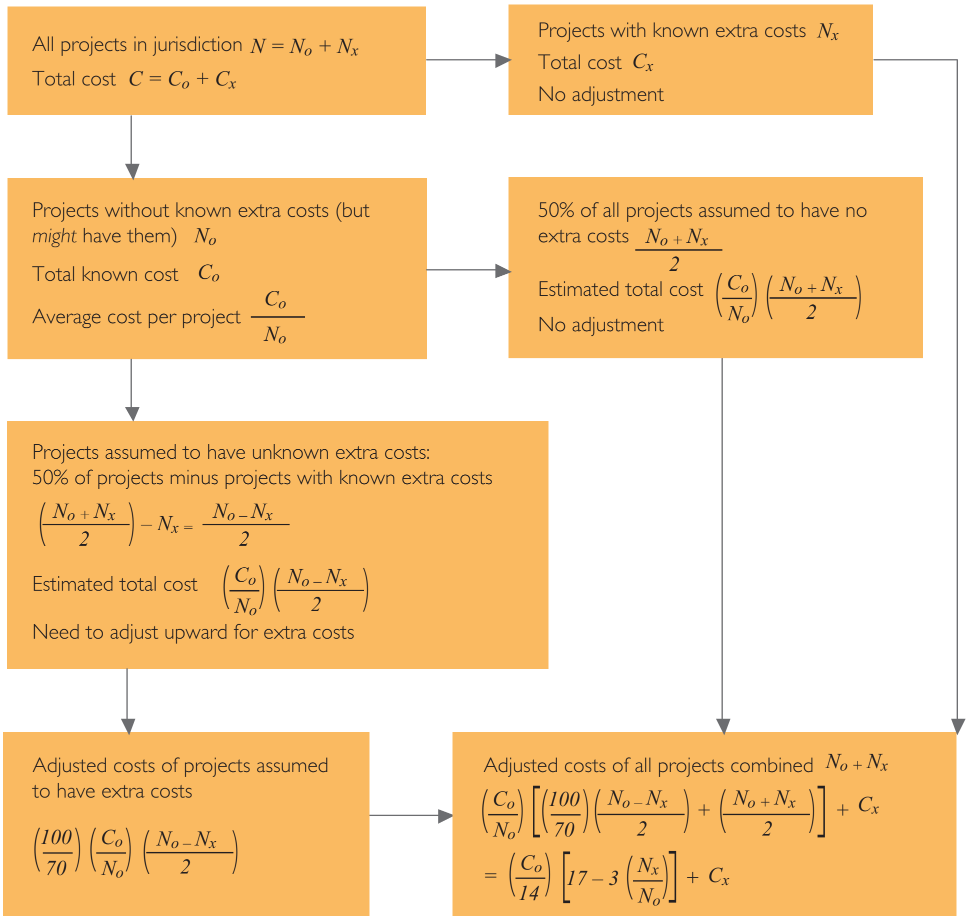
Note that the closer N_x comes to N_o, the smaller the adjustment. If 50% of projects were known to have extra funds ($N_x = N_o$), then no adjustment would be made. The maximum possible adjustment is to increase costs by a factor of 17/14 ≈ 1.2143, which would occur if no projects at all were known to have extra funds ($N_x = C_x = 0$).

The adjustment formula was applied to each jurisdiction's total project costs in the last row of table 8.2, except for ACT and Queensland. The process is shown in tables 8.8 and 8.9. The jurisdictions with the smallest proportions of projects with known extra costs, Victoria, South Australia, Western Australia, and Tasmania have the largest adjustment factors. These are also the four 'low-cost' jurisdictions as defined previously based on the regression coefficients.

The jurisdiction adjustment factors in table 8.8 were applied to the costs of projects without known extra costs (C_o) for all years. Then the costs of the projects with known extra costs (C_x) were added back in. The results are shown in table 8.10 for total costs and table 8.11 for costs per project for each jurisdiction and year.

Table 8.12 shows the percentage change in costs for each project for each year as a result of the adjustment process. After adding back the unadjusted costs for ACT and Queensland, total costs for all projects in the database are increased by 10.3%. The effect on the BCR estimated for the program as a whole is to multiply it by a factor of 0.9.

F8.2 Derivation of under-reporting adjustment formula



T8.8 Adjustment factors

Jurisdiction	N_x	N_o	$N_x/(N_o+N_x)$%	N_x/N_o	Adjustment factor[a]
ACT	3	10	23.1	0.300	1.000
NSW	124	229	35.1	0.541	1.098
NT	5	21	19.2	0.238	1.163
Qld	105	128	45.1	0.820	1.000
SA	6	97	5.8	0.062	1.201
Tas	3	38	7.3	0.079	1.197
Vic	25	488	4.9	0.051	1.203
WA	21	297	6.6	0.071	1.199
Total[b]	292	1308	18.3	0.223	1.166

a. For ACT and Queensland, the adjustment factor is one. For all other jurisdictions, the adjustment factor is $[17 - 3(N_x / N_o)]/14$

b. Total row shown only for completeness. The total adjustment factor was not used. See note to table 8.9

T8.9 Cost adjustment

($ millions)

Jurisdiction	C_o	Adjusted C_o	C_x	$C_x + C_o$	C_x + Adjusted C_o	% Change
ACT	1.6	1.6	2.3	4.0	4.0	0.0
NSW	34.8	38.2	33.4	68.2	71.6	5.0
NT	2.7	3.1	1.3	4.0	4.5	11.0
Qld	18.7	18.7	34.3	53.1	53.1	0.0
SA	15.8	19.0	0.9	16.8	19.9	19.0
Tas	3.5	4.2	2.3	5.9	6.6	11.8
Vic	62.2	74.8	6.1	68.2	80.9	18.5
WA	27.7	33.2	3.3	30.9	36.5	17.8
Total[a]	167.1	193.0	84.0	251.1	277.0	10.3

a. Total adjusted C_o obtained by summing values for jurisdictions, not applying the total adjustment factor shown in table 8.8.

T8.10 Costs adjusted for under-reporting of non-NBSP contributions

($millions in 2007 prices)

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	na	9.4	1.4	3.1	3.6	0.8	10.0	5.5	33.8
1998	0.3	10.6	0.3	7.6	3.4	0.9	10.8	5.1	39.0
1999	0.9	7.6	0.4	9.7	2.5	2.5	12.5	3.6	39.7
2000	0.8	6.2	1.1	8.1	3.7	0.8	14.7	6.1	41.5
2001	na	11.2	0.7	8.8	5.2	1.5	9.2	6.7	43.3
2002	0.5	13.4	0.0	6.4	0.2	0.0	9.8	3.6	33.8
2003	1.5	13.3	0.6	9.5	1.3	0.0	13.9	5.9	46.0
Total	4.0	71.6	4.5	53.1	19.9	6.6	80.9	36.5	277.0

T8.11 Cost per project after under-reporting adjustment

($'000 in 2007 prices)

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	na	208	241	183	202	89	141	274	182
1998	107	170	98	200	287	93	108	89	137
1999	904	271	94	214	148	191	176	84	179
2000	153	201	183	270	192	165	146	102	161
2001	na	150	220	201	216	494	151	95	154
2002	228	220	na	276	56	41	188	137	200
2003	756	260	146	263	144	na	244	145	230
Total	305	203	171	228	194	160	158	115	173

T8.12 Percentage adjustment to project costs for under-reporting of non-NBSP contributions[a]

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	na	6.9	8.9	0.0	20.1	19.7	20.3	16.1	13.1
1998	0.0	5.2	16.3	0.0	20.1	19.7	16.6	17.6	10.1
1999	0.0	3.1	5.1	0.0	18.1	11.8	16.5	16.7	8.7
2000	0.0	4.7	16.3	0.0	20.1	19.7	19.5	19.5	12.4
2001	na	4.7	16.3	0.0	17.6	0.3	17.4	17.6	9.5
2002	0.0	5.0	na	0.0	20.1	19.7	18.6	17.3	8.8
2003	0.0	5.1	3.0	0.0	16.6	na	20.3	19.1	9.9
Total	0.0	5.0	11.0	0.0	19.0	11.8	18.5	17.8	10.3

a. Percentages by which values of table 8.10 exceed values in table 8.2.

End note

A range of evidence supports the contention that there is serious under-reporting of contributions to project costs from non-NBSP sources with the amount of under-reporting varying between jurisdictions. For the CBA, it is important to have the full costs of the projects. Upward adjustments have been made to project costs to offset under-reporting. Although imprecise, they should reduce potential bias in the CBA results from missing costs.

The detailed examination of the cost data, in addition to providing evidence of missing costs, has led to some interesting observations.

Project costs have been rising over time faster than the rate of inflation and road construction costs in general. Work undertaken at the start of a new financial year costs more than at other times of the year. Instances of synergies and diminishing returns in construction costs were found between some treatment type pairs. There are trends towards a greater proportion of multiple treatment projects, and more treatments in each multiple-treatment project.

CHAPTER 9
Cost–benefit analysis

Summary

Assumptions

The program-wide cost–benefit analysis (CBA) was undertaken at discount rates of 3%, 4%, 5% and 7%. Headline results are reported for the ends of the range, 3% and 7%.

The unit crash costs used to estimate safety benefits are the standard values recommended by Austroads for project appraisal derived using the human capital approach. It is usual for CBAs of black spot projects to count only benefits of savings in casualty crashes.

Assumed project lives range from five years for T07 line marking and T02.3 painted medians, to 30 years for realignments of T15 road lengths and T16 intersections. Multiple-treatment projects are assumed to last for the duration of the longest-lived project component. In such cases, replacement costs were estimated for component treatments that reach the ends of their lives before the life of the whole project.

Annual operating and maintenance costs were assumed to be 3% of construction costs for T03 new signals and T06 lighting treatments, and 1% for T04 modifying existing signals, treatments involving new pavements and T14 barriers/guardrails.

Results

- The program has performed well overall — a benefit–cost ratio (BCR) of 7.7 with a 3% discount rate and 4.7 with a 7% discount rate — hereafter written as 7.7 (4.7).
- Urban projects have higher BCRs 9.9 (6.1) than rural projects 6.1 (3.7).
- Average benefits per project ($1.6 million ($0.9 million)) are comprised of 24%, 63%, and 13% savings in fatal, serious and minor injury crashes respectively.
- Average costs per project ($0.2 million) are comprised of 81% (86%) construction costs and the remainder, replacement and maintenance costs.
- Subtracting costs from benefits, the average net present value per project was $1.4 million ($0.7 million).

- BCRs for six of the eight jurisdictions are bunched in a range of 6.4 (3.9) for Queensland to 8.5 (5.2) for Victoria. The two smallest jurisdictions had outlying results — the ACT 13.0 (7.9) and Northern Territory –0.2 (–0.1), but due to small sample sizes, it is uncertain whether they are representative.
- Grouping projects by year of completion, BCRs range from 9.5 (5.7) in 1997 to 5.4 (3.4) in 2002. Over time, BCRs show no general trend.
- Single-treatment projects have a BCR of 9.1 (5.4). Each additional project reduces the BCR indicating diminishing returns from multiple-treatment projects down to a BCR of 4.8 (3.1) for projects comprised of four or more treatments. This indicates successful combining of treatments.
- The best performing treatment types are T20 priority signs and T22 alter traffic flow direction with BCRs above 20 (15).
- Other high-performing treatment types are T17 clear obstacles, T18 warning signs, T01 roundabout, and T04 modify signals with BCRs of around 14 (9).
- The worst performing treatment types are T12 alter width, T16 realign intersection, T14 barriers/guardrails, T11 non-skid treatments and T06 lighting treatments with BCRs of 3 (2) and below.
- Three sensitivity tests were carried out.
    - Adding benefits of PDO crashes avoided increases benefits by 8.5% (13% urban and 5% rural) regardless of discount rate. The increase could be as high as 30% if estimated unreported PDO crashes were included.
    - Limiting project lives to 15 years reduces BCRs by 19% (13%).
    - Assuming constant forecast crash rates reduces BCRs by 3.1% (2.5%).

What cost–benefit analysis does

CBA 'aims to identify and express, in monetary terms, all the gains and losses (benefits and costs) created by an initiative to all members of society, and to combine the gains and losses into a single measure'. If total benefits exceed total costs, then the project can be regarded as an economically efficient use of resources and society, as a whole, can be said to be better off (ATC 2006a p. 52).

A CBA is always a comparison between a base case, without the project, and a project case, with the project. (ATC 2006a, p. 49). It is not a comparison between the before and after situations, but rather, between two alternative states of the world. Normally, a CBA is intended to inform a decision about whether or not to proceed with a project — looking ahead into the future. The present evaluation is an ex-post CBA — looking back at decisions that have already been implemented.

Discount rates

The previous BITRE evaluation, BTE (2001), provided results calculated using discount rates of 3%, 5%, 7% and 8%. Headline results were reported at the 5% rate.

The traditional rate used for road projects is 7%. BITRE recommends use of the long-term bond rate, which is has been around 3% in real terms in recent years. For national projects funded under the Australian Government's Nation Building program the specified discount rate is 4.4% (DIT 2009b, p. 32). The Notes on Administration for the Black Spot Program specifies 7% as the discount rate to use when calculating BCRs, but allows jurisdictions to employ a different rate where they use an alternative rate to assess proposals for state government funding (DIT 2009a, p. 9).

It is a simple matter to derive CBA results using different discount rates. This report provides results using the 3%, 4%, 5% and 7% rates. Only results with discount rates of 3% and 7% are provided in the main part of this chapter, showing the upper and lower boundaries of the results. Tables of results calculated at 4% and 5% discount rates are presented at the end of the chapter.

Benefits and costs of Black Spot Projects

Savings in crash costs

For black spot projects, the primary benefits are savings in crash costs.

Numbers of crashes that would have occurred in the absence of black spot projects have to be forecast (base case). Numbers of crashes that have occurred between the time of completion of each project and the end of observations at each site are known, but crashes thereafter and into the future need to be forecast (project case). Since actual numbers of crashes at individual sites are subject to randomness, the numbers of crashes avoided due to black spot treatments have been estimated entirely from the regression equations.

Numbers of crashes avoided per period of time need to be multiplied by unit costs to obtain benefits in monetary terms.

Austroads publishes recommended sets of unit costs for use in CBAs of road projects. The most recently published set of unit costs for crashes applies as at 30 June 2007 (Austroads 2008, p. 21). These crash costs were originally derived from estimates of total crash costs for Australia in BTE (2000) obtained using the 'human capital approach' with inclusion of costs of loss of quality of life derived from compensation awards, and the imputed value of unpaid labour lost to households and the community. Appendix B contains a brief discussion of the human capital approach to crash costing and of the alternative 'willingness-to-pay' approach.

Table 9.1 sets out the unit crash costs assumed for the study.

The Austroads unit crash costs were derived using a 7% discount rate (Austroads 2003, p. 6). The crash costs for the 7% discount rate table 9.1 come directly from Austroads (2008). The original BITRE crash cost estimates from which the Austroads values were derived were published for both 4% and 7% rates.

The total cost of crashes (in 1996 dollars) for all Australia for the year 1996 estimated by BTE (2000), was $14 980m using a 4% discount rate and $13 159m at a 7% discount rate. The discount rate makes a difference to some major components of the estimated costs of crashes under the BITRE's human capital approach. The components affected are loss of future earnings, costs of long-term care, and loss of quality of life.

Other major components of the cost of crashes are not discounted at all, such as costs of repairs to vehicles, travel delays and administration. The impact of a change in the discount rate on total crash costs is therefore, not large — a 14% increase in total crash costs from a reduction in the discount rate from 7% to 4%. Nevertheless, to ensure consistency, BITRE estimated adjustment factors for the Austroads crash costs to allow for changes in discount rates. The adjustment factors were obtained by interpolating for 5% and extrapolating for 3% the components of total crash costs that change with discount rates in BTE (2000, p.83).

The Austroads crash costs differ between urban and non-urban areas. Urban crash costs were used for estimating benefits for sites classified as urban in the NBSP database and non-urban crash costs for sites classified as rural.

T9.1 Unit crash cost assumptions

($'000)

	3%	4%	5%	7%	3%	4%	5%	7%
		Fatal urban				Fatal rural		
NSW	2 075	1 966	1 873	1 727	2 716	2 573	2 451	2 260
NT	2 324	2 202	2 098	1 934	2 647	2 508	2 390	2 203
Qld	2 353	2 229	2 124	1 958	2 526	2 393	2 280	2 102
SA	2 337	2 214	2 110	1 945	2 831	2 682	2 556	2 356
Tas	2 072	1 963	1 870	1 724	2 589	2 453	2 338	2 155
Vic	2 318	2 196	2 092	1 929	2 558	2 424	2 309	2 129
WA	2 221	2 104	2 005	1 848	2 408	2 281	2 174	2 004
		Serious injury urban				Serious injury rural		
NT	572	542	516	476	705	668	637	587
Qld	566	536	511	471	603	571	545	502
SA	586	556	529	488	627	594	566	522
Tas	517	490	466	430	547	518	494	455
Vic	561	532	507	467	589	558	532	490
WA	586	556	529	488	636	602	574	529
		Minor injury urban				Minor injury rural		
NT	16	15	14	13	24	23	22	20
Qld	25	23	22	21	22	21	20	19
SA	23	22	21	19	23	22	21	19
Tas	24	23	22	20	23	22	21	19
Vic	25	23	22	21	25	24	22	21
WA	25	24	23	21	24	22	21	20
		Injury urban				Injury rural		
NSW	203	192	183	169	230	217	207	191
		PDO urban				PDO rural		
All	9.0	8.5	8.1	7.5	9.0	8.5	8.1	7.5

Note: Austroads does not publish any ACT unit crash costs. ACT unit costs were assumed to be identical to those for Victoria.

Project lives

Table 9.2 shows the assumed projects lives by treatment type.

The life assumptions were derived from information supplied by ARRB Group obtained in preparing Austroads (2010). ARRB Group undertook a literature review and a survey of asset managers in Australian road agencies. Austroads (2010) notes that lives of individual treatments will vary in specific situations depending on changes in traffic volumes, climate, and other conditions.

The life assumptions in table 9.2 are generally longer than is typical for road safety evaluations. CBA results can be quite sensitive to project life assumptions, especially at low discount rates. This will affect any comparisons made with CBA results obtained by other black spot evaluations. A sensitivity test was undertaken capping project lives at 15 years.

T9.2 Project life assumptions by treatment type

Code	Description	Life (years)
T01	Roundabout	25
T02.3	Medians painted	5
T02 other	Medians raised	20
T03	New signals	15
T04	Modify existing signals/change phase	15
T05	Traffic calming measures	20
T06	Lighting treatments	20
T07	Turning lane	25
T08.1 to T08.4	Pedestrian treatments: painted	5
T08.5,T08.8,T08.11,T08.12	Pedestrian treatments: signals	15
T08.6,T08.7,T08.9	Pedestrian treatments: fences, barriers, footpaths	20
T09.1	Cycle lane (painted)	5
T09 other	Other cycling treatments	20
T10	Sealing/resealing	25
T11	Non-skid treatment	10
T12	Alter road width	25
T13	Overtaking lane/s	25
T14	Barriers/guardrails	20
T15	Realign road length	30
T16	Realign intersection	30
T17	Clear obstacles or hazards	20
T18	Warning signs	10
T19	Line marking	5
T20	Priority sign treatments	10
T21	Ban turns	10
T22	Alterations to direction of traffic flow	10
T24	Speed limits	10
T25	Parking	10
T26	Railway crossing modification	20
T28	Channelisation	5
T29	Other	case by case

Replacement costs for components of multiple-treatment projects

Determining project lives is problematic for multiple-treatment projects where the different treatments have different lives. Using the life of the shortest-lived treatment penalises the project by omitting the benefits from the longer-lived treatments following the assumed end of the project's life. Using the life of the longest-lived treatment overstates the net worth of the project because it omits the costs of replacing the short-lived treatments one or more times during the project's life.

A compromise solution was adopted whereby the project life is assumed to be that for the longest-lived treatment and replacement costs are incurred for the shorter-lived treatments. Replacement costs were estimated from the regression model in chapter 8.

For each multiple-treatment, the component treatments types were grouped by life years: 5, 10, 15, 20, 25 and 30. The standalone cost of the project was estimated from the regression equation for the project if it consisted only of the treatments in each life-year group.

The proportion born by each life-year group of treatment types to the sum of the standalone costs for all the groups was used to allocate the total construction cost to each group. The replacement cost for each life-year group of treatments was assumed to be incurred each time the group required replacement. The replacement cost for the longest-lived group of projects would not be incurred because the life of the entire project would be completed.

To illustrate this, several projects are comprised of T28 channelisation (presumed to be line painting) assumed to last for 5 years and modification of T04 traffic existing signals assumed to last for 15 years. The regression model estimates broadly similar costs for the each of the two treatments if carried out alone. So the construction cost of the project is split 50:50 between the two treatments. Half the project's cost is assumed to be reincurred at the end of year five and again at the end of year 10 to replace the line painting.

For another set of projects, there was roughly a 50:50 split in costs allocated to T04 modification of existing traffic signals with T07 turning lanes. The assumed lives are 15 and 25 years respectively. The cost of signal modification would be incurred again at the end of year 15, but the replacement traffic signal treatment will last for five years longer than the turning lane treatment. Where the project life is not an exact multiple of a component treatment, a residual value accrues as a negative cost at the end of the project's life.

For calculation purposes, the cost of replacing the signal modification in year 15 would be annuitised over 15 years into the future at the discount rate. The present value of the annual amounts for the ten years from year 15 to year 25 would be counted as a cost and the annual amounts for the remaining five years, from year 25 to 30, omitted.

A total of 495 projects had replacement costs, less than the total of 606 multiple treatment projects in the database because projects where all the treatments had the same lives did not require estimation of replacement costs.

Table 9.3 summarises the present values of replacement costs for the 495 projects as a proportion of project construction costs. For some projects, adding replacement costs more than doubled the present value of their costs at lower discount rates. These are projects that have a component treatment or treatments that needs to be replaced every five years over a 20 to 30 year life and the five-year replacement treatments represent a substantial proportion of the initial construction cost (up to 78%). For the entire database of projects, replacement costs add 8.5% to 13.0% to total adjusted construction costs, depending on the discount rate.

T9.3 Present value of replacement costs as a proportion of construction costs

Discount rate (%)	3	4	5	7
Maximum for a project	1.406	1.259	1.132	0.924
Average for 495 projects	0.391	0.354	0.320	0.265
Minimum for 495 projects	0.041	0.036	0.032	0.024
All 1599 projects	0.130	0.116	0.104	0.085

For the sensitivity test with project lives capped at 15 years, only 244 projects involve replacement costs. Replacement costs as present values add 4.6% to 6.0% to total construction costs, depending on the discount rate.

Maintenance costs

Maintenance costs were estimated on an annual basis, mostly as percentages of construction costs. The assumptions are set out in table 9.4. Although referred to as maintenance costs, they include operating costs in the case of traffic signals and street lights. Projects that did not include any of the treatments listed in the table were assumed to have no maintenance costs at all.

For multiple-treatment projects that feature one more or more of the treatments in table 9.4, the regression model for project construction costs in chapter 8 was employed to estimate the cost of the project if it consisted solely of the treatment(s) assumed to give rise to maintenance costs, that is, the standalone cost. In some cases, the standalone cost estimated from the regression equation exceeded the actual cost. The standalone costs used to estimate maintenance costs were capped at the actual costs.

If the project involved more than one maintenance treatment in either the signals or the pavement category in table 9.4, for example medians and turning lanes in the pavement category, the treatments were combined in estimating the standalone cost, and the percentage maintenance cost factor was applied only once.

T9.4 Annual maintenance cost assumptions

Broad category	Treatment type	% of construction cost
Signals	T03 New signals	3
Signals	T04 Modify existing signals	1
Signals	T08.5 Pedestrian treatments, signals	4
Lighting	T06 Lighting treatments	3
Pavement	T02 Medians	1
Pavement	T07 Turning lane	1
Pavement	T12 Alter road width	1
Pavement	T13 Overtaking lane/s	1
Other	T14 Barriers/guardrails	1
Other	T26 Railway crossing modification	$5000 per annum

The percentages in table 9.4 were derived from information supplied by Vicroads and the Queensland Department of Main Roads. They were estimated so that the average maintenance cost was approximately equal to a desired dollar amount, for example, $7000 per annum for new signals.

The reason for using percentages of construction costs rather than absolute dollar amounts was that that latter lead to disproportionately high or low annual maintenance costs compared with the construction costs for some projects. The construction cost is related to the size of the project, and maintenance costs are expected to behave similarly. An exception was made for the sole project in the database involving railway crossing modification.

A total of 856 of the 1599 projects in the database had maintenance costs totalling $2.0m per annum. The annual maintenance cost was charged for each project for each year of its life. When converted to a present values, maintenance costs added 7.3% to 10.2% to the total adjusted construction costs.

Cost–benefit analysis summary measures

Net present value and benefit–cost ratio

The main summary measures of CBA results are the net present value (NPV) and benefit–cost ratio (BCR).

The NPV of a project is the difference between the discounted stream of benefits and the discounted stream of costs.

$$NPV = \sum_{t=0}^{n} \frac{B_t - OC_t - IC_t}{(1+r)^t}$$

where

t is time in years

n is the number of years during which benefits and costs occur (project life)

r is the discount rate

B_t is benefits in year t

OC_t is infrastructure operating and maintenance costs in year t

IC_t is investment costs (planning, design, land acquisition, construction) in year t.

A positive NPV means that the project represents an improvement in economic efficiency compared with the base case.

The BCR is the present value of benefits divided by the present value of costs. Operating and maintenance costs can be treated either as a negative benefit in the numerator or a cost in the denominator.

$$BCR = \frac{PV(B-OC)}{PV(IC)} \quad \text{or} \quad BCR = \frac{PV(B)}{PV(IC+OC)} \quad \text{where} \quad PV(X) = \sum_{t=0}^{n} \frac{X_t}{(1+r)^t}$$

Regardless of which definition is used, a BCR greater than one implies a positive NPV. The BCR measure is used to rank projects where there is a budget constraint (ATC 2006a, p. 75). Because the BCR is independent of the scale of the project, it serves as a measure of the relative economic worth of a project.

ATC (2006b, pp. 84–88) shows that the BCR definition with operating and maintenance costs in the numerator is the correct definition where the aim is to prioritise projects to fund out a single budget. The reason is that only investment costs come from the budget being allocated — operating and maintenance costs come out of future budgets. The present study adopts the alternative definition, putting operating, maintenance and replacement costs in the denominator, in order to maintain a clear distinction between safety benefits and infrastructure costs.

The total NPV for the all projects in the evaluation database is not, by itself, a very useful result because the database represents an arbitrary proportion of projects in the entire program. The BCR, on the other hand, is independent of the number of projects. The combined BCR for all the projects in the database can be considered indicative of the BCR for the program as a whole. Other measures independent of the number of projects are benefits, costs and NPV *per project*. These are presented in the tables below instead of the totals for the database.

Definition of program BCR

The formula for the BCR for a single treatment is straightforward because there is an investment cost followed by a stream of net benefits over the life of the treatment. For an ongoing program considered as a whole, there is a stream of investment costs as projects are undertaken over time. Benefits build up over time as more and more projects are implemented. Once the treatments reach the end of their assumed lives, the benefits from the replacement infrastructure would not be counted because the replacement infrastructure is not part of the program. The annual benefits will therefore taper off in the future, eventually reaching zero.

In the present evaluation, an aggregate BCR is desired because the program as a whole is being evaluated.

One approach is to discount all benefits and costs to 1996 regardless of when the project was actually implemented. Another approach is to discount to the year of project implementation, and then to take the weighted average of the BCRs, using costs as the weights. The two methods produce the same result only if all individual projects have the same BCR. The first method, discounting all benefits and costs to a single year at the start of the program, gives greater weight to projects undertaken earlier.

The second method, the weighted average BCR, treats projects implemented at different times the same. The second method has been adopted because there is no reason to give earlier treatments a higher weighting in the calculation of the BCR for the overall program. If anything, the BCRs of later projects should be weighted more highly because they give a better indication of the levels of BCRs likely to be achieved in the future.

The weighted average BCR is

$$\frac{\sum\left\{BCR_i \times [PV(IC_i)+PV(OC_i)]\right\}}{\sum [PV(IC_i)+PV(OC_i)]}$$

where the subscript *i* refers to projects. Since

$$BCR_i = \frac{PV(B_i)}{PV(IC_i)+PV(OC_i)}$$

the weighted average BCR equals

$$\frac{\sum PV(B_i)}{\sum [PV(IC_i)+PV(OC_i)]}$$

the sum of benefits divided by the sum of costs for all projects in the evaluation, with benefits and costs for each project discounted to the project's implementation year.

Timing assumptions

All project investment costs are assumed to be incurred on the last day of the calendar year in which the project was completed. All benefits and maintenance costs are assumed to accrue on the last day of the calendar year in which they occur, commencing one year after project completion.

Results

Overall with urban/rural split

Table 9.5 summarises the overall results with the urban/rural split. The overall program BCR ranges from 4.7 to 7.7 depending on the discount rate, which is an excellent result.

More than half the benefits from crashes avoided come from the serious injury category with savings in fatal, serious injury and minor injury comprising respectively, 24%, 63% and 13% of benefits regardless of the discount rate.

The proportion of benefits from serious injury crashes is 63% for both urban and rural projects. The proportion of benefits from fatal crashes avoided is higher in rural areas and the proportion of benefits from minor injury crashes avoided is lower in rural areas compared with urban. This may reflect the higher speed environments in rural areas leading to more severe crashes.

The program-wide BCRs for urban projects are just over 60% higher than for rural projects regardless of discount rate. Benefits per project are only slightly larger for rural projects than urban projects, despite the finding in chapter 7 (see table 7.5) that numbers of crashes avoided per project in urban areas are higher. The reason is the higher unit costs of crashes in rural areas compared with urban areas (see table 9.1). However, the greater costs per project in rural areas are offsetting

T9.5 Overall results including benefits and costs per project

($'000 per project present values except for BCRs)

Discount rate	3%			7%		
	Urban	Rural	Total	Urban	Rural	Total
Benefits						
Fatal	345	452	395	200	253	224
Serious injury	1 016	1 065	1 033	596	606	598
Minor injury	244	156	208	142	89	121
Total benefits	1 605	1 673	1 636	938	949	943
Costs						
Construction	132	221	173	132	221	173
Maintenance	18	17	18	13	12	13
Replacement	13	34	23	8	22	15
Total costs	163	272	213	153	255	201
NPV	1 442	1 400	1 423	784	693	742
BCR	9.9	6.1	7.7	6.1	3.7	4.7

Notes: Benefits from NSW injury crashes have been included with the serious injury and minor injury benefits in such a way that the ratio of combined serious injury benefits to combined minor injury benefits per project for the other jurisdictions is unaltered.

Replacement costs occur only for component treatments of multiple-treatment projects having lives that expire before the longest-lived component treatment.

Year and jurisdiction

Table 9.6 shows BCRs by jurisdiction and year of project completion.

There is great variability in individual cells due in part to small numbers of projects in some cells. Project numbers in each cell were reported in table 8.1 in the previous chapter. For all years taken together, the ACT and the NT are outliers and the other jurisdictions are bunched in a range from 6.4 for Queensland to 8.5 for Victoria at the 3% discount rate and 3.9 to 5.2 at the 7% discount rate. The two outlying jurisdictions have the smallest sample sizes — 13 projects for ACT and 26 for NT.

For all projects together, the last two years have distinctly lower BCRs. Table 9.7 shows that the reason is higher costs per project in the last two years. In chapter 8, it was suggested that the principle cause is higher numbers of treatments per project in those years. The impact of multiple-treatments on BCRs is explored in the next section.

T9.6 Benefit–cost ratios by jurisdiction and year of project completion

3% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	na	9.7	3.5	6.2	10.0	19.0	10.8	8.3	9.5
1998	12.2	11.4	-11.3	8.6	4.5	9.9	9.2	6.8	8.6
1999	16.7	5.0	7.1	6.1	9.4	10.2	8.6	4.6	7.2
2000	22.8	6.3	-3.4	6.1	9.7	1.9	12.3	7.9	8.8
2001	na	10.1	5.2	7.3	2.8	3.6	7.5	10.0	7.7
2002	10.6	4.7	na	5.0	7.8	5.9	4.9	8.7	5.4
2003	5.4	7.3	-4.8	5.3	33.1	na	5.9	6.9	6.8
Total	13.0	7.7	-0.2	6.4	8.2	8.1	8.5	7.8	7.7

7% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	na	5.7	2.2	3.8	6.2	11.6	6.5	4.7	5.7
1998	7.0	6.8	-7.7	5.2	2.6	6.2	5.9	4.2	5.3
1999	9.0	3.1	4.1	3.7	5.5	6.5	5.3	2.8	4.4
2000	15.5	3.9	-2.1	3.7	5.8	1.3	7.4	4.8	5.4
2001	na	6.1	3.4	4.5	1.7	2.3	4.6	6.1	4.7
2002	6.8	3.0	na	3.1	4.8	4.1	3.1	5.5	3.4
2003	3.1	4.3	-2.6	3.5	20.6	na	3.6	4.3	4.2
Total	7.9	4.7	-0.1	3.9	5.1	5.2	5.2	4.7	4.7

T9.7 Benefit–cost ratios by year of project completion including benefits and costs per project

($'000 per project except for BCRs)

	3% discount rate				7% discount rate			
	Benefits	Costs	NPV	BCR	Benefits	Costs	NPV	BCR
1997	1 964	207	1 757	9.5	1 131	200	932	5.7
1998	1 424	165	1 260	8.6	828	156	672	5.3
1999	1 619	225	1 394	7.2	923	209	713	4.4
2000	1 749	199	1 550	8.8	1 002	187	815	5.4
2001	1 446	189	1 257	7.7	835	177	658	4.7
2002	1 401	262	1 139	5.4	817	242	574	3.4
2003	1 972	289	1 683	6.8	1 134	269	865	4.2
Total	1 636	213	1 423	7.7	943	201	742	4.7

Table 9.8 shows benefits and costs per project by jurisdiction. There is considerable variation across jurisdictions. A number of factors contribute to differences between jurisdictions including small sample sizes for smaller jurisdictions, the crash rates at individual sites, the mix of treatment types, the urban/rural and local/state road splits, and cost levels.

The NT has negative benefits per project for serious injury crashes and relatively low benefits for fatal and minor injury crashes. As discussed in chapter 7 in relation to the low and negative predicted numbers of crashes avoided in the NT, the results reflect the crash data from the NT sites in the database, but due to the small number of NT sites, we cannot be confident that the results are representative of NT sites in general.

T9.8 Benefits and costs per project by jurisdiction

($'000 per project)

3% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1 712	413	15	271	460	965	467	230
Serious injury	2 525	na	-164	1 307	1 185	802	1 000	688
Minor injury	491	na	97	202	241	112	194	192
Injury	na	1 474	na	na	na	na	na	na
Benefits	4 728	1 887	-52	1 780	1 886	1 879	1 661	1 110
Costs	363	246	231	280	229	233	195	143
NPV	4 365	1 641	-283	1 500	1 657	1 646	1 465	968
BCR	13.0	7.7	-0.2	6.4	8.2	8.1	8.5	7.8

7% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1 054	232	15	152	266	554	264	132
Serious injury	1 432	na	-88	763	691	466	580	393
Minor injury	288	na	57	117	143	66	113	110
Injury	na	851	na	na	na	na	na	na
Total benefits	2 774	1 083	-16	1 031	1 100	1 086	956	634
Costs	349	232	214	263	217	210	183	134
NPV	2 425	851	-230	768	883	877	773	500
BCR	7.9	4.7	-0.1	3.9	5.1	5.2	5.2	4.7

Multiple treatment projects

Table 9.9 shows the CBA results by numbers of treatments in projects.

Projects with four, five and six treatments were grouped together because there are only four projects with five or six treatments. Adding additional treatments to projects increases both benefits and costs but at decreasing rates. The costs rise faster than the benefits causing the BCR to fall. However, it is still worthwhile to add treatments as long as the NPV rises. Table 9.9 suggests that state, territory and local governments have been very successful at designing and implementing multiple treatment projects.

T9.9 Benefit–cost ratios for numbers of treatments in projects including benefits and costs per project

($'000 per project except for BCRs)

Number of treatments	3% discount rate				7% discount rate			
	Benefits	Costs	NPV	BCR	Benefits	Costs	NPV	BCR
1	1 587	174	1 413	9.1	923	171	753	5.4
2	1 638	254	1 384	6.4	937	232	705	4.0
3	1 747	285	1 462	6.1	982	250	732	3.9
4, 5 & 6	2 508	522	1 987	4.8	1390	452	938	3.1
Total	1 636	213	1 423	7.7	943	201	742	4.7

Treatment types with urban/rural split

Table 9.10 shows the results by treatment type including the urban and rural breakdown.

The top BCRs in the cells are projects classified by primary treatment type and thus include multiple-treatment projects. The bottom, bracketed BCRs are for single-treatment projects only, excluding multiple-treatment projects. BCRs based on less than 10 projects are starred because they are most susceptible to influence by outliers.

Urban BCRs are generally higher than for rural BCRs for the same treatment type but for some of the extreme cases, there are only small numbers of projects. T01 roundabouts has a much higher urban BCR compared with the rural BCR and, since there is a large number of roundabout projects in the data (152 urban and 151 rural with roundabouts as primary treatments), the result has a high level of confidence.

BCRs for all projects grouped by primary treatment are generally lower than for single treatment projects, which would be expected given the diminishing returns from adding treatments to projects.

T9.10 Benefit–cost ratios for treatment types

Treatment type	3% discount rate			7% discount rate		
	Urban	Rural	All	Urban	Rural	All
T01 Rndabout	19.3 (17.6)	10.3 (10.6)	13.6 (13.3)	10.7 (9.7)	5.8 (5.9)	7.6 (7.4)
T02 Medians	5.4 (2.8)	4.7 (7.3)	5.1 (3.8)	3.4 (1.7)	3.1 (4.5)	3.3 (2.3)
T03 New sigs	7.7 (7.2)	4.7 (5.8)	6.8 (6.7)	5.1 (4.9)	3.2 (3.9)	4.6 (4.5)
T04 Mod sigs	13.9 (17.0)	8.9 (12.9)	13.2 (16.5)	9.0 (11.0)	5.8 (8.4)	8.6 (10.7)
T05 Traf calm	23.7* (29.2)*	3.9* (2.0)*	6.9 (8.3)	14.7* (17.4)*	2.5* (1.2)*	4.4 (4.9)
T06 Lighting	-15.2 (-34.0)*	2.2 (-1.5)	-2.0 (-8.2)	-10.2 (-22.1)*	1.4 (-1.0)	-1.3 (-5.3)
T07 Turn lane	9.4 (12.4)	4.2 (5.1)	6.1 (8.2)	5.7 (7.2)	2.6 (3.0)	3.7 (4.8)
T08 Ped trmts	7.0 (5.6)	2.3 (3.6)*	4.1 (4.7)	4.8 (3.9)	1.6 (2.5)*	2.9 (3.3)
T10 Sealing	8.3 (13.0)	6.6 (7.8)	6.9 (9.2)	4.9 (7.2)	3.9 (4.3)	4.1 (5.1)
T11 Non-skid	-2.4 (-3.7)	0.2 (-0.1)	-1.3 (-1.9)	-1.6 (-2.5)	0.1 (0.0)	-0.9 (-1.3)
T12 Alt width	2.2 (0.0)*	3.8 (2.3)*	3.2 (1.4)*	1.4 (0.0)*	2.3 (1.4)*	2.0 (0.8)*
T14 Barriers	0.3 (-2.1)	4.0 (3.9)	2.6 (1.3)	0.1 (-1.3)	2.5 (2.4)	1.6 (0.8)
T15 Realign len	12.3* (na)*	4.2 (1.5)	4.7 (1.5)	7.4* (na)*	2.4 (0.8)	2.6 (0.8)
T16 Realign int	-1.6 (-1.6)	4.3 (10.3)	2.7 (4.7)	-0.8 (-0.8)	2.6 (5.4)	1.6 (2.5)
T17 Clear obs	21.3 (18.0)*	9.6 (11.4)*	14.5 (15.3)	12.7 (10.7)*	6.0 (6.8)*	8.9 (9.1)
T18 Wrn sgns	9.8* (30.1)*	14.6 (14.6)*	13.7 (16.8)*	7.0* (20.9)*	9.6 (10.0)*	9.1 (11.6)*
T19 Lines	10.7 (17.9)*	8.7 (11.1)	9.3 (12.3)	7.8 (13.4)*	6.6 (8.3)	7.0 (9.1)
T20 Prty sgns	21.3 (0.3)*	24.5 (38.2)*	23.6 (25.8)*	14.2 (0.2)*	15.9 (26.2)*	15.4 (17.8)*
T22 Alt dir	30.3 (13.9)*	13.1 (10.3)*	22.2 (11.9)	20.7 (9.4)*	8.7 (7.1)*	15.0 (8.1)
Unspecified	-0.1 (0.9)*	-0.3 (0.7)	-0.2 (0.8)	-0.1 (0.5)*	0.1 (0.5)	0.0 (0.5)
Total	9.9 (10.8)	6.1 (7.6)	7.7 (9.1)	6.1 (6.5)	3.7 (4.4)	4.7 (5.4)

Notes: The first BCR in each cell is for projects classified by primary treatment, including multiple-treatment projects. The second, bracketed BCR is for single-treatment projects only.

* = BCR based on less than 10 projects.

Table 9.11 provides some analysis of the BCR results in table 9.10. BCRs for all projects have been sorted into descending order and compared with the weighted average effectiveness for casualty crashes (average of day and night where different). Also shown are indicators of relative treatment costs. The regression coefficient is expressed as a percentage from table 8.6.

T9.11 Benefit–cost ratios for treatment types compared with effectivenesses and cost indicators

Treatment	Effectiveness	Cost indicator	BCR 3%, all projects	BCR 3% single treatment projects	BCR 7% all projects	BCR 7% single treatment projects
T20 Prty sgns	-20	-62	23.6	25.8	15.4	17.8
T22 Alt dir	-58	16	22.2	11.9	15.0	8.1
T17 Clear obs	-42	20	14.5	15.3	8.9	9.1
T18 Wrn sgns	-32	-53	13.7	16.8	9.1	11.6
T01 Rndabout	-71	212	13.6	13.3	7.6	7.4
T04 Mod sigs	-36	-3	13.2	16.5	8.6	10.7
T19 Lines	-24	-32	9.3	12.3	7.0	9.1
T10 Sealing	-17	257	6.9	9.2	4.1	5.1
T05 Traf calm	-34	20	6.9	8.3	4.4	4.9
T03 New sigs	-43	245	6.8	6.7	4.6	4.5
T07 Turn lane	-26	34	6.1	8.2	3.7	4.8
T02 Medians	-43	-1	5.1	3.8	3.3	2.3
T15 Realign len	-41	224	4.7	1.5	2.6	0.8
T08 Ped trmts	-25	35	4.1	4.7	2.9	3.3
T12 Alt width	-40	97	3.2	1.4	2.0	0.8
T16 Realign int	-40	97	2.7	4.7	1.6	2.5
T14 Barriers	-28	76	2.6	1.3	1.6	0.8
Unspecified	-19	31	-0.2	0.8	0.0	0.5
T11 Non-skid	-23	39	-1.3	-1.9	-0.9	-1.3
T06 Lights	-24	17	-2.0	-8.2	-1.3	-5.3

The table illustrates how effectiveness and costs interact to influence BCRs.

T20 priority signs, T18 warning signs and T19 lines have high BCRs because they have relatively low costs. T22 alter traffic flow direction, T17 clear obstacles or hazards, T01 roundabouts have high BCRs because of relatively high effectiveness. T12 alter width, T15 realign length and T16 realign intersection are highly effective but their high costs lead to BCRs towards the low end of the range.

Unspecified, T11 non-skid treatments and T06 lighting treatments have negative BCRs being at the low end of the effectiveness range while having medium-level costs.

T10 sealing/resealing has medium-level BCRs despite the lowest effectiveness and the highest cost ranked by the measures in table 9.11. The reason is relatively high proportions of the more costly fatal and serious crashes avoided.

Sensitivity tests

Three sensitivity tests were undertaken: adding benefits from PDO crashes avoided, limiting project lives to 15 years, and assuming no change in forecast crashes over time.

Including PDO crashes

As data on PDO crashes are not available for Victoria, the impact on the CBA results of adding benefits from PDO crashes avoided has to be gauged by comparison with casualty crash results excluding Victoria, which table 9.12 does. If benefits from PDO crashes avoided are added to the CBA, total benefits and the BCR for the program as whole are increased by 8.5% to 8.6% depending on the discount rate. Even though PDO crashes are much more numerous than casualty crashes, their relatively low cost limits their impact on CBA results.

When urban and rural projects are separated, there is a marked difference — a 12.6% to 12.7% increase for urban and 4.6% for rural. The estimated number of PDO crashes avoided per project in urban areas is more than three times that for rural areas (see table 7.5). Greater traffic levels and hence exposure explains the higher estimated numbers of crashes avoided for urban projects in general. That the difference is more pronounced for PDO crashes can be explained by the lower speed environments in urban areas giving rise to less severe crashes.

As discussed in chapter 4, from data collected for BITRE (2009), it is estimated that for every reported PDO crash, there are a further 2.48 unreported PDO crashes.

The lower part of table 9.12 shows that effect of multiplying the benefits from PDO crashes avoided by 3.48 to adjust for unreported crashes. Only the totals are shown because the adjustment factor is for total crashes only and is likely to be different for urban and rural areas. Compared with the results for casualty crashes only, the BCR is increased from 3.7 to 4.7 at the 3% discount rate and from 2.2 to 2.9 at the 7% discount rate, an increase of almost 30%.

T9.12 Main results with PDO crash benefits added and excluding Victoria

($'000 per project except for BCRs and % increases)

	3% discount rate			7% discount rate		
	Urban	Rural	Total	Urban	Rural	Total
Casualty benefits	1 567	1 682	1 624	917	956	937
PDO benefits	198	77	137	117	44	80
Total benefits	1 764	1 759	1 762	1 034	999	1 017
Costs	165	279	444	157	261	418
NPV casualty	1 401	1 404	1 180	761	695	519
NPV with PDO	1 599	1 481	1 318	877	738	599
BCR casualty	9.5	6.0	3.7	5.9	3.7	2.2
BCR with PDO	10.7	6.3	4.0	6.6	3.8	2.4
% increase	12.6	4.6	8.5	12.7	4.6	8.6
Indicative adjustment for unreported PDO crashes[a]						
PDO benefits			478			279
Total benefits			2 102			1 216
NPV all			1 658			798
BCR all			4.7			2.9
% increase[b]			29.4			29.8

a. PDO benefits multiplied by 3.48. Urban and rural results are not shown because the adjustment factor is available only for all crashes, and is likely to be different for urban and rural crashes.

b. Percentage increase over the BCR for casualty crashes.

Table 9.13 shows the impact of adding PDO crashes to the CBA by jurisdiction. The percentage increases in benefits and BCRs vary greatly between jurisdictions probably due to the different reporting requirements for PDO crashes.

T9.13 Results by jurisdiction with PDO costs added

($'000 per project except for BCRs and % increases)

3% discount rate

Jurisdiction	ACT	NSW	NT	Qld	SA	Tas	WA
Casualty benefits	4 728	1 887	-52	1 780	1 886	1 879	1 110
PDO benefits	1 904	81	165	113	319	26	99
Total benefits	6 633	1 968	113	1 892	2 205	1 905	1 209
Costs	363	246	231	280	229	233	143
NPV casualty	4 365	1 641	-283	1 500	1 657	1 646	968
NPV with PDO	6 269	1 722	-118	1 612	1 976	1 672	1 067
BCR casualty	13.0	7.7	-0.2	6.4	8.2	8.1	7.8
BCR with PDO	18.3	8.0	0.5	6.8	9.6	8.2	8.5
% increase	40.3	4.3	na	6.3	16.9	1.4	8.9

7% discount rate

Jurisdiction	ACT	NSW	NT	Qld	SA	Tas	WA
Casualty benefits	2 774	1 083	-16	1 031	1 100	1 086	634
PDO benefits	1 116	47	97	66	188	15	57
Total benefits	3 890	1 131	80	1 097	1 288	1 102	691
Costs	349	232	214	263	217	210	134
NPV casualty	2 425	851	-230	768	883	877	500
NPV with PDO	3 541	899	-134	834	1 071	892	557
BCR casualty	7.9	4.7	-0.1	3.9	5.1	5.2	4.7
BCR with PDO	11.1	4.9	0.4	4.2	5.9	5.3	5.2
% increase	40.2	4.4	na	6.4	17.1	1.4	9.0

Table 9.14 shows the percentage increases in benefits and BCRs from adding PDO crashes by treatment type.

The first number in each cell refers to projects grouped by primary treatments and the second (bracketed) for single-treatment projects only. The results are presented only at the 5% discount rate because, as the previous two tables show, the changes to the discount rate have little effect on the percentage increases.

As the impact of adding PDO crashes varies greatly between jurisdictions, the values are influenced by the jurisdictional splits of projects in each cell. Values in cells with small numbers of projects are particularly susceptible to influence from the particular jurisdictions of the projects.

Benefits from T02 medians in both urban and rural areas and T07 turning lanes and T14 barriers in urban areas are considerably increased when benefits from PDO crashes are added in. For roundabouts in urban areas, the increase in benefits is below the average across all treatments probably because they reduce the severity of crashes converting some casualty crashes into PDO crashes.

T9.14 Percentage increase in benefits from adding PDO crashes at 5% discount rate, excluding Victoria

	Urban	Rural	All
T01 Rndabout	4.6 (4.3)	5.2 (5.0)	4.9 (4.7)
T02 Medians	36.0 (56.1)	11.7 (16.4)	27.1 (42.4)
T03 New sigs	11.8 (12.9)	4.6 (4.1)	10.0 (10.2)
T04 Mod sigs	10.8 (11.3)	-2.9 (4.3)	9.1 (10.6)
T05 Traf calm	5.0* (4.3)*	11.2* (49.1)*	7.7 (6.8)
T06 Lights	na (na)*	67.3 (na[1])	173.5 (na)
T07 Turn lane	27.8 (27.9)	0.1 (2.4)	14.9 (20.4)
T08 Ped trmts	11.7 (11.4)	2.1 (-0.1)*	7.2 (6.4)
T10 Sealing	-45.2 (-135.0)	3.0 (1.9)	2.3 (-1.2)
T11 Non-skid	na[2] (na)	na (na)	na (na)
T12 Alt width	8.2 (na)*	4.1 (1.3)*	4.6 (12.1)*
T14 Barriers	28.1 (na)	6.0 (2.6)	9.6 (14.7)
T15 Realign len	na* (na)*	4.4 (1.6)	4.4 (1.6)
T16 Realign int	na (na)	2.1 (1.3)	17.8 (6.0)
T17 Clear obs	11.9 (11.9)*	2.6 (2.1)*	4.2 (6.4)
T18 Wrn sgns	69.7* (na)*	4.1 (6.7)*	8.6 (3.6)*
T19 Lines	337.3 (22.8)*	1.2 (3.7)	47.9 (4.5)
T20 Prty sgns	-1.5 (160.5)*	2.6 (5.2)*	1.8 (5.8)*
T22 Alt dir	5.9 (7.7)*	4.1 (3.6)*	5.3 (5.7)
Unspecified	13.0 (11.5)*	na (30.6)	29.7 (18.5)
Total	12.7 (10.9)	4.6 (5.0)	8.5 (8.2)

Notes: The figures are percentage increases in benefits and BCRs (costs do not change) compared with table 9.10. The figures should not be confused with BCRs.

The first BCR in each cell is for projects classified by primary treatment, including multiple-treatment projects. The second, bracketed BCR is for single-treatment projects only.

* = based on less than 10 projects.

na = The benefits based on casualty crashes alone are negative. Instances where negative benefits changed to positive after adding PDO benefits are indicated.

1. BCR for T06 lighting treatments in rural areas changed from –5.6 to 0.7.

2. BCR for T11 non-skid treatment in urban areas changed from –0.5 to 0.4.

15 year maximum project lives

Table 9.15 presents the overall results with project lives restricted to a maximum of 15 years. The last line of the table shows the percentage increase in BCRs compared with the main results in table 9.5. As would be expected, shortening assumed project lives reduces BCRs, more so at the lower discount rate, from 7.7 to 6.2 or a 19% reduction at the 3% discount rate, compared with from 4.7 to 4.1 or a 13% reduction at the 7% discount rate.

T9.15 Overall results including benefits and costs per project: 15 year maximum project lives

($'000 per project present values except for BCRs and % increases)

Discount rate	3%			7%		
	Urban	Rural	Total	Urban	Rural	Total
Benefits						
Fatal	263	313	286	168	200	183
Serious injury	816	772	792	518	494	504
Minor injury	192	114	160	122	73	102
Total	1 271	1 199	1 238	809	767	789
Costs						
Construction	132	221	173	132	221	173
Maintenance	16	14	15	12	10	11
Replacement	5	16	10	4	13	8
Total	153	251	198	148	244	192
NPV	1 118	948	1 039	661	523	597
BCR	8.3	4.8	6.2	5.5	3.1	4.1
% increase[a]	-16	-22	-19	-11	-16	-13

a. Percentage increase in BCR compared with main results in table 9.5.

Constant crash rates over time

As discussed in chapter 7, in forecasting rates of crashes avoided over the lives of projects, rates were increased in line with forecast population in each jurisdiction less one percentage point per year to account for the general decreasing trend in crash numbers. To show the impact of the assumption on the CBA results, predicted rates for crashes avoided in the last year modelled for each jurisdiction, that is, the year just before the forecast rates commenced, were held constant over project lives.

The overall CBA results are set out in table 9.16 in a format comparable with table 9.5 for the main results. Present values of costs are unaffected by the change. Total benefits and BCRs are reduced by around 3%, slightly more in urban areas. Hence, the assumption of changing crash rates over time has little impact on the overall CBA results.

T9.16 Overall results including benefits and costs per project: constant forecast crash rates

($'000 per project present values except for BCRs and % increases)

Discount rate	3%			7%		
	Urban	Rural	Total	Urban	Rural	Total
Benefits						
Fatal	334	442	384	195	248	220
Serious injury	981	1033	1000	580	592	582
Minor injury	235	151	201	138	87	117
Total benefits	1550	1626	1585	912	928	919
Costs	163	272	213	153	255	201
NPV	1387	1354	1372	758	672	719
BCR	9.5	6.0	7.4	5.9	3.6	4.6
% increase[a]	-3.4	-2.8	-3.1	-2.8	-2.2	-2.5

a. Percentage increase in BCR compared with main results in table 9.5.

Since the population growth assumptions vary between jurisdictions, table 9.17 is presented in the same format as table 9.8 for the main results.

Some jurisdictions experience increases in benefits and some decreases. Queensland and WA have the highest forecast growth rates in total crashes and are therefore experience the largest percentage reductions in benefits, apart from the NT. The NT has the next highest forecast growth rate, but the percentage change in benefits is measured from a low base. SA and Tasmania have negative forecast growth rates in total crashes in nearly all years and therefore experience increases in benefits from assuming no change over time.

T9.17 Benefits and costs per project by jurisdiction: constant forecast crash rates

($'000 per project except for BCRs and % increases)

3% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1 695	411	17	245	465	984	454	215
Serious injury	485	na	93	184	244	114	189	179
Minor injury	2 495	na	-152	1 198	1 199	817	975	642
Injury	na	1 467	na	na	na	na	na	na
Benefits	4 675	1 877	-43	1 627	1 908	1 915	1 618	1 035
Costs	363	246	231	280	229	233	195	143
NPV	4 312	1 632	-274	1 347	1 680	1 682	1 423	893
BCR	12.9	7.6	-0.2	5.8	8.3	8.2	8.3	7.3
% increase[a]	-1.1	-0.5	-17.2	-8.6	1.2	1.9	-2.6	-6.7

7% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1 046	231	16	140	269	562	258	125
Serious injury	285	na	54	108	144	67	110	104
Minor injury	1 417	na	-83	709	699	473	568	372
Injury	na	848	na	na	na	na	na	na
Total benefits	2 748	1 079	-13	958	1 112	1 102	937	600
Costs	349	232	214	263	217	210	183	134
NPV	2 399	847	-227	694	895	893	754	466
BCR	7.9	4.7	-0.1	3.6	5.1	5.3	5.1	4.5
% increase[a]	-0.9	-0.4	-23.4	-7.1	1.1	1.5	-2.0	-5.4

a. Percentage increase in BCR compared with main results in table 9.8.

End note

The program has performed well overall achieving a BCR of 7.7 with a 3% discount rate and 4.7 with a 7% discount rate based on benefits from casualty crashes avoided.

BCRs remain well above one when the projects are split into urban and rural categories, by jurisdiction with the exception of the NT, by year of completion, and by numbers of treatments in projects. BCRs vary widely between treatment types, ranging from negative values to around 20. The three sensitivity tests had limited impacts on the overall BCRs demonstrating that the results are not greatly affected by the exclusion of PDO crashes or the assumptions about project lives and forecast changes in future crash rates in general.

Tables with 4% and 5% discount rates

T9.5a Overall results including benefits and costs per project

($'000 per project except for BCRs)

Discount rate	4%			5%		
	Urban	Rural	Total	Urban	Rural	Total
Benefits						
Fatal	296	385	337	257	331	291
Serious injury	876	910	887	763	787	770
Minor injury	210	133	179	182	115	155
Total benefits	1 382	1 428	1 403	1 203	1 233	1 217
Costs						
Construction	132	221	173	132	221	173
Maintenance	17	16	16	15	14	15
Replacement	11	30	20	10	27	18
Total costs	160	267	210	157	263	206
	1 222	1 161	1 194	1 046	971	1 011
NPV	8.6	5.3	6.7	7.6	4.7	5.9
BCR	296	385	337	257	331	291

Notes: Benefits from NSW injury crashes have been included with the serious injury and minor injury benefits in such a way that the ratios of combined serious injury benefits to combined minor injury benefits per project for the other jurisdictions are unaltered.

Replacement costs occur only for component treatments of multiple-treatment projects having lives that expire before the longest-lived component treatment.

T9.6a Benefit–cost ratios by jurisdiction and year of project completion

4% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	na	8.4	3.1	5.4	8.8	16.6	9.4	7.1	8.2
1998	10.5	9.8	-10.1	7.4	3.8	8.7	8.1	6.0	7.6
1999	14.1	4.4	6.1	5.3	8.1	9.0	7.5	4.0	6.3
2000	20.5	5.5	-3.0	5.3	8.4	1.7	10.7	6.9	7.7
2001	na	8.8	4.6	6.4	2.5	3.2	6.6	8.7	6.7
2002	9.4	4.2	na	4.4	6.8	5.3	4.3	7.6	4.7
2003	4.6	6.3	-4.1	4.7	29.0	na	5.2	6.0	6.0
Total	11.4	6.7	-0.2	5.6	7.2	7.2	7.4	6.8	6.7

continued

T9.6a Benefit–cost ratios by jurisdiction and year of project completion (continued)

5% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA	Total
1997	na	7.3	2.8	4.8	7.8	14.6	8.3	6.2	7.2
1998	9.1	8.6	-9.2	6.5	3.3	7.7	7.2	5.3	6.7
1999	12.0	3.9	5.3	4.7	7.1	8.0	6.6	3.5	5.5
2000	18.6	4.9	-2.7	4.6	7.4	1.5	9.4	6.1	6.8
2001	na	7.7	4.1	5.6	2.2	2.9	5.8	7.7	5.9
2002	8.4	3.7	na	3.9	6.0	4.9	3.8	6.8	4.2
2003	4.0	5.5	-3.5	4.2	25.7	na	4.6	5.3	5.3
Total	10.0	5.9	-0.1	4.9	6.4	6.4	6.6	6.0	5.9

T9.7a Benefit–cost ratios year of project completion including benefits and costs per project

($'000 per project except for BCRs)

	4% discount rate				5% discount rate			
	Benefits	Costs	NPV	BCR	Benefits	Costs	NPV	BCR
1997	1 685	205	1 480	8.2	1 461	203	1 258	7.2
1998	1 225	162	1 063	7.6	1 065	160	905	6.7
1999	1 385	220	1 164	6.3	1 197	216	981	5.5
2000	1 498	195	1 303	7.7	1 297	192	1 105	6.8
2001	1 241	185	1 056	6.7	1 077	182	894	5.9
2002	1 206	256	950	4.7	1 049	251	798	4.2
2003	1 690	283	1 407	6.0	1 465	278	1 187	5.3
Total	1 403	210	1 194	6.7	1 217	206	1 011	5.9

T9.8a Benefits and costs per project by jurisdiction

($'000 per project except for BCRs)

4% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1 497	352	15	230	395	827	398	197
Serious injury	2 159	na	-138	1 125	1 020	689	859	589
Minor injury	424	na	84	174	208	97	167	164
Injury	na	1 265	na	na	na	na	na	na
Benefits	4 080	1 616	-39	1 529	1 623	1 613	1 424	950
Costs	359	241	226	275	225	226	192	140
NPV	3 721	1 375	-265	1 254	1 398	1 388	1 232	810
BCR	11.4	6.7	-0.2	5.6	7.2	7.2	7.4	6.8

5% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1 321	303	15	198	343	717	344	170
Serious injury	1 865	na	-117	979	887	599	746	510
Minor injury	369	na	73	151	182	84	145	142
Injury	na	1 097	na	na	na	na	na	na
Total benefits	3 555	1 400	-29	1 328	1 412	1 400	1 235	822
Costs	355	238	221	271	222	220	188	138
NPV	3 200	1 162	-251	1 058	1 190	1 181	1 046	684
BCR	10.0	5.9	-0.1	4.9	6.4	6.4	6.6	6.0

T9.9a Benefit–cost ratios for numbers of treatments in projects including benefits and costs per project

($'000 per project except for BCRs)

Number of treatments	4% discount rate				5% discount rate			
	Benefits	Costs	NPV	BCR	Benefits	Costs	NPV	BCR
1	1 365	173	1 192	7.9	1 187	172	1 015	6.9
2	1 402	247	1 155	5.7	1 213	242	972	5.0
3	1 488	274	1 214	5.4	1 282	265	1 017	4.8
4, 5 & 6	2 129	500	1 629	4.3	1 828	482	1 346	3.8
Total	1 403	210	1 194	6.7	1 217	206	1 011	5.9

T9.10a Benefit–cost ratios for treatment types

	4% discount rate			5% discount rate		
Treatment type	Urban	Rural	All	Urban	Rural	All
T01 Rndabout	16.4 (14.9)	8.8 (9.0)	11.6 (11.3)	14.1 (12.8)	7.5 (7.7)	10.0 (9.7)
T02 Medians	4.8 (2.5)	4.2 (6.4)	4.5 (3.3)	4.2 (2.2)	3.8 (5.6)	4.0 (2.9)
T03 New sigs	6.9 (6.5)	4.3 (5.2)	6.1 (6.1)	6.2 (5.8)	3.9 (4.7)	5.5 (5.5)
T04 Mod sigs	12.3 (15.1)	7.9 (11.4)	11.7 (14.7)	11.0 (13.5)	7.1 (10.2)	10.5 (13.1)
T05 Traf calm	20.8* (25.3)*	3.4* (1.7)*	6.1 (7.2)	18.3* (22.1)*	3.1* (1.5)*	5.4 (6.3)
T06 Lighting	-13.6 (-30.2)*	1.9 (-1.3)	-1.8 (-7.3)	-12.3 (-27.0)*	1.7 (-1.2)	-1.6 (-6.5)
T07 Turn lane	8.2 (10.7)	3.7 (4.4)	5.3 (7.1)	7.2 (9.3)	3.3 (3.8)	4.7 (6.2)
T08 Ped trmts	6.3 (5.0)	2.1 (3.3)*	3.7 (4.3)	5.7 (4.6)	1.9 (3.0)*	3.4 (3.9)
T10 Sealing	7.2 (11.0)	5.7 (6.6)	6.0 (7.8)	6.3 (9.5)	5.0 (5.7)	5.2 (6.7)
T11 Non-skid	-2.1 (-3.4)	0.2 (-0.1)	-1.1 (-1.7)	-1.9 (-3.0)	0.2 (-0.1)	-1.0 (-1.5)
T12 Alt width	1.9 (0.0)*	3.3 (2.0)*	2.8 (1.2)*	1.7 (0.0)*	2.9 (1.7)*	2.5 (1.1)*
T14 Barriers	0.2 (-1.9)	3.5 (3.4)	2.3 (1.1)	0.2 (-1.6)	3.1 (3.0)	2.0 (1.0)
T15 Realign len	10.7* (na)*	3.6 (1.3)	4.0 (1.3)	9.4* (na)*	3.1 (1.1)	3.4 (1.1)
T16 Realign int	-1.3 (-1.3)	3.7 (8.6)	2.4 (3.9)	-1.1 (-1.1)	3.3 (7.3)	2.0 (3.3)
T17 Clear obs	18.4 (15.6)*	8.5 (9.9)*	12.6 (13.2)	16.1 (13.6)*	7.5 (8.6)*	11.1 (11.6)
T18 Wrn sgns	8.9* (27.2)*	13.0 (13.2)*	12.2 (15.2)*	8.2* (24.8)*	11.7 (11.9)*	11.0 (13.8)*
T19 Lines	9.8 (16.5)*	8.1 (10.3)	8.6 (11.3)	9.0 (15.3)*	7.5 (9.5)	8.0 (10.5)
T20 Prty sgns	19.0 (0.3)*	21.8 (34.4)*	21.0 (23.3)*	17.2 (0.3)*	19.5 (31.2)*	18.8 (21.2)*
T22 Alt dir	27.3 (12.5)*	11.7 (9.3)*	19.9 (10.7)	24.7 (11.3)*	10.5 (8.4)*	18.0 (9.7)
Unspecified	-0.1 (0.8)*	-0.1 (0.7)	-0.1 (0.7)	-0.1 (0.7)*	0.0 (0.6)	0.0 (0.6)
Total	8.6 (9.4)	5.3 (6.5)	6.7 (7.9)	7.6 (8.2)	4.7 (5.7)	5.9 (6.9)

Notes: The BCR in each cell is for projects classified by primary treatment, including multiple-treatment projects. The second, bracketed BCR is for single-treatment projects only.

* = BCR based on less than 10 projects.

T9.12a Main results with PDO crashes added and excluding Victoria

($'000 per project except for BCRs and % increases)

	4% discount rate			5% discount rate		
	Urban	Rural	Total	Urban	Rural	Total
Casualty benefits	1 350	1 437	1 394	1 176	1 242	1 209
PDO benefits	171	66	118	149	57	103
Total benefits	1 521	1 503	1 512	1 325	1 298	1 312
Costs	163	273	436	160	269	429
NPV casualty	1 187	1 164	957	1 015	973	780
NPV with PDO	1 358	1 230	1 076	1 165	1 030	883
BCR casualty	8.3	5.3	3.2	7.3	4.6	2.8
BCR with PDO	9.3	5.5	3.5	8.3	4.8	3.1
% increase	12.6	4.6	8.5	12.7	4.6	8.5
Indicative adjustment for unreported PDO crashes[a]						
PDO benefits			412			358
Total benefits			1 805			1 567
NPV all			1 369			1 138
BCR all			4.1			3.7
% inc			29.5			29.6

a. PDO benefits multiplied by 3.48. Urban and rural results not shown because the adjustment factor is available only for all crashes, and may be different for urban and rural crashes.

T9.13a Results by jurisdiction with PDO costs added

($'000 per project except for BCRs and % increases)
4% discount rate

Jurisdiction	ACT	NSW	NT	Qld	SA	Tas	WA
Casualty benefits	4 080	1 616	-39	1 529	1 623	1 613	950
PDO benefits	1 643	70	142	97	275	23	85
Total benefits	5 723	1 686	104	1 627	1 898	1 636	1 035
Costs	359	241	226	275	225	226	140
NPV casualty	3 721	1 375	-265	1 254	1 398	1 388	810
NPV with PDO	5 364	1 445	-122	1 352	1 673	1 410	895
BCR casualty	11.4	6.7	-0.2	5.6	7.2	7.2	6.8
BCR with PDO	15.9	7.0	0.5	5.9	8.4	7.3	7.4
% increase	40.3	4.3	na	6.4	17.0	1.4	8.9

continued

T9.13a Results by jurisdiction with PDO costs added (continued)

5% discount rate

Jurisdiction	ACT	NSW	NT	Qld	SA	Tas	WA
Casualty benefits	3 555	1 400	-29	1 328	1 412	1 400	822
PDO benefits	1 432	61	124	84	240	20	74
Total benefits	4 987	1 461	95	1 413	1 652	1 420	896
Costs	355	238	221	271	222	220	138
NPV casualty	3 200	1 162	-251	1 058	1 190	1 181	684
NPV with PDO	4 632	1 223	-127	1 142	1 430	1 200	758
BCR casualty	10.0	5.9	-0.1	4.9	6.4	6.4	6.0
BCR with PDO	14.0	6.1	0.4	5.2	7.4	6.5	6.5
% increase	40.3	4.3	na	6.4	17.0	1.4	9.0

T9.15a Overall results including benefits and costs per project: 15 year maximum project lives

($'000 per project except for BCRs and % increases)

Discount rate	4%			5%		
	Urban	Rural	Total	Urban	Rural	Total
Benefits						
Fatal	233	276	253	207	246	225
Serious injury	720	682	699	641	608	623
Minor injury	169	101	141	151	90	126
Total	1 122	1 060	1 093	999	945	974
Costs						
Construction	132	221	173	132	221	173
Maintenance	15	13	14	14	12	13
Replacement	4.9	15.3	9.7	4.5	14	9
Total	151	249	197	150	247	195
NPV	971	810	897	849	697	779
BCR	7.4	4.3	5.6	6.7	3.8	5.0
% increase[a]	-14	-20	-17	-13	-19	-15

a. Percentage increase in BCR compared with main results in table 9.5a.

T9.16a Overall results including benefits and costs per project: constant forecast crash rates

($'000 per project except for BCRs and % increases)

Discount rate	4%			5%		
	Urban	Rural	Total	Urban	Rural	Total
Benefits						
Fatal	288	376	329	250	324	284
Serious injury	848	885	860	740	766	748
Minor injury	202	130	173	176	113	151
Total benefits	1 337	1 391	1 362	1 166	1 203	1 183
Costs	160	267	210	157	263	206
NPV	1 178	1 123	1 153	1 009	940	977
BCR	8.4	5.2	6.5	7.4	4.6	5.7
% increase[a]	-3.2	-2.6	-2.9	-3.1	-2.5	-2.8

a. Percentage increase in BCR compared with main results in table 9.5a.

T9.17a Benefits and costs per project by jurisdiction: constant forecast crash rates

($'000 per project except for BCRs and % increases)
4% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1 483	350	16	210	399	843	388	184
Serious injury	419	na	80	159	211	98	163	154
Minor injury	2 134	na	-128	1 036	1 032	702	839	551
Injury	na	1 259	na	na	na	na	na	na
Benefits	4 036	1 609	-32	1 404	1 642	1 642	1 390	890
Costs	359	241	226	275	225	226	192	140
NPV	3 677	1 367	-258	1 129	1 416	1 417	1 198	749
BCR	11.2	6.7	-0.1	5.1	7.3	7.3	7.3	6.4
% increase[a]	-1.1	-0.5	-18.3	-8.2	1.2	1.8	-2.4	-6.4

continued

T9.17a Benefits and costs per project by jurisdiction: constant forecast crash rates (continued)

5% discount rate

	ACT	NSW	NT	Qld	SA	Tas	Vic	WA
Fatal	1309	302	16	181	346	729	335	160
Serious injury	365	na	70	139	184	86	141	134
Minor injury	1844	na	-109	904	897	609	730	479
Injury	na	1092	na	na	na	na	na	na
Total benefits	3519	1394	-23	1224	1428	1424	1206	773
Costs	355	238	221	271	222	220	188	138
NPV	3163	1156	-245	954	1206	1204	1018	635
BCR	9.9	5.9	-0.1	4.5	6.4	6.5	6.4	5.6
% increase[a]	-1.0	-0.5	-19.6	-7.8	1.1	1.7	-2.3	-6.0

a. Percentage increase in BCR compared with main results in table 9.8a.

CHAPTER 10
Traffic impacts

Summary

In cost–benefit analyses (CBAs) of black spot projects, it is normal to omit benefits and costs of traffic impacts altogether. This is understandable given the detailed data and complex modelling requirements to estimate them. In making recommendations about black spot treatments, experts subjectively weigh up the traffic impacts against the safety benefits.

To provide some information about the relative size of traffic impact benefits or costs compared with safety benefits, BITRE commissioned a traffic modelling consultant to undertake case studies of 18 black spot projects at intersections — four roundabouts, six new traffic signals, five modify existing traffic signals, one extend right turning lanes, and two that combine the latter two treatments.

The consultant obtained detailed data on traffic flows, intersection layouts, and traffic signal phases before and after each black spot project. For each project, four runs of the aaSIDRA model were undertaken, without and with the project for the first year of the project's life, and without and with the project in the last year, allowing for traffic growth during the intervening period. Unit cost parameters for vehicle operating and time costs were adjusted to be consistent with the Austroads recommendations for 2007.

Roundabout projects are undertaken at intersections with relatively low traffic flows and new traffic signals at intersections with higher traffic flows. The most highly trafficked intersections among the case studies already had traffic lights installed and the black spot project was to modify the signals.

In most cases, the black spot projects gave rise to negative traffic impacts. Roundabouts imposed costs of up to five cents per vehicle, traffic signals up to 11 cents, and modify traffic signals up to seven cents. Extending turning lanes by itself reduces costs by over one cent per vehicle.

Two roundabout projects and one traffic signal project imposed costs in the first year and benefits in the last year because, at high traffic levels, these treatments improve traffic flows. BITRE commissioned the consultant to undertake additional model runs for intervening years for one of the roundabouts to illustrate how traffic impact costs per vehicle vary with traffic flows.

The present values of traffic impact costs showed great variation, from a benefit of $5.4 ($2.8) million to a cost of $26.1 ($16.2) million (present values at 3% discount rate followed by 7% discount rate in brackets). Installation and modification of traffic signals have more pronounced impacts than roundabouts reflecting the higher traffic levels at signalised intersections. Four of the projects produced traffic benefits in present value terms.

In ten cases, the traffic costs were greater than the road safety benefits leading to negative NPVs for the projects. Eight of the ten involve new traffic signals or modifications to existing traffic signals. The traffic costs range up to 12 times the size of the crash benefits at the 3% discount rate and up to 14 at the 7% discount rate. The lowest negative NPV was –$19 (–$13) million for a new signals project.

The case studies show that traffic impact costs of black spot projects vary greatly between projects and can be substantial. They are more likely to be negative and can more than offset the safety benefits, particularly for projects involving traffic signals. Greater attention should be paid to traffic impacts of black spot projects in future.

Omission of traffic impacts

In undertaking economic appraisals of black spot projects, it is normal to omit impacts on road user costs altogether. Such was the case for the previous BITRE black spot evaluations, for evaluations of state government road programs (Scully et al. 2006, Meuleners et al. 2005 and 2008), and for estimation of benefit-cost ratios (BCRs) for funding purposes as required by the NBSP Notes on Administration.

Omission of traffic impact costs and benefits is understandable given the detailed data and complex modelling requirements to estimate them. Yet some black spot treatments clearly have significant impacts on road user costs. Roundabout and traffic signal treatments are the most obvious examples. In making recommendations about the need for black spot treatments and the types of treatment to implement, experts consider the traffic impacts and subjectively weigh them up against the safety benefits. But the traffic impacts are rarely quantified.

Changes in road user costs arise because the treatment alters one or more of vehicle speeds, deceleration, acceleration, stopping, waiting, and distance travelled. The main benefits or costs result from changes in road users' time and fuel consumption. Changes in wear and tear on brakes and tyres are additional minor impacts. There are also emissions and noise externalities.

Traffic volume is a major determinant of the road user cost impacts of black spot treatments. Total road user costs for a site over a period of time are a product of numbers of vehicles and costs for average vehicles, summed over vehicle type categories and time periods. Overlying the proportional relationship between vehicle numbers and total cost, traffic volume in relation to capacity determines the level of congestion at the site, which affects vehicle speeds and hence costs per vehicle.

As the modelling results presented below illustrate, the same treatment that impedes traffic at low volumes can improve flows at high volumes. So the inclusion of traffic impacts in a CBA of a black spot project can alter the benefits in either direction. Where traffic volumes are sufficiently high, some black spot projects may be economically warranted on the basis of their traffic impacts alone.

Case study approach

Since it would be too costly to undertake the data collection and modelling to estimate the road user cost impacts of all projects with significant impacts in the evaluation, BITRE has adopted a case study approach. BITRE engaged consultants John Piper Traffic Pty Ltd to obtain the necessary data from state road agencies and to undertake the modelling. Their report is published in full in volume 3.

Modelling was undertaken for 18 projects to provide some indicative orders of magnitude. The treatment types chosen were those expected to be associated with the greatest road user cost impacts.

- T01 installation of new roundabouts (4 projects)
- T03 installation of new traffic signals (6 projects)
- T04 modification of existing traffic signals (5 projects)
- T07 extension of right turn lanes at intersections with traffic signals (1 project)
- T04T07 modification of existing traffic signals combined with extension of right turn lanes (2 projects).

BITRE aimed to spread the case study projects across jurisdictions and to include sites with a range of traffic levels. Table 10.1 lists project and site details. The case study projects have been grouped by treatment type and then sorted into ascending order of average daily vehicle flows. Vehicle flow for an intersection is the sum of vehicles entering the intersection from all directions.

Results of the modelling suggest that the traffic impacts of black spot projects at intersections, measured in economic costs, tend to be negative at lower traffic levels and positive at higher traffic levels. Where there is little or no congestion, a roundabout or set of traffic signals delays traffic. In congested conditions, they can help the traffic to flow more smoothly.

To explore this further, BITRE had the consultant undertake some additional runs of case study S00028, a roundabout in South Australia, with traffic levels extrapolated at five-year intervals from 1986 to 2016.[15] Project S00028 was selected because the negative traffic impact in the first year was reversed in the final year and the site had the sufficient capacity with and without the roundabout to handle the range of traffic levels.

15 The first year of the project's life was 1996, so the 1986 and 1991 model runs are projections backwards in time.

T10.1 Case study projects

State	Reference	Street location	Suburb	Treatment (code for charts)	First year ADVF[a]	First year	Project life (years)
NSW	N01073	Boundary St / Lang St	Cessnock	T01 Installation of roundabout (r)	5 480	2001	15
NSW	N00114	Brisbane St / Tamworth St	Dubbo	T01 Installation of roundabout (r)	5 540	1998	15
SA	S00028	Adelaide Rd / Wellington Rd / Alexandrina Rd / Flax Rd	Mount Barker	T01 Installation of roundabout (r)	17 465	1996	20
VIC	V01062	Boronia Rd / Forest Rd	Boronia	T01 Installation of roundabout (r)	20 601–21 103	1998	20
SA	S00004	Eastern Pde / Bedford St	Gillman	T03 Installation of traffic signals (t)	13 949	1996	4
NSW	N00239	William St / Howick St	Bathurst	T03 Installation of traffic signals (t)	15 645–15 748	1999	15
NSW	N00851	Pacific Hwy / Halls Rd	Coffs Harbour	T03 Installation of traffic signals (t)	20 730	2000	15
NSW	N00228	Stewart Ave / Parkway Ave	Hamilton South	T03 Installation of traffic signals (t)	33 070	2001	15
VIC	V03035	Dorset Rd / Francis Cr	Ferntree Gully	T03/T12 Installation of traffic signals (t)	38 150–38 382	2003	15
NSW	N00846	Pacific Hwy / Cook Dr / North Boambee Rd	Coffs Harbour	T03 Installation of traffic signals (t)	42 323–39 579	1999	15
VIC	V00385	Warrandyte Rd / Wonga Rd	Ringwood North	T04/T17 Modify traffic signals: one right turn arrow display altered from 2 to 3 aspects ("partial" to "full" control) (m)	28 281	1998	10
NSW	N00995	Canley Vale Rd / Sackville St	Canley Vale	T04/T08 Modify traffic signals: one right turn altered from "filter" to "partial" control and one right turn banned (m)	35 231–35 250	2001	15

continued

a. Average daily vehicle flow (ADVF) is the sum of vehicle flows into the intersection from all approaches. The traffic levels shown here apply in the first year of analysis, not the final. Where two values are provided, the first is the base case and the second is the project case. Small differences have arisen where the base case layout was suffering from capacity problems (for movements from the minor road(s)) even in the first year. The 'project case' layouts would usually be designed to cope with volume growth on all approaches, so the project-case total vehicle flows are higher than for the base case. For N00846, a complex aaSIDRA base case model had to be developed due to vehicles turning right from the side road being able to store in the main road median space before merging with traffic in the far carriageway. Some vehicle movements would be double counted in the model. Hence the volume totals for the base case layout are greater than those for the project case layout.

b. Project V01340 is classified in the database as a multiple treatment project comprised of T04 and T07. The T07 component of the project is described as 'extend right turn lane'. As this a relatively minor change to the site, it was not considered in the traffic modelling.

T10.1 Case study projects (continued)

State	Reference	Street location	Suburb	Treatment (code for charts)	First year ADVFa	First year	Project life (years)
VIC	V01340[b]	Burwood Hwy / Dawson St	Upper Ferntree Gully	T04/T07 Modify traffic signals: one set of 3-aspect (full control) right turn arrows added, with one right turn arrow display altered from 2 to 3 aspects ("partial" to "full" control) (m)	37 348	2000	10
VIC	V01590	Mountain Hwy / High St / Valentine St	Bayswater	T04/T11 Modify traffic signals: two 3-aspect (full control) right turn arrows added (m)	45 424	2002	10
VIC	V01145	Stud Rd / Boronia Rd	Wantirna	T04 Modify traffic signals: one set of 2-aspect (partial control) right turn arrows added (m)	64 484	2000	10
QLD	Q00569	Southport – Burleigh Rd / Benowa Rd	Southport	T07 Extension of right turn lanes at traffic signals (l)	43 319	2001	15
VIC	V01311	Dorset Rd / Eastfield Rd	Croydon South	T04/T07 Extension of right turn lane at traffic signals. Modify traffic signals: two right turn arrow displays altered from 2 to 3 aspects ("partial" to "full" control) (lm)	41 697	2000	10
QLD	Q00768	Gold Coast Hwy / Kirribin St	Currumbin	T04/T07 Extension of right turn lanes at traffic signals. Modify traffic signals: two right turn arrow displays altered from 2 to 3 aspects, with red arrows dropping off in through phase (lm)	49 829	2001	10

a. Average daily vehicle flow (ADVF) is the sum of vehicle flows into the intersection from all approaches. The traffic levels shown here apply in the first year of analysis, not the final. Where two values are provided, the first is the base case and the second is the project case. Small differences have arisen where the base case layout was suffering from capacity problems (for movements from the minor road(s)) even in the first year. The 'project case' layouts would usually be designed to cope with volume growth on all approaches, so the project-case total vehicle flows are higher than for the base case. For N00846, a complex aaSIDRA base case model had to be developed due to vehicles turning right from the side road being able to store in the main road median space before merging with traffic in the far carriageway. Some vehicle movements would be double counted in the model. Hence the volume totals for the base case layout are greater than those for the project case layout.

b. Project V01340 is classified in the database as a multiple treatment project comprised of T04 and T07. The T07 component of the project is described as 'extend right turn lane'. As this a relatively minor change to the site, it was not considered in the traffic modelling.

Modelling methodology

The modelling was undertaken using the aaSIDRA software (Traffic Signalised and Unsignalised Intersection Design and Research Aid, developed by Akcelik and Associates).

Data

The data requirements for each site included information on:

- the layout of the site before and after treatment
- cycle times and phasing of traffic signals
- traffic count data in the year of implementation of the black spot project in the form of left-turning, right-turning and through traffic numbers
- the number of heavy vehicles
- traffic variability by time of day (AM peak, PM peak, business hours, medium off-peak and light off-peak) and then for work days, weekends and holidays separately
- historical traffic volumes on which to base future projections

The model has default percentages to apply if heavy vehicle and traffic variability information is missing or incomplete.

Treatment life

Each black spot treatment was assumed to have a 'notional life', which the consultant obtained from the guidelines of the road agencies supplying the data. Roundabouts were assumed to have lives of either 15 or 20 years, new traffic signals 15 years, modifications to traffic signals and turning lanes 10 or 15 years.

An exception was project S0004, installation of traffic signals. Even a slight traffic growth after the first year, 1996, would have seen the 'without-project' layout saturated (demand reaching the capacity of the intersection) in the AM and PM peak periods. The consultant therefore allowed only four years of growth. Due to opening of a new expressway nearby in 2005, there was a substantial drop in traffic volumes at the intersection.

Traffic levels for each period of the day were extrapolated linearly, except in cases where the volume of traffic would have been too great for the without-project infrastructure to service.

For each case study (except S00028), the model was run four times — without and with the project at traffic levels for the first year of the project' life, and without and with the project at traffic levels for the final year of the project' life.

Model outputs

The outputs of the aaSIDRA model supplied by the consultant include estimates of annual time taken, fuel consumption, vehicle stops, emissions of four gases, and road user costs for all vehicles using the intersection. These apply between set start-point and end-point spatial limits on approach and exit roads over a period of a year.

The end points for each approach and exit are set at the closest point where the vehicles would be travelling at a 'cruise' speed, unaffected by the presence of the intersection. Usually, the cruise speed is left at the default of 60 km/h. The magnitudes of the annual totals are therefore heavily dependent on the distances between the start and end points.[16] Hence, they are not, by themselves, very useful.

The interesting numbers are the differences between the totals with and without the black spot project. These reveal the project's traffic impacts. A traffic impact can be defined as the additional time lost or cost imposed by a project, which is the project case total minus the base case total. The consultant's report provides totals only. All the tables in this chapter show differences, that is, project impacts.

Cost estimation

Time, fuel, stops, emissions and costs for the average vehicle are estimated for each for each traffic stream, period of the day, and for light and heavy vehicles. These are multiplied by annual traffic volumes and summed to obtain yearly totals. The stops affect time delay and fuel consumption.

Average cost per vehicle is estimated using the formula:

$$\text{fuel consumption per vehicle (litres)} \times P_p \times f_r \times f_c + \text{time per vehicle (hours)} \times W \times f_p \times f_o$$

where

P_p = the pump price of fuel ($/litre)

f_r = fuel resource cost factor

f_c = running cost / fuel cost ratio

W = average income (full-time adult average hourly total earnings) ($/hour)

f_p = time value factor as a proportion of average hourly volume

f_o = average occupancy in persons per vehicle.

The resource cost of fuel excludes taxes, in particular, the fuel excise tax. Resource costs are used rather than financial costs because resource costs represent the opportunity cost to society, in this case, the costs of earning the foreign exchange needed to import crude oil and the refining, storage and transport costs. Savings in working time are valued at average earnings and savings in non-work time at a multiple of this — 31% in the case of the Austroads (2008, p. 18) values. The f_p factor is a weighted average for work and non-work time.

Other cost elements — tyres, vehicle maintenance, oil, and capital costs — are estimated by the aaSIDRA model in a simplified way. These other costs are assumed to be proportional to fuel consumption using a running cost to fuel cost ratio.

16 The total times are obtained from the 'delay' columns of the 'annual sums' tables produced by the model and reproduced in the consultant's report. The 'delay' is the difference between the travel time at the cruise speed and the predicted travel time taken. It includes deceleration and acceleration caused by the geometry of the intersection and stopping due to traffic signals or queuing. The estimated increase in total time taken as a result of the project equals total delays with the project (the project case) minus total delays without the project (the base case).

Although the model treats heavy and light vehicles separately for estimating fuel consumption and time delays, the same set of unit costs and factors are used for both vehicle types to estimate costs. The resource cost of fuel therefore has to be a weighted average of petrol and diesel costs. The running cost–fuel cost ratio, time value factor, that is, drivers' earnings for trucks and average earnings for cars, and average occupancy — one for trucks and greater than one for cars — are also weighted averages.

Table 10.2 lists the aaSIDRA default values and updated values for the parameters in the cost formula. BITRE developed updated values based on Austroads (2007) and which were current at 30 June 2005. The figures in the consultant's report were estimated using these 2005 values. Since completion of the modelling, Austroads (2008) was released, updating the parameter values to 30 June 2007. As the crash cost savings in chapter 9 are estimated using the 30 June 2007 Austroads values, for consistency, the consultant's costs were adjusted to 2007 values. This was done using the fuel consumption and time figures provided by the consultant. No costs were applied to emissions because there is much uncertainty about values and they vary greatly with local factors.

T10.2 Updated aaSIDRA cost parameters

		aaSIDRA default values	Updated 2005 values	Updated 2007 values
P_p	pump price of fuel ($/litre)	0.9	1.12	1.31
f_r	fuel resource cost factor	0.5	0.58	0.5
f_c	running cost / fuel cost ratio	3.0	3.0	3.0
W	average income (full-time adult average hourly total earnings) ($/hour)	27.00	34.35	36.76
f_p	time value factor as a proportion of average hourly volume	0.6	0.5	0.5
f_o	average occupancy in persons per vehicle	1.5	1.5	1.5

Notes on BITRE calculation methods

P_p average capital city prices, weighted 0.56 petrol and 0.44 diesel. The weights were derived from total sales of automotive petrol and diesel.

f_r ratio of P_p to resource price calculated in the same manner as P_p, ratios averaged for capital cities.

f_c Ratios were estimated for cars, light commercial vehicles and heavy commercial vehicles using average capital city fuel costs and the urban vehicle operating cost and fuel consumption models in Austroads (2007, pp. 10–11) and (2008, pp. 31–36). Ratios at a speed of 60km/h for cars, light commercial vehicles and heavy commercial were 2.5, 2.7 and 4.2 respectively for the 2005 models and costs. For 2007 models costs, the ratios were 3.1, 3.1 and 2.9 respectively. The differences between the 2005 and 2007 ratios are due to major changes in the parameter values in the Austroads models. The aaSIDRA default value of 3.0 was retained because it represents a central value for the ratios in both years.

W The Austroads value of time per occupant for business cars was taken as average income.

f_p weighted average value of time per person × weighted average vehicle occupancy rate/W/ f_o rounded

f_o weighted average of 1.7 for private cars, 1.3 for business cars, 1.3 for light commercial vehicles and 1.0 for heavy commercial vehicles; weighted by total vehicle kilometres travelled from Austroads (2005) and the business car to private ratio 78:22. The updated weighted averages when rounded off equal the aaSIDRA default value of 1.5.

Sources: John Piper Traffic (2008), Austroads (2005b), (2007) and (2008).

Case study results

Tables 10.3 to 10.6 and figures 10.1 to 10.3 summarise the results of the case studies.

For each case study, there was a first- and a final-year result, except for S00028 for which additional model runs were undertaken. Table 10.3 shows total annual costs. Table 10.5 shows average costs obtained by dividing the totals in table 10.3 by annual vehicle flows. Tables 10.4 and 10.6 set out the minimum, maximum, and average values for each treatment type group for the total and average tables respectively.

T10.3 Traffic impact case studies: summary of results: total costs

Project reference	Type code[a]	First year: Average daily vehicle flow[b]	First year: Increase in annual running cost	First year: Increase in annual time cost	First year: Increase in annual total cost	First year: Proportion running cost	Final year: Average daily vehicle flow[b]	Final year: Increase in annual running cost	Final year: Increase in annual time cost	Final year: Increase in annual total cost	Final year: Proportion running cost
		('000)	($'000)	($'000)	($'000)	%	('000)	($'000)	($'000)	($'000)	%
N01073	r	5.5	34	38	72	47	6.6	37	42	79	47
N00114	r	5.5	11	13	24	46	5.7	11	13	24	45
S00028	r	17.5	115	138	253	46	27.6	83	-651	-568	-15
V01062	r	20.9	91	184	275	33	23.0	24	180	204	12
S00004	t	13.9	71	43	113	63	15.6	62	-156	-94	-66
N00239	t	15.7	72	499	571	13	17.0	70	533	603	12
N00851	t	20.7	194	468	663	29	27.0	269	666	935	29
N00228	t	33.1	334	920	1 254	27	36.4	406	1 049	1 455	28
V03035	t	38.3	383	476	859	45	44.5	792	893	1 685	47
N00846	t	41.0	251	552	803	31	54.1	68	-2 230	-2 161	-3
V00385	m	28.3	41	236	278	15	31.2	47	270	317	15
N00995	m	35.2	12	54	65	18	40.9	10	56	65	15
V01340	m	37.3	12	105	117	10	39.3	10	107	117	9
V01590	m	45.4	200	865	1 065	19	47.0	208	900	1107	19
V01145	m	64.5	73	331	404	18	67.8	90	442	532	17
Q00569	l	43.3	-35	-126	-161	22	49.6	-50	-191	-242	21
V01311	lm	41.7	35	226	261	13	40.3	35	219	254	14
Q00768	lm	49.8	0	0	1	58	54.8	0	1	1	0
S00028[c]	r	13.6	93	126	219	43					
S00028	r	15.4	105	135	240	44					
S00028	r	17.5	115	138	253	46					
S00028	r	19.8	129	128	257	50					
S00028	r	22.5	140	91	231	61					
S00028	r	25.0	140	-30	110	127					
S00028	r	27.6	83	-651	-568	-15					

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together

b. Where there were small differences between the base and project case traffic levels (see note to table 10.1 for explanation), the traffic levels were averaged.

c. The last seven rows show all the model runs undertaken for project S00028, with traffic levels extrapolated at five-year intervals: 1986, 1991, 1996, 2001, 2006, 2011 and 2016. The 1996 and 2016 results are repeated above in the table because they are the first and final years respectively for this project.

T10.4 Total costs: comparisons between treatment types (summary of table 10.3)

Type code[a]		First year					Final year				
		Average daily vehicle flow	Increase in annual running cost	Increase in annual time cost	Increase in annual total cost	Proportion running cost	Average daily vehicle flow	Increase in annual running cost	Increase in annual time cost	Increase in annual total cost	Proportion running cost
		('000)	($'000)	($'000)	($'000)	%	('000)	($'000)	($'000)	($'000)	%
r	Minimum	5.5	11	13	24	33	5.7	11	-651	-568	-15
r	Average	12.3	63	93	156	43	15.7	39	-104	-65	22
r	Maximum	20.9	115	184	275	47	27.6	83	180	204	47
t	Minimum	13.9	71	43	113	13	15.6	62	-2230	-2161	-66
t	Average	27.1	218	493	711	35	32.4	278	126	404	8
t	Maximum	41.0	383	920	1254	63	54.1	792	1049	1685	47
m	Minimum	28.3	12	54	65	10	31.2	10	56	65	9
m	Average	42.2	68	318	386	16	45.2	73	355	428	15
m	Maximum	64.5	200	865	1065	19	67.8	208	900	1107	19
l		43.3	-35	-126	-161	22	49.6	-50	-191	-242	21
lm	Minimum	41.7	0	0	1	13	40.3	0	1	1	0
lm	Average	45.8	18	113	131	35	47.6	17	110	128	7
lm	Maximum	49.8	35	226	261	58	54.8	35	219	254	14
All	Minimum	5.5	-35	-126	-161	10	5.7	-50	-2230	-2161	-66
All	Average	31.0	105	279	384	31	34.9	121	119	240	13
All	Maximum	64.5	383	920	1254	63	67.8	792	1049	1685	47

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together.

T10.5 Traffic impact case studies: summary of results: costs per vehicle

Project reference	Type code[a]	First year: Average daily vehicle flow[b] ('000)	First year: Increase in average running cost (c/vehicle)	First year: Increase in average time cost (c/vehicle)	First year: Increase in average total cost (c/vehicle)	Final year: Average daily vehicle flow[b] ('000)	Final year: Increase in average running cost (c/vehicle)	Final year: Increase in average time cost (c/vehicle)	Final year: Increase in average total cost (c/vehicle)
N01073	r	5.5	1.68	1.92	3.60	6.6	1.51	1.74	3.25
N00114	r	5.5	0.55	0.64	1.18	5.7	0.53	0.65	1.18
S00028	r	17.5	1.81	2.16	3.97	27.6	0.83	-6.47	-5.65
V01062	r	20.9	1.20	2.42	3.61	23.0	0.29	2.15	2.43
S00004	t	13.9	1.39	0.83	2.23	15.6	1.09	-2.74	-1.65
N00239	t	15.7	1.26	8.72	9.97	17.0	1.13	8.59	9.72
N00851	t	20.7	2.57	6.19	8.76	27.0	2.73	6.77	9.50
N00228	t	33.1	2.77	7.62	10.39	36.4	3.06	7.90	10.96
V03035	t	38.3	2.74	3.41	6.15	44.5	4.88	5.50	10.38
N00846	t	41.0	1.68	3.69	5.37	54.1	0.35	-11.29	-10.94
V00385	m	28.3	0.40	2.29	2.69	31.2	0.41	2.37	2.78
N00995	m	35.2	0.09	0.42	0.51	40.9	0.06	0.38	0.44
V01340	m	37.3	0.09	0.77	0.86	39.3	0.07	0.74	0.82
V01590	m	45.4	1.21	5.22	6.42	47.0	1.21	5.25	6.46
V01145	m	64.5	0.31	1.41	1.72	67.8	0.36	1.79	2.15
Q00569	l	43.3	-0.22	-0.80	-1.02	49.6	-0.28	-1.06	-1.33
V01311	lm	41.7	0.23	1.48	1.71	40.3	0.24	1.49	1.73
Q00768	lm	49.8	0.00	0.00	0.00	54.8	0.00	0.00	0.00
S00028[c]	r	13.6	1.88	2.53	4.42				
S00028	r	15.4	1.86	2.40	4.26				
S00028	r	17.5	1.81	2.16	3.97				
S00028	r	19.8	1.78	1.76	3.54				
S00028	r	22.5	1.71	1.11	2.81				
S00028	r	25.0	1.54	-0.33	1.21				
S00028	r	27.6	0.83	-6.47	-5.65				

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together

b. Where there were small differences between the base and project case traffic levels (see note to table 10.1 for explanation), the traffic levels were averaged. In these cases, increases in costs per vehicle were calculated using the averaged traffic level.

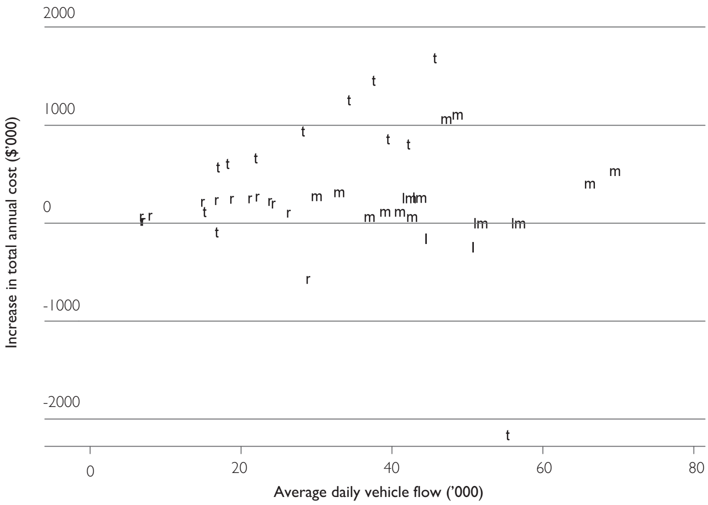
c. The last seven rows show all the model runs undertaken for project S00028, with traffic levels extrapolated at five-year intervals: 1986, 1991, 1996, 2001, 2006, 2011 and 2016. The 1996 and 2016 results are repeated above in the table because they are the first and final years respectively for this project.

T10.6 Costs per vehicle: comparisons between treatment types (summary of table 10.5)

Type code[a]		First year: Average daily vehicle flow ('000)	First year: Increase in average running cost (c/vehicle)	First year: Increase in average time cost (c/vehicle)	First year: Increase in average total cost (c/vehicle)	Final year: Average daily vehicle flow ('000)	Final year: Increase in average running cost (c/vehicle)	Final year: Increase in average time cost (c/vehicle)	Final year: Increase in average total cost (c/vehicle)
r	Minimum	5.5	0.5	0.6	1.2	5.7	0.3	-6.5	-5.6
r	Average	12.3	1.3	1.8	3.1	15.7	0.8	-0.5	0.3
r	Maximum	20.9	1.8	2.4	4.0	27.6	1.5	2.1	3.3
t	Minimum	13.9	1.3	0.8	2.2	15.6	0.3	-11.3	-10.9
t	Average	27.1	2.1	5.1	7.1	32.4	2.2	2.5	4.7
t	Maximum	41.0	2.8	8.7	10.4	54.1	4.9	8.6	11.0
m	Minimum	28.3	0.1	0.4	0.5	31.2	0.1	0.4	0.4
m	Average	42.2	0.4	2.0	2.4	45.2	0.4	2.1	2.5
m	Maximum	64.5	1.2	5.2	6.4	67.8	1.2	5.2	6.5
l		43.3	-0.2	-0.8	-1.0	49.6	-0.3	-1.1	-1.3
lm	Minimum	41.7	0.0	0.0	0.0	40.3	0.0	0.0	0.0
lm	Average	45.8	0.1	0.7	0.9	47.6	0.1	0.7	0.9
lm	Maximum	49.8	0.2	1.5	1.7	54.8	0.2	1.5	1.7
All	Minimum	5.5	-0.2	-0.8	-1.0	5.7	-0.3	-11.3	-10.9
All	Average	31.0	1.1	2.7	3.8	34.9	1.0	1.3	2.3
All	Maximum	64.5	2.8	8.7	10.4	67.8	4.9	8.6	11.0

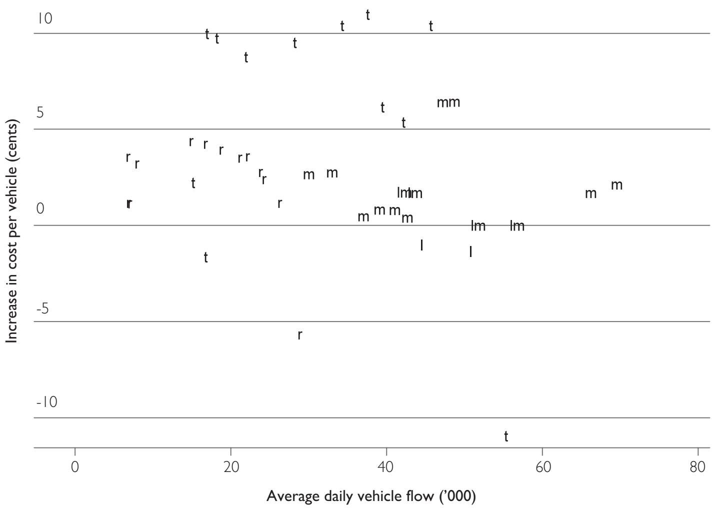
a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together.

F10.1 Plot of increases in total annual costs for all model runs[a]



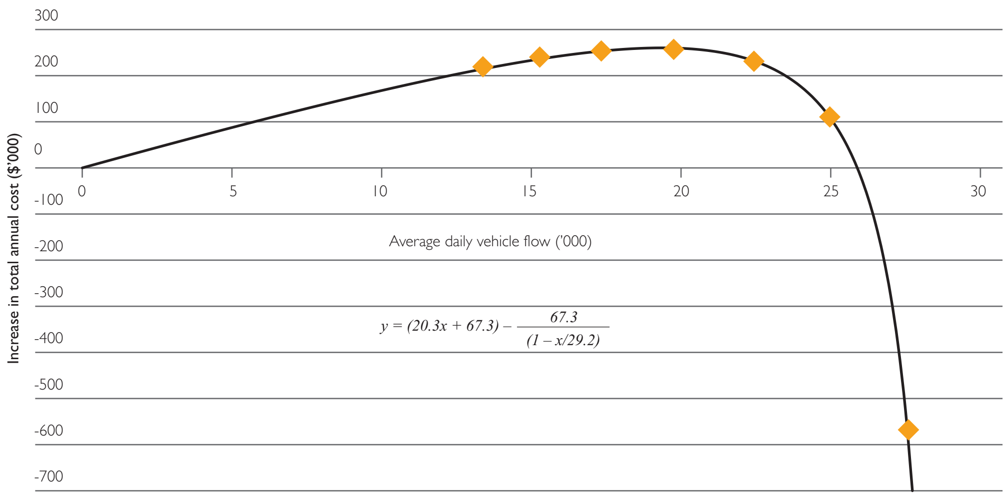
a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together

F10.2 Plot of increases in average costs per vehicle for all model runs[a]



a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together

F10.3 Plot of increases in total annual costs for roundabout site S00028



To illustrate the relationships between traffic levels, treatment types and costs, the total and average costs for all the case studies are plotted in figures 10.1 and 10.2 respectively, using the codes to distinguish between the project types. Figure 10.3 shows total costs for all model runs of project S00028 with a fitted curve.

The increases in traffic costs can be either positive or negative (a saving in costs), but the increases predominate.

Increases in annual traffic costs in the first year range from –$0.2 million to $1.3 million. On a per vehicle basis, the range is –1 cent to 10 cents. As traffic grows, the upper and lower limits grow further apart, illustrated by the range of final year costs, –$2.2 million to $1.7 million for the totals and –11 cents to 11 cents for the averages.

Grouping the sites by treatment type is instructive. Roundabouts (r) tend to be built for lower traffic levels and new traffic signals (t) for higher levels. Modifications to existing traffic signals (m) occur at sites with still higher traffic levels, which is understandable since they have already had traffic signals installed in the past.

Where they increase costs, both the total and average cost increases are almost always higher for traffic signals compared with roundabouts. With one exception, modifications to traffic signals cause relatively small cost increases.

There was only one project that consisted of the addition of a turning lane by itself (l). All the other turning lane projects were accompanied by modifications to traffic signals (lm). The one pure turning lane treatment reduced costs by a small amount, which is to be expected since turning lanes enable turning vehicles to get out of the path of through-traffic.

All the projects except the turning lane by itself lead to higher costs in the first year after implementation. Three projects, two roundabouts and one set of traffic signals, lead to cost savings in their final years. The multiple model runs for the roundabout project S00028 illustrate the relationship between traffic flow and costs.

At low and moderate traffic levels for which there is no congestion, total traffic costs of roundabouts and traffic signals are proportional to vehicle numbers.

For roundabouts, in the absence of other vehicles, all vehicles have to decelerate and accelerate and travel additional distance. For traffic lights, a proportion of vehicles must decelerate and accelerate, and most of these have to come to a complete stop and wait. At higher traffic levels where vehicles interact, the relationship becomes less than proportional, reaches a maximum and then becomes negative as the roundabout or traffic signals reduce average waiting times by ensuring more orderly flows. Finally, at traffic levels where the base case layout is nearing capacity during peak periods, the roundabout or traffic signal generates a net saving in costs.

Hints of such a relationship for roundabouts and traffic signals are evident in figures 10.1 where the *r*'s and *t*'s increase with traffic, then fall off. Figure 10.3 features a curve, fitted to the points by means of least squares, having the form

$$y = (ax + b) - \frac{b}{(1 - x/c)}$$

where

y = annual total cost ($'000)

x = traffic level ('000 vehicles per day), and

a, b, and c are parameters (a = 20.3; b = 67.3; and c = 29.2)

The equation is the sum of an upward-sloping straight line and a rectangular hyperbola constructed so that the curve passes through the origin, and asymptotically approaches *c* from above. In the absence of congestion, the total cost is proportional to the number of vehicles.

The slope of the linear component of the curve starting from the origin (the parameter *a*) is the additional cost per vehicle caused by the roundabout in the absence of congestion ($20 279/365 000 vehicles per year = 5.6 cents per vehicle).

The rectangular hyperbola represents the impact of the treatment in alleviating congestion at higher traffic levels. The value of *c* corresponds to the maximum capacity in the base case, 29 207 vehicles per day, so x/c is the volume–capacity ratio.[17] The maximum cost is reached at 19 361 vehicles per day.

Tables 10.3 and 10.4 include the proportion of cost increases that is running costs. The remainder is time costs. Under the costing assumptions of the aaSIDRA model, fuel (resource) costs are exactly one third of running costs. The traffic costs of black spot treatments are predominately time costs. There are very few instances where the impact on running costs exceeds that on time costs. For the roundabout S00028 for which multiple model runs were undertaken, time costs increase to reach a maximum and begin to turn down well before running costs.

17 Capacity here is expressed in vehicles per day, and assumes an hourly volume distribution that does not change as vehicle flow increases. Normally, capacity would be expressed in vehicles per hour and capacity would be reached only during peak hours.

Effect on CBA results

Estimation of present values

To incorporate traffic impact benefits and costs into CBAs, they have to be expressed as present values. Calculation of a present value requires an estimate of the cost impact in each year of the project's life. For all the case studies except S00028, cost impacts were available for only two years, the first year of the project's life and the last for the notional life assumed by the consultant. The project lives assumed for the CBA are longer than the notional lives, with the exception of new traffic signals. So interpolation and extrapolation were needed.

For case study S00028, there were seven model runs for each of the base and project cases. It was found that exponential curves ($y = ae^{bx}$) fitted well the seven points relating total annual cost to vehicle flow for each of the base and project cases.

For the other case studies, the two available points were used to fix an exponential curve relating total costs to vehicle flow, first for the base case and second for the project case. Traffic was assumed to grow linearly between the two years modelled, in line with the assumption made by the consultant. From the curves, total costs were estimated for each year for the base case and the project case, and the difference taken to obtain the cost increase.

For three case studies, the roundabout S00028 and traffic signals S00004 and N00846, the cost increases for road users changed from positive to negative between the first year and the last year modelled.

- For S00028, the last year modelled was 2016, but the costs needed to be extrapolated to 2022 because roundabouts are assumed to have a 25-year life.
- In the case of S00004, the base case layout became saturated soon after the project was implemented. The last year modelled by the consultant was only four years after the first. The assumed life for traffic signals is 15 years, so extrapolation was required for 11 years.
- For N00846, the notional life matched the life assumed for estimation of safety benefits, so no extrapolation was required.

Where vehicle flow is close to the capacity of the layout, simple extrapolation is unsound.

As evidenced in figure 10.3, the cost impact curve becomes very steep close to capacity. In this region, cost estimates are very sensitive to traffic levels. Where project case traffic exceeds base case traffic because the latter is restricted by capacity, the methodology for estimating benefits becomes more complex and requires additional data that is not available, such as costs of using alternative routes. Rather than produce benefit estimates based on questionable assumptions, the approach taken for S00028 and S00004 was to assume that the traffic benefits in the last year modelled remain constant for the remaining years of the project's life — six years for S00028 and 11 years for S00004.

Table 10.7 shows the present values for all sites grouped by treatment type and ordered by vehicle flow. Table 10.8 summarises table 10.7 providing the minimum, maximum, and average values for each treatment type group.

There is a very wide range present values from a benefit of $5.4 million to a cost of $26.1 million at the 3% discount rate, or a benefit of $2.8 million to a cost of $16.2 million at the 7% discount rate. Within each treatment type group, the degree of variation is less. Installation and modification of traffic signals have more pronounced impacts than roundabouts reflecting the higher traffic levels at signalised intersections. Net traffic benefits (negative costs) occur for four projects. The roundabout S00028 does so only at the 3% discount rate.

T10.7 Present values of traffic cost impacts at various discount rates

($ millions)

Project	Type code[a]	Discount rate (%)			
		3	4	5	7
N01073	r	1.34	1.20	1.08	0.89
N00114	r	0.42	0.38	0.34	0.28
S00028	r	-0.07	0.26	0.50	0.83
V01062	r	4.10	3.70	3.37	2.82
S00004	t	-0.80	-0.73	-0.67	-0.56
N00239	t	7.01	6.52	6.08	5.33
N00851	t	9.44	8.75	8.14	7.09
N00228	t	16.14	15.00	13.98	12.23
V03035	t	26.14	22.98	20.32	16.17
N00846	t	-5.35	-4.59	-3.93	-2.84
V00385	m	4.64	4.22	3.85	3.25
N00995	m	0.78	0.73	0.68	0.60
V01340	m	2.03	1.82	1.65	1.36
V01590	m	13.04	12.14	11.32	9.92
V01145	m	5.80	5.38	5.00	4.35
Q00569	l	-3.79	-3.36	-2.99	-2.41
V01311	lm	4.42	3.97	3.59	2.97
Q00768	lm	0.02	0.01	0.01	0.01

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together

T10.8 Present values of traffic impacts: summary of table 10.7

($ millions)

Type code[a]		Discount rate (%)			
		3	4	5	7
r	Minimum	-0.1	0.3	0.3	0.3
r	Average	1.4	1.4	1.3	1.2
r	Maximum	4.1	3.7	3.4	2.8
t	Minimum	-5.4	-4.6	-3.9	-2.8
t	Average	8.8	8.0	7.3	6.2
t	Maximum	26.1	23.0	20.3	16.2
m	Minimum	0.8	0.7	0.7	0.6
m	Average	5.3	4.9	4.5	3.9
m	Maximum	13.0	12.1	11.3	9.9
l	only project	-3.8	-3.4	-3.0	-2.4
lm	Minimum	0.0	0.0	0.0	0.0
lm	Average	2.2	2.0	1.8	1.5
lm	Maximum	4.4	4.0	3.6	3.0
All	Minimum	-5.4	-4.6	-3.9	-2.8
All	Average	4.7	4.4	4.0	3.5
All	Maximum	26.1	23.0	20.3	16.2

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together.

Table 10.9 combines the present values of the traffic impact costs with the present values of the crash benefits and project costs.

As the benefits and costs for individual projects vary widely, the averages for each treatment type are also shown for comparison. The turning lane project Q00569 was not included in the database for the regression analysis so no crash benefits are available. The average present values of the safety benefits for projects with the relevant intersection treatments range from $1.2 million for T07 turning lanes to $2.9 million for T01 roundabouts at the 3% discount rate and $0.7 to $1.6 million at the 7% rate.

For the 17 case study projects, all had positive NPVs based on crash benefits alone. In ten cases, inclusion of traffic costs made the NPVs negative. Eight of the ten involve new traffic signals or modifications to existing traffic signals, the two treatment types with the greatest traffic cost impacts. The traffic costs are up to 12 times the size of the crash benefits at the 3% discount rate and 14 times at the 7% discount rate. Negative NPVs ranged down to –$19 million at the 3% discount rate and –$13 million at the 7% discount rate for a new signals project.

The effects on the BCRs of including traffic costs are quite dramatic in some cases, especially for the modify traffic signals projects. These projects have relatively low costs, which makes their BCRs extremely sensitive to changes in benefits.

T10.9 Effect on CBA results of including traffic impact costs

($ millions present values)
3% discount rate

Project reference	Type code[a]	Crash benefits	Traffic costs	Total benefits	Costs	NPV	BCR crashes only	BCR all
N01073	r	3.9	1.3	2.5	0.2	2.3	17.2	11.2
N00114	r	0.6	0.4	0.2	0.1	0.1	5.8	2.0
S00028	r	4.7	-0.1	4.7	0.6	4.2	8.2	8.3
V01062	r	2.5	4.1	-1.6	0.3	-1.9	8.6	-5.5
Average T01	**r**	**2.9**			**0.2**		**13.6**	
S00004	t	12.7	-0.8	13.5	0.4	13.1	30.8	32.7
N00239	t	1.0	7.0	-6.0	0.4	-6.4	2.5	-15.8
N00851	t	2.0	9.4	-7.4	0.5	-7.9	4.4	-16.2
N00228	t	1.5	16.1	-14.6	0.9	-15.5	1.7	-16.7
V03035	t	8.4	26.1	-17.7	1.4	-19.1	6.0	-12.6
N00846	t	1.0	-5.4	6.3	0.5	5.8	1.9	12.4
Average T03	**t**	**2.4**			**0.4**		**6.8**	
V00385	m	1.4	4.6	-3.2	0.0	-3.2	57.5	-128.3
N00995	m	3.3	0.8	2.5	0.1	2.4	34.1	26.0
V01340	m	2.1	2.0	0.1	0.2	-0.1	13.3	0.6
V01590	m	1.1	13.0	-11.9	0.2	-12.1	6.2	-66.7
V01145	m	1.7	5.8	-4.1	0.0	-4.1	151.8	-369.7
Average T04	**m**	**1.7**			**0.1**		**13.2**	
Q00569[b]	l	na	-3.8	na	na	na	na	na
Average T07	**l**	**1.2**			**0.2**		**6.1**	
V01311	lm	2.8	4.4	-1.7	0.1	-1.7	39.8	-24.2
Q00768	lm	1.6	0.0	1.6	0.2	1.5	10.4	10.3

continued

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together

b. No estimates of crash reduction benefits or project costs are available for the turning lane project Q00569 because it was not included in the database for the Poisson regression analysis and CBA.

T10.9 Effect on CBA results of including traffic impact costs (continued)

($ millions present values)
4% discount rate

Project reference	Type code[a]	Crash benefits	Traffic costs	Total benefits	Costs	NPV	BCR crashes only	BCR all
N01073	r	3.3	1.20	2.1	0.2	1.9	14.7	9.3
N00114	r	0.5	0.38	0.2	0.1	0.1	5.0	1.5
S00028	r	4.0	0.26	3.7	0.6	3.2	7.0	6.5
V01062	r	2.1	3.70	-1.6	0.3	-1.9	7.3	-5.4
Average T01	**r**	**2.5**			**0.2**		**11.6**	
S00004	t	11.2	-0.73	11.9	0.4	11.5	27.6	29.5
N00239	t	0.8	6.52	-5.7	0.4	-6.0	2.3	-15.1
N00851	t	1.8	8.75	-7.0	0.4	-7.4	4.0	-15.5
N00228	t	1.3	15.00	-13.7	0.9	-14.5	1.6	-15.9
V03035	t	7.1	22.98	-15.8	1.3	-17.2	5.3	-11.8
N00846	t	0.9	-4.59	5.5	0.5	5.0	1.7	10.9
Average T03	**t**	**2.1**			**0.3**		**6.1**	
V00385	m	1.2	4.22	-3.0	0.0	-3.0	50.6	-121.4
N00995	m	2.9	0.73	2.2	0.1	2.1	30.9	23.1
V01340	m	1.8	1.82	0.0	0.2	-0.2	11.6	-0.1
V01590	m	1.0	12.14	-11.2	0.2	-11.3	5.6	-63.5
V01145	m	1.5	5.38	-3.9	0.0	-3.9	134.9	-352.0
Average T04	**m**	**1.5**			**0.1**		**11.7**	
Q00569[b]	l	na	-3.36	na	na	na	na	na
Average T07	**l**	**1.0**			**0.2**		**5.3**	
V01311	lm	2.3	3.97	-1.6	0.1	-1.7	34.8	-24.4
Q00768	lm	1.4	0.01	1.4	0.2	1.2	9.1	9.0

continued

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together.

b. No estimates of crash reduction benefits or project costs are available for the turning lane project Q00569 because it was not included in the database for the Poisson regression analysis and CBA.

T10.9 Effect on CBA results of including traffic impact costs (continued)

($ millions present values)
5% discount rate

Project reference	Type code[a]	Crash benefits	Traffic costs	Total benefits	Costs	NPV	BCR crashes only	BCR all
N01073	r	2.8	1.08	1.7	0.2	1.5	12.6	7.8
N00114	r	0.5	0.34	0.1	0.1	0.0	4.3	1.2
S00028	r	3.4	0.50	2.9	0.6	2.3	6.0	5.1
V01062	r	1.8	3.37	-1.5	0.3	-1.8	6.3	-5.3
Average T01	**r**	**2.1**			**0.2**		**10.0**	
S00004	t	10.0	-0.67	10.6	0.4	10.2	25.0	26.7
N00239	t	0.8	6.08	-5.3	0.4	-5.7	2.0	-14.4
N00851	t	1.6	8.14	-6.6	0.4	-7.0	3.6	-14.8
N00228	t	1.2	13.98	-12.8	0.8	-13.6	1.4	-15.1
V03035	t	6.1	20.32	-14.2	1.3	-15.5	4.7	-11.0
N00846	t	0.8	-3.93	4.7	0.5	4.2	1.6	9.5
Average T03	**t**	**1.9**			**0.3**		**5.5**	
V00385	m	1.1	3.85	-2.8	0.0	-2.8	44.9	-114.7
N00995	m	2.6	0.68	1.9	0.1	1.8	28.1	20.7
V01340	m	1.6	1.65	-0.1	0.2	-0.2	10.2	-0.6
V01590	m	0.9	11.32	-10.5	0.2	-10.6	5.0	-60.5
V01145	m	1.3	5.00	-3.7	0.0	-3.7	120.8	-334.6
Average T04	**m**	**1.3**			**0.1**		**10.5**	
Q00569[b]	l	na	-2.99	na	na	na	na	na
Average T07	**l**	**0.9**			**0.2**		**4.7**	
V01311	lm	2.0	3.59	-1.6	0.1	-1.6	30.6	-24.2
Q00768	lm	1.2	0.01	1.2	0.1	1.0	7.9	7.9

continued

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together.

b. No estimates of crash reduction benefits or project costs are available for the turning lane project Q00569 because it was not included in the database for the Poisson regression analysis and CBA.

T10.9 Effect on CBA results of including traffic impact costs (continued)

($ millions present values)
7% discount rate

Project reference	Type code[a]	Crash benefits	Traffic costs	Total benefits	Costs	NPV	BCR crashes only	BCR all
N01073	r	2.2	0.89	1.3	0.2	1.1	9.7	5.7
N00114	r	0.4	0.28	0.1	0.1	0.0	3.3	0.7
S00028	r	2.6	0.83	1.8	0.6	1.2	4.6	3.1
V01062	r	1.4	2.82	-1.4	0.3	-1.7	4.8	-4.9
Average T01	**r**	**1.6**			**0.2**		**7.6**	
S00004	t	8.1	-0.56	8.6	0.4	8.2	20.9	22.3
N00239	t	0.6	5.33	-4.7	0.4	-5.1	1.7	-13.2
N00851	t	1.3	7.09	-5.8	0.4	-6.2	3.0	-13.5
N00228	t	1.0	12.23	-11.3	0.8	-12.1	1.2	-13.7
V03035	t	4.7	16.17	-11.5	1.2	-12.7	3.8	-9.5
N00846	t	0.6	-2.84	3.5	0.5	3.0	1.3	7.2
Average T03	**t**	**1.5**			**0.3**		**4.6**	
V00385	m	0.8	3.25	-2.4	0.0	-2.4	36.1	-102.3
N00995	m	2.1	0.60	1.5	0.1	1.4	23.6	16.9
V01340	m	1.2	1.36	-0.2	0.1	-0.3	8.1	-1.2
V01590	m	0.7	9.92	-9.2	0.2	-9.4	4.2	-54.9
V01145	m	1.1	4.35	-3.3	0.0	-3.3	98.9	-301.7
Average T04	**m**	**1.0**			**0.1**		**8.6**	
Q00569[b]	l	na	-2.41	na	na	na	na	na
Average T07	**l**	**0.7**			**0.2**		**3.7**	
V01311	lm	1.5	2.97	-1.4	0.1	-1.5	24.4	-23.1
Q00768	lm	0.9	0.01	0.9	0.1	0.7	6.3	6.2

a. r = roundabout, t = traffic signals, m = modify traffic signals, l = turning lane, lm = turning lane and modify traffic signals together.

b. No estimates of crash reduction benefits or project costs are available for the turning lane project Q00569 because it was not included in the database for the Poisson regression analysis and CBA.

End note

The case studies show that traffic impact costs of black spot projects at intersections vary greatly between projects and can be substantial. They are more likely to be negative than positive and have the potential to greatly offset the safety benefits, particularly for projects involving traffic signals.

At very high traffic levels, black spot projects can improve traffic flows adding to the safety benefits. Ignoring traffic impacts of black spot projects can lead to bad decisions from the point of view of society as a whole. It may therefore be desirable that greater attention be paid to traffic impacts in future when making decisions about black spot projects.

Such a recommendation is difficult to implement in a rigorous way because each case is different and the data and modelling requirements make quantification costly. Greater weight could be given to the subjective assessments of traffic impacts by experts.

In the longer term, it may be possible to develop 'lookup tables' from which indicative estimates of traffic impact benefits and costs can be made, just as lookup tables of crash reduction factors by treatment type and crash type are used to estimate ex-ante safety benefits.

Inclusion of traffic impacts in CBAs of black spot projects implies acceptance of lower levels of road safety in exchange for savings in time, vehicle operating costs and emissions. The balance would be shifted back towards safety to a certain extent if Australia switched from the human capital to the willingness-to-pay approach for costing crashes, discussed in appendix B.

CHAPTER 11

Lessons learned for future evaluations

The report's closing chapter summarises the lessons learned from the study for the benefit of future black spot program evaluations.

Methodology

The study has shown how data from a very large number of black spot projects can be analysed using Poisson regression. Each regression model relates to a single crash severity category, but covers all treatment types in all locations (jurisdiction, urban/rural, local road/state road). The approach therefore avoids the need for separate regression models for different treatment types and location categories.

Numerous issues that arise when applying Poisson regression to black spot data have been discussed and practical solutions implemented for many of them. Examples include:

- adjusting for the time trend for crashes in general by including time trend offsets
- removing potential biases caused by uncertain observation periods at some sites
- adjusting for over-dispersion by factoring up the standard errors of coefficient estimates
- adjusting for the effects of regression to the mean by using the period between application for funds and implementation as the base for estimating treatment effects
- estimating a rate of change for effectiveness of treatments over time
- taking account of all the treatments in multiple-treatment projects, not just the primary treatment, and estimating interactions between treatments for pairs of types that occur frequently in the data

Although non-target crashes could not be removed from the data, the implications for the study were considered in detail. Appendix C provides a mathematical exploration of the issue.

Appendix C also shows how to estimate maximum likelihood treatment effectiveness indexes from before-and-after crash data when treatment is the sole explanatory variable, and to test for statistical significance.

For regression models that include locational explanatory variables, there are huge numbers of individual treatment effect results that can be calculated, as evidenced by appendix D in volume 2. The weighted averaging method in chapter 6 provides a convenient way to summarise the results for individual treatment types.

The regression models were specified to estimate different daytime and night-time effect terms for treatments types for which they are expected to differ significantly, for example, street lights.

Data

Some state and territory road agencies required considerable time to assemble the necessary data and then it took a great deal of effort for BITRE to process the data into a form suitable for the regression analysis. For many projects, no data were available at all.

Many projects for which data were supplied had to be dropped from the database because critical items were missing. Future evaluations would be easier and more comprehensive if project and crash data were better managed by road agencies.

Crash data

The Notes on Administration for the current Australian Government black spot program state:

> *It is of fundamental importance that Nation Building Program Black Spot Projects be accountable for results in terms of outcomes. To determine its actual effect on crashes, formal evaluation of Nation Building Program Black Spot Projects may be conducted from time to time. As set out under Section 84 of the Act, funding recipients must maintain, and make available as required, records relating to the nature and frequency of motor vehicle crashes involving death or personal injury occurring at the site of funded projects. (DIT 2009a, p. 17)*

The 'Act' here refers to the Nation Building Program (National Land Transport) Act 2009. Maintenance and supply of crash data in relation to Australian Government funded black spot projects is required by law.

For a number of sites, it was uncertain when the observations commenced or ended. This necessitated excluding the either first or last recorded crash. Such loss of data reduces the statistical significance of estimates from the regression analysis. It is desirable that crash data for black spot sites be recorded and supplied in a way that ensures the commencement and the end of the observation periods are known.

Standardisation of crash severity definitions across jurisdictions is desirable. There are currently differences in definitions of injury (non-fatal casualty) crashes. BITRE (2009) divided injury crashes into hospitalised and non-hospitalised categories instead of the serious injury and minor injury categories used in BTE (2000).

Reporting requirements for PDO crashes vary greatly between jurisdictions and there is enormous under-reporting of PDO crashes. Sensitivity testing in the present study suggests that including reported PDO crashes in cost–benefit analyses of black spot programs does not make much difference to benefit–cost ratios (a 9% increase), but adding estimated unreported PDO crashes makes a significant difference — a 30% increase.

For a few individual treatment types in urban areas, including reported PDO crashes can make a significant difference to benefit–cost ratios. It could be argued there is limited value in considering PDO crash data in black spot program evaluations unless the level of reporting is improved.

The level of under-reporting for minor injury crashes is believed to be even greater than for PDO crashes. Reducing this should improve the accuracy of both exante appraisals of individual black spot projects and expost program evaluations.

A degree of arbitrariness is inevitable in nominating the boundaries around project sites that determine whether or not a crash is deemed to have occurred at the site. However, it is desirable that the methods, parameters and definitions used to assign crashes to black spot project sites be standardised, preferably based on research and expert advice.

The National Road Safety Strategy 2011–2020 (ATC 2011, p. 104) states that jurisdictions will 'work towards the adoption of nationally consistent road crash classification definitions and the development of an improved national serious injury database'. Such developments will be invaluable for future administration and evaluation of black spot programs.

Project and site data

Data on legal speed limits at sites of black spot projects is desirable because individual treatment types can have different levels of effectiveness in low-speed and high-speed environments. The urban/rural distinction in the present study, which is more accurately described as metropolitan/non-metropolitan, only partly captures the effects of different speed environments.

Data on traffic levels at sites, preferably for more than a single year, would avoid the need to assume that crash reduction factors do not vary with exposure level. The data would also improve the accuracy of black spot evaluations by enabling changes in crash rates due to changes in traffic levels to be distinguished from changes due to black spot projects.

Greater consistency and care in describing treatments would improve the ability of evaluators to identify differences in effectiveness between treatment types. With multiple-treatment projects becoming more commonplace, the risk of omitting or misclassifying treatments is growing. The generic treatment description 'channelisation' should be replaced with specific descriptions such as medians, turning lanes and line marking.

The study has produced a detailed treatment classification system, documented in appendix A, developed specifically to facilitate expost evaluations. It is desirable that this be adopted by all jurisdictions.

For cost–benefit analysis, the full construction costs of projects are required regardless of who contributes the funds. ANAO (2007) found that information about contributions to the costs of black spot projects by state and local governments often does not reach the Australian Government. Analysis of project cost data for the present study strongly suggested major differences in reporting levels between jurisdictions. BITRE made upward adjustments to the cost data to compensate for under-reporting of costs.

End note

The present study has made significant advances in the methodology for black spot program evaluation. Heeding the lessons learned should improve the accuracy and reduce the time and resource requirements of future black spot program evaluations.

APPENDIX A

Bitre treatment classification system

Definitions for Coding Treatments

The new Definitions for Coding Treatments (DCT) table developed by BITRE for the present evaluation provides a way to code treatments at both the aggregate (treatment category/code) and detailed (sub-code) levels for the purposes of program administration and evaluation. It is intended to replace the system set out in BTE (2001, pp. 157–8).

The table does away with the distinction between 'spot' and 'length' treatments in the old system (Andreassen 1994, BTE 2001) because most treatments can be implemented at both lengths and spots. Treatments undertaken at spots or lengths are best distinguished via a separate spot/length field in the database.

To avoid unnecessary complexity, the number of sub-codes has been kept to a minimum and separate codes have not been created for combined treatments. The table is structured to allow the user to develop more refined sub-codes, if required. The codes and sub codes can be further sub-divided to classify minor distinctions or alternate forms of treatments.

Table A1 lists the treatment types and codes. Table A2 lists sub-types codes. A 'Glossary of Terms' is provided below that lists some definitions and synonymous terms used in the tables. Table A3 explains the symbols used.

TA1 Treatment types and codes

Code	Treatment Category
T01	Roundabout
T02	Medians
T03	New signals (including those with turning arrows)
T04	Modify existing signals/change phase
T05	Traffic calming measures
T06	Lighting treatments
T07	Turning lanes
T08	Pedestrian treatments
T09	Bicycle treatments
T10	Sealing and resealing (includes sealing of previously unpaved roads)
T11	Non-skid treatment
T12	Alter road width (includes addition/reduction of lane/s)
T13	Overtaking lane/s
T14	Barriers/guardrails (includes safety fences)
T15	Realign road length — horizontal and vertical (primarily mid-block treatments)
T16	Realign intersection
T17	Clear obstacles or hazards
T18	Warning signs
T19	Line marking (painted and audible)
T20	Priority sign treatments
T21	Ban turns
T22	Alterations to direction of traffic flow (includes road closure or reopening and allowing of previously banned turns)
T23	Cameras
T24	Speed limits
T25	Parking (includes bus, set down/pick up, stopping bays, etc.)
T26	Railway crossing
T27	Grade separation
T28	Channelisation
T29	Other

TA2 Treatment sub-types and codes

T01 Roundabout	
T01.1	Install roundabout [number of lanes unspecified]
T01.2	Install 1-lane roundabout
T01.3	Install 2-lane roundabout
T01.4	Install >2-lane roundabout
T01.5	Reconstruct/modify existing roundabout
T02 Medians	
T02.1	Install central median island/s [raised or painted is unspecified]
T02.2	Install central median – raised
T02.3	Install central median – painted
T02.4	Install central median & kerb blisters/extensions [raised or painted central median is unspecified]
T02.5	Install central median & kerb blisters/extensions – raised
T02.6	Install traffic islands or medians on approaches to an intersection
T02.7	Install a painted median & kerb blisters/extensions
T02.8	Extend median into an intersection to move holding line forward [including extensions to kerb]
T02.9	Extend existing median islands [type not specified]
T03 New signals (including those with turning arrows)	
T03.1	Install new traffic signals [turn movements unspecified]
T03.1.1	Install new traffic signals with no turning arrows (i.e. no control phase on turning movements)
T03.2	Install new traffic signals with fully controlled right turn (FCRT) phase
T03.3	Install new traffic signals with partially controlled right turn (PCRT) phase
T03.4	Install new traffic signals with fully controlled left turn (FCLT) phase
T03.5	Install new traffic signals with partially controlled left turn (PCLT) phase
T03.6	Install new traffic signals with FCRT & FCLT phase [full or partial control unspecified]
T04 Modify existing signals/change phase	
T04.1	Re-model or modify existing signal/s [unspecified]
T04.2	Install mast arms to existing signals
T04.3	Add fully or partially controlled right turn phase to existing signal/s [the phase may operate either full or part-time]
T04.3.1	Add fully controlled right turn phase (FCRT) to existing signals, where the phase operates full-time
T04.3.2	Add partially controlled right turn phase (PCRT) to existing signals, where the phase operates full-time
T04.3.4	Add fully controlled right turn phase (FCRT) to existing signals, where the phase operates part-time
T04.3.4	Add partially controlled right turn phase (PCRT) to existing signals, where the phase operates part-time
T04.4	Add protected left turn phase to existing signal/s [includes signalising of left turn slip lanes]
T04.5	Upgrade existing signal lanterns [e.g. Increase lantern size and/or visibility, replace faded lantern screens, or refit with led's, add backing boards, etc.]
T04.6	Alter signal phase timing
T04.7	Remove turn phase [right or left]
T04.8	Install U-turn control/phase

continued

TA2 Treatment sub-types and codes (continued)

T05 Traffic Calming Measures	
T05.1	Install a slow point or speed attenuation device [unspecified, but includes narrow points using kerb extensions, or blisters, or barriers etc.]
T05.2	Install one way chicane [horizontal displacement]
T05.3	Install tadpole treatment [or two-way chicane; horizontal displacement]
T05.4	Narrow intersection with blisters only
T05.5	Install speed humps [i.e. Vertical displacement, includes; platforms, cushions & raised thresholds at intersections or along mid-blocks etc.]
T05.6	Install both vertical & horizontal displacement treatments
T05.7	Improve or replace existing traffic calming devices
T05.8	Install a traffic calming scheme [unspecified, or may involve multiple measures]
T05.9	Narrow intersection with kerb blisters/extensions [may include a raised central median]
T05.9.1	Narrow intersection with kerb blisters/extensions only
T06 Lighting Treatments	
T06.1	Install lighting at intersection - where none previously existed [standard not specified]
T06.1.1	[To meet category 'P' lighting schemes - as described in AS/NZS 1158.3]
T06.1.2	[To meet category 'V' lighting schemes - as described in AS/NZS 1158.1]
T06.1.3	[No standard specified or 'other']
T06.2	Install lighting at mid-block - where none previously existed [standard not specified]
T06.2.1	[To meet category 'P' lighting schemes - as described in AS/NZS 1158.3]
T06.2.2	[To meet category 'V' lighting schemes - as described in AS/NZS 1158.1]
T06.2.3	[No standard specified or 'other']
T06.3	Improve or upgrade existing street lighting at intersection [standard not specified]
T06.3.1	[To meet category 'P' lighting schemes - as described in AS/NZS 1158.3]
T06.3.2	[To meet category 'V' lighting schemes - as described in AS/NZS 1158.1]
T06.3.3	[No standard specified or 'other']
T06.4	Improve or upgrade existing street lighting at mid-block [standard not specified]
T06.4.1	[To meet category 'P' lighting schemes - as described in AS/NZS 1158.3]
T06.4.2	[To meet category 'V' lighting schemes - as described in AS/NZS 1158.1]
T06.4.3	[No standard specified or 'other']

continued

TA2 Treatment sub-types and codes (continued)

T07 Turning Lane	
T07.1	Install right turn bay or lane – painted [or raised unknown]
T07.2	Install left turn bay or lane – painted [or raised unknown]
T07.3	Install raised right turn bay or lane [a new median may be installed, or an existing median modified to form the turn bay]
T07.4	Install raised left turn bay or lane [a new median may be installed, or an existing median modified to form the turn bay]
T07.5	Install right turn slip lane
T07.6	Install left turn slip lane
T07.7	Extend existing right turning lane, bay or slip lane
T07.8	Extend existing left turning lane, bay or slip lane
T07.9	Install flush median [i.e. A mid-block painted island allowing both left and right turns]
T07.10	Install turning lane/s [turn direction unspecified, but may include installing of both left and right turning lane/s]
T07.11	Install seagull island – painted or raised [acceleration or deceleration lanes not specified]
T07.12	Install a raised seagull island with right turn [from side street] acceleration lane
T07.13	Install a raised seagull island with right turn deceleration lane [a left turn slip lane/s in side street are optional but may be included]
T07.14	Install turning lane, bay or slip lane [painted or raised, turn direction unspecified]
T07.15	Extend turning lane, bay or slip lane [painted or raised, turn direction unspecified]
T07.16	Install additional turning lane/s [left &/or right turn – can be used in conjunction with road widening treatments T12.8 (alter road width - install additional road lane/s) where this work is known to have also been undertaken]
T07.17	Install a 'u'-turn lane/s
T08 Pedestrian Treatments	
T08.1	Install pedestrian refuge
T08.2	Install zebra crossing
T08.3	Install pelican crossing
T08.4	Install wombat crossing
T08.5	Install or modify pedestrian signals [unspecified - can be at mid-block or intersection]
T08.5.1	Add a protected pedestrian crossing phase ahead of turning traffic to existing traffic signal/s
T08.5.2	Install a signalised pedestrian crossing only
T08.5.3	Add vehicle detector loops in roadway to activate existing downstream pedestrian operated signals
T08.5.4	Install an illuminated "give way to pedestrians" sign
T08.6	Install pedestrian safety fencing or barrier
T08.7	Install pedestrian kerb extensions/blisters
T08.8	Install pedestrian signals & pedestrian safety fencing or barrier
T08.9	Install pedestrian footpath
T08.10	Install pedestrian underpass or tunnel
T08.11	Remove existing signalised pedestrian crossing only or, pedestrian crossing phase on traffic signal/s
T08.12	Remove existing non-signalised pedestrian crossing facility [unspecified - but can include zebra, pelican, wombat crossing etc.]

continued

TA2 Treatment sub-types and codes (continued)

T09 Cycling Treatments	
T09.1	Install on-road cycle lane
T09.2	Install off-road cycle lane
T09.3	Install on-road head start storage area at intersection
T09.4	Install 'dual use' cycle & pedestrian path
T09.4.1	Upgrade existing 'dual use' cyclist & pedestrian path – including widening, resealing etc.
T09.5	Install cyclist 'grab/support' rail at crossing hold point/s
T10 sealing & resealing (includes sealing of previously unpaved roads)	
T10.1	Seal surface of unpaved road [shoulders not specified]
T10.2	Seal surface of unsealed shoulders only on a paved road [shoulder width not specified]
T10.2.1	& shoulder is 1.0m or less (≤ 1.0m) wide
T10.2.2	& shoulder is greater than 1.0m and no more than 2.5m (>1.0m ≤ 2.5m) wide
T10.2.3	& shoulder is greater than 2.5m (> 2.5m) wide
T10.3	Seal surface of unpaved road lanes and unpaved shoulders [shoulder width not specified]
T10.3.1	where shoulder is 1.0m wide or less (≤ 1.0m)
T10.3.2	where shoulder between 1.0m and no more than 2.5m wide (>1.0m ≤ 2.5m)
T10.3.3	where shoulder greater than 2.5m wide (> 2.5m)
T10.4	Reseal surface of an existing paved road [shoulders not specified]
T10.5	Reseal surface of existing paved shoulder/s on a paved road [shoulder width not specified]
T10.5.1	& shoulder is 1.0m or less (≤ 1.0m) wide
T10.5.2	& shoulder is greater than 1.0m and no more than 2.5m (>1.0m ≤ 2.5m) wide
T10.5.3	& shoulder is greater than 2.5m (> 2.5m) wide
T10.6	Reseal surface of existing paved road lanes and paved shoulder/s [shoulder width not specified]
T10.6.1	& shoulder is 1.0m or less (≤ 1.0m) wide
T10.6.2	& shoulder is greater than 1.0m and no more than 2.5m (>1.0m ≤ 2.5m) wide
T10.6.3	& shoulder is greater than 2.5m (> 2.5m) wide
T11 Non-Skid Treatment	
T11.1	Apply non-skid treatment [lane/shoulder plus type of materials not specified]
T11.2	Apply a non-skid treatment to a sealed lane [type of materials unspecified]
T11.2.1	using epoxy/calcined bauxite coating
T11.2.2	using pavement grooving
T11.2.3	using high pressure water or air retexturing (incl. with grit/granulation additives)
T11.3	Apply a non-skid treatment to a sealed lane and shoulder [type of materials unspecified]
T11.3.1	using epoxy/calcined bauxite coating
T11.3.2	using pavement grooving
T11.3.3	using high pressure water or air retexturing (incl. with grit/granulation additives)

continued

TA2 Treatment sub-types and codes (continued)

T12 Alter Road Width (includes addition/reduction of lane/s)	
T12.1	Widen existing road lane/s only [not adding to the number of road lanes! – see T12.8 below]
T12.2	Narrow width of existing road lane/s [not reducing the number of road lanes! – see T12.14 below]
T12.3	Add a shoulder/s to a road – where no shoulder previously existed [width not specified]
T12.3.1	& shoulder is 1.0m or less (≤ 1.0m) wide
T12.3.2	& shoulder is greater than 1.0m and no more than 2.5m (>1.0m ≤ 2.5m) wide
T12.3.3	& shoulder is greater than 2.5m (> 2.5m) wide
T12.4	Widen an existing road shoulder [width not specified]
T12.4.1	Widen existing road shoulder to 1.0m or less (≤ 1.0m) wide
T12.4.2	Widen existing road shoulder to greater than 1.0m and no more than 2.5m (>1.0m ≤ 2.5m)
T12.4.3	Widen existing road shoulder to greater than 2.5m (> 2.5m)
T12.5	Widen entire roadway [width unspecified – can include lanes, shoulders, medians, etc. where these exist, of intersections or mid-blocks]
T12.6	Widen approaches & departures
T12.7	Widen a bridge weir, culvert etc.
T12.8	Widen by installing additional road lane/s [unspecified, but not overtaking lanes! – see T13 below. Also, use T12.8.1–3 in conjunction with T07.16 in cases where turning lanes are added and road widening is known to have been undertaken at the same time]
T12.8.1	where lanes are right turning lanes
T12.8.2	where lanes are left turning lanes
T12.8.3	where lanes are both right turning & left turning lanes
T12.9	Widen an intersection [unspecified – however, see also T12.8.1–3 above for turning lanes]
T12.10	Widen by installing a deceleration lane/s
T12.11	Widen by extend existing deceleration lane/s
T12.12	Widen by installing an acceleration lane/s
T12.13	Widen by extend existing acceleration lane/s
T12.14	Narrow by reducing the number of road lanes
T12.14.1	Merge two lanes into one lane
T12.15	Widen by conversion to dual carriageway
T13 Overtaking Lane/s	
T13.1	Install passing/overtaking lane/s
T13.2	Install slow vehicle lane

continued

TA2 Treatment sub-types and codes (continued)

T14 Barriers/Guardrails (including safety fences)	
T14.1	Install guardrail/barrier [median, road-side, rigid, semi-rigid or flexible is unspecified]
T14.2	Install a median guardrail/barrier [rigid, semi-rigid or flexible is unspecified]
T14.3	Install a median guardrail/barrier – rigid [e.g. concrete barriers]
T14.4	Install a median guardrail/barrier – semi-rigid [e.g. 'w' beams]
T14.5	Install a median guardrail/barrier – flexible [e.g. wire rope barriers]
T14.6	Install a road-side guardrail/barrier [rigid, semi-rigid or flexible is unspecified]
T14.7	Install a road-side guardrail/barrier – rigid [e.g. concrete barriers]
T14.8	Install a road-side guardrail/barrier – semi-rigid [e.g. 'w' beams]
T14.9	Install a road-side guardrail/barrier – flexible [e.g. wire rope barriers]
T14.10	Replace or improve an existing guardrail/barrier [median, road-side, rigid, semi-rigid or flexible is unspecified]
T14.10.1	Replace 'BCT's (breakaway cable terminals) on existing guardrail/fence with 'MELT's (modified eccentric loader terminals)
T14.11	Install impact attenuation device/s
T15 realign road length - horizontal & vertical (primarily for mid-block treatments)	
T15.1	Realign road [including curves - unspecified]
T15.2	Realign road & improve road surface
T15.3	Realign road to improve sight distance
T15.4	Decrease radius of curve/s [these works may also include the improvement, correction or addition of two-way crossfall and/or superelevation]
T15.5	Increase radius of curve/s [includes straightening of curves along mid-blocks - these works may also include the improvement, correction or addition of two-way crossfall and/or superelevation]
T15.6	Remove curve entirely to straighten road
T15.7	Add or improve existing superelevation of curve/s [these works may also include the correction, improvement or addition of two-way crossfall]
T15.8	Add, improve or reconstruct road crossfall only
T15.9	Improve vertical alignment [typically a reduction of the road grade, including the removal of a crest of a hill]
T16 Realign Intersection	
T16.1	Realign intersection [unspecified]
T16.2	Modify existing 'Y' intersection to a 'T' (╦) intersection
T16.3	Construct a 'staggered-T' (╦╩) intersection from existing 'cross' (╬) intersection
T16.4	Realign approaches to an intersection [can include approaches to a bridge or underpass]
T16.5	Reduce radius of right or left turning lane [including slip lanes]
T16.6	Remove a curved or a slip entry and construct a 'T' (╦) intersection
T16.7	Add, improve or reconstruct intersection crossfall only

continued

TA2 Treatment sub-types and codes (continued)

T17 Clear Obstacles or Hazards	
T17.1	Remove roadside hazards [unspecified – includes clear zone 'enhancement']
T17.2	Remove roadside vegetation [including trees]
T17.3	Widen clearzones
T17.4	Modify culverts [to improve visibility or collision safety - for 'culvert widening' see T12.7]
T17.5	Remove infrangible or other object from a footway
T17.6	Relocate poles away from carriageway [poles include those used for lighting, traffic signals, power, etc]
T17.7	Replace existing hard posts or poles with frangible posts/poles
T17.8	Modify/improve drainage
T18 Warning Signs	
T18.1	Install advance warning signs [unspecified – however, these may comprise the following: traffic signals ahead, stop sign ahead, warn of specific hazard/s on road ahead, curve ahead, steep decent/ascent, slippery surface when wet, etc.]
T18.2	Install curve alignment markers (C.A.M.S)
T18.3	Install speed advisory sign/s [includes the 'reduce speed' warning signs, and speed signs installed after RGDAS surveys]
T18.4	Install road alignment warning sign/s
T18.5	Install combined road alignment and speed advisory warning sign/s
T18.6	Install signs warning of rail crossing ahead [not to be confused with T26, where signs are added at the rail crossing point itself]
T18.7	Install flashing advance warning signs [unspecified - fog, steep decent, low bridge, etc. But not railway warning sign, use T18.6 - see also T26]
T18.8	Install flood warning signs [includes depth indicators]
T18.9	Upgrade existing warning signs [unspecified]
T19 line marking (painted & audible)	
T19.1	Install painted line markings [unspecified]
T19.2	Install painted edgelines only
T19.3	Install painted centrelines only
T19.4	Install both painted edgelines and centrelines
T19.5	Install audible and painted line markings [unspecified]
T19.6	Install audible and painted edgelines only
T19.7	Install audible and painted centrelines only
T19.8	Install both audible and painted edgelines or centrelines
T19.9	Install raised reflective pavement markers (RRPM's)
T19.10	Improve night visibility of existing painted edgelines
T19.11	Improve night and wet weather visibility of existing painted edgelines
T19.12	Install new, or upgrade existing, visual guide posts [includes posts with reflectors]
T19.12.1	Install visual guide posts where none existed previously
T19.12.2	Upgrade existing visual guide posts
T19.13	Improve/upgrade existing painted line markings [unspecified]

continued

TA2 Treatment sub-types and codes (continued)

T20 Priority Sign Treatments	
T20.1	Install priority or control signs at intersection [unspecified]
T20.1.1	Install stop sign where no priority sign existed previously [see T20.4 for change from give way to stop]
T20.1.2	Install give way sign where no priority sign existed previously
T20.2	Install regulatory signs along road length [speed limit, stop, give way, roundabout, pavement arrows]
T20.3	Reinforce or improve existing priority sign/s [includes adding additional signage]
T20.4	Change from give-way to stop where a give way sign already existed [if not see T20.1.1]
T21 Ban Turns	
T21.1	Ban left turn movement [directions & arms unspecified]
T21.1.1	Ban left turns only out of one arm at a ╬ intersection [all other turns may still be allowed]
T21.1.2	Ban left turns only out of two or more arms at a ╬ intersection [all other turns may still be allowed]
T21.1.3	Ban left turns out of the stem of a ╦ intersection [all other turns may still be allowed]
T21.1.4	Ban left turns into the stem of a ╦ intersection [all other turns may still be allowed]
T21.1.5	Ban left turns out of and into the stem of a ╦ intersection [all other turns may still be allowed]
T21.2	Ban right turn movement [directions & arms unspecified]
T21.2.1	Ban right turns only out of one arm at a ╬ intersection [all other turns may still be allowed]
T21.2.2	Ban right turns only out of two or more arms at a ╬ intersection [all other turns may still be allowed]
T21.2.3	Ban right turns only out of the stem of a ╦ intersection [all other turns may still be allowed]
T21.2.4	Ban right turns only into the stem of a ╦ intersection [all other turns may still be allowed]
T21.2.5	Ban right turns out of and into the stem of a ╦ intersection [all other turns may still be allowed]
T21.3	Ban U-turn movement [in one or both directions]

continued

TA2 Treatment sub-types and codes (continued)

T22 Alterations to Direction of Traffic Flow (includes road closure or reopening & allowing of previously banned turns)	
T22.1	Close a street to traffic movements in both directions
T22.2	Close one arm to all traffic movements at a cross (╬) intersection [to create a ╦ intersection]
T22.3	Close two opposing arms of a cross (╬) intersection to all traffic movements [to create a straight through road: '═']
T22.4	Close the stem of a '╦' intersection [to create a straight through road: '═']
T22.5	Close a cross arm of a '╦' intersection [to create a corner: '╔' or '╗']
T22.6	Change from two way traffic to one way only
T22.7	Open a closed road [to one-way or two-way traffic]
T22.8	Change from one way traffic only to two-way
T22.9	Allow turns where previously banned [direction/s & arms unspecified]
T22.10	Allow left turns where previously banned [arms unspecified]
T22.10.1	Allow right turns into one arm at a ╬ intersection [other turns may still be banned]
T22.10.2	Allow right turns into two or more arms at a ╬ intersection [other turns may still be banned]
T22.10.3	Allow right turns out of the stem of a ╦ intersection [other turns may still be banned]
T22.10.4	Allow right turns into the stem of a ╦ intersection [other turns may still be banned]
T22.11	Allow right turns where previously banned [arms unspecified]
T22.11.1	Allow Left turns into one arm at a ╬ intersection [other turns may still be banned]
T22.11.2	Allow Left turns into two or more arms at a ╬ intersection [other turns may still be banned]
T22.11.3	Allow Left turns out of the stem of a ╦ intersection [other turns may still be banned]
T22.11.4	Allow Left turns into the stem of a ╦ intersection [other turns may still be banned]
T22.12	Close a 'cross' (╬) intersection to through traffic movements along one axis [this effectively creates a ╣╠ intersection – usually accomplished by installing or extending a raised median or other barrier through the intersection along one axis only, or, by placing triangular 'splitter' islands on opposite sides of the intersection to which exiting traffic is forced to make only left turns in order to exit. See also T21]
T22.12.1	ban right turns only out of two opposing arms at a ╬ intersection by installing or extending a raised median or other barrier through the intersection [all other turns may still be allowed]
T22.12.2	ban right turns only out of two opposing arms at a ╬ intersection by placing triangular 'Splitter' islands on opposite sides of the intersection [all other turns may still be allowed]
T23 Cameras (see notes below)	
T23.1	Install red light camera
T23.2	Install speed camera
T23.3	Install combined red light & speed camera

continued

TA2 Treatment sub-types and codes (continued)

T24 Speed Limits	
T24.1	Reduce speed limit on road length [amount unspecified]
T24.2	Reduce speed limit on road length – 110 to 100km/hr
T24.3	Reduce speed limit on road length – 100 to 90km/hr
T24.4	Reduce speed limit on road length – 90 to 80km/hr
T24.5	Reduce speed limit on road length – 80 to 70km/hr
T24.6	Reduce speed limit on road length – 70 to 60km/hr
T24.7	Reduce speed limit on road length – 60 to 50km/hr
T24.8	Reduce speed limit on road length – 50 to 40km/hr
T24.9	Reduce speed limit on approach to intersection [amount unspecified]
T24.10	Reduce speed limit on approach to intersection by no more than 10 km/hr
T24.11	Reduce speed limit on approach to intersection by > 10 km/hr
T24.12	Introduce speed restrictions at certain times [times unspecified]
T24.13	Introduce speed restrictions during school hours [e.g. 40 km/hr limit between 08:00 hrs and 16:00 hrs on school days]
T24.14	Decrease speed for heavy vehicles only [unspecified, e.g. A 100 to 90km/hr heavy vehicle speed zone]
T24.15	Increase speed limit by no more than 10 km/hr
T24.16	Increase speed limit by >10 km/hr
T25 parking (includes bus, set down/pick up, stopping bays, etc.)	
T25.1	Prohibit parking
T25.2	Prohibit parking at certain times [e.g. Clearways, etc.]
T25.3	Allow right angle parking
T25.4	Allow parallel parking
T25.5	Change from angle to parallel parking
T25.6	Install, modify or remove an existing set down/pick up bay [including bus bay, taxi bay but not a parking bay – see T25.7]
T25.6.1	Install a set down/pick up bay [including a bus bay, taxi bay]
T25.6.2	Modify an existing set down/pick up bay [including a bus bay, taxi bay]
T25.6.3	Remove an existing set down/pick up bay [including a bus bay, taxi bay]
T25.7	Install parking bay [including loading zone, parking zone, breakdown bay, etc. But not a bus bay or a taxi bay – see T25.6]
T25.8	Modify/improve existing parking [unspecified]

continued

TA2 Treatment sub-types and codes (continued)

T26 Railway Crossing Modification	
T26.1	Modify rail crossing - add warning signs
T26.2	Modify rail crossing - add warning signs, lights & bells
T26.3	Modify rail crossing - add warning signs, lights, bells & boom gates
T27 Grade Separation	
T27.1	Construct bridge over roadway [i.e. Replace an intersection with an interchange etc.]
T27.2	Construct bridge over railway [i.e. Replace an existing rail crossing]
T27.3	Construct bridge over waterway [i.e. Replace an existing ford or causeway]
T27.4	Construct bridge over roadway, railway, waterway, etc. - including realignment of approaches
T28 Channelisation (see notes below)	
T28.1	Channelise intersection [unspecified – can include line marking, painting etc.]
T28.2	Channelise road length [unspecified – can include line marking, painting etc.]
T29 Other (see notes below)	
T29	Used for coding treatments with insufficient detail to determine a treatment category

TA3 Symbols used in table A2

Cross or '+' intersection	╬
Tee or 'T' intersection or junction	╦
'Y' Intersection	Y
Corner	╔ or ╗
Opposing 'T' junctions	╣╠
Staggered 'T' junction	╦╩

Notes on specific categories

T21 Ban turns

T21 ban turns should not be confused with T22 alterations to direction of traffic flow. For example, banning a right turn from an arm of an intersection with only left turn or straight through movements allowed is coded as 'ban right turn movement' (T21.2).

T22 Alterations to direction of traffic flow

T22 alterations to direction of traffic flow also covers allowing movements through an intersection where the movement was previously banned. For example, prior to the treatment, only left turns were permitted into and out of an arm of an intersection. Right turns into the arm or out of the arm were banned. If right turns were allowed as part of the treatment, the code T22.11 would be used.

Another example is the closure to through traffic along one axis of a cross '+' intersection, which would be coded as T22.12. Typically, the closure is enforced with a raised median or fence or other barrier through the middle of the intersection, but that does not make the treatment a case of T02 medians or T14 barriers/guardrails. The T22 treatment category should also not be confused with T21 ban turns.

If alterations to the direction of traffic flow as per T22 are implemented together with some form of turning movement ban, then it is a multiple-treatment project with T22 as the primary treatment and T21 as a secondary treatment.

T27 Grade separation

Grade separation involves the placing of a road above an existing road, railway, or waterway such as an overpass, bridge or culvert. The grade separation category is also used in situations where a ford or causeway is replaced by a similar higher structure or by a bridge in order to remove waterway hazards (T28.3). For example, the projects aims to prevent debris including sediments, soil, stones, and vegetation from accumulating on the crossing and creating an access hazard, and also to reduce or remove the risk of vehicles being swept away when crossing attempts are made during flood events.

T28 Channelisation

The term 'channelisation' is somewhat generic. It is often used to describe a treatment or combination of treatments designed to guide or channel traffic into clearly defined paths to produce more orderly and safer traffic operation and to increase capacity (Austroads 2002).

Channelisation treatments aim to reduce the number of conflict points and minimise potential conflict areas at a site. This is achieved by preventing undesirable or unnecessary road movements and ensuring that a driver is confronted with only one decision at a time.

Raised traffic islands, raised markers, painted markings and safety bars can all be used for channelization, and at intersections, traffic islands are typically used. An example is a merging lane, which forces two separate lanes or streams of traffic into one.

Channelisation can refer to treatments in other categories, in particular, T02 medians, T07 turning lanes and T19 line marking. T01 roundabouts are a form of channelisation.

In black spot project databases, the channelisation category is sometimes used when more than one treatment was undertaken at the site. The description field typically lacks sufficient detail to determine the individual treatments undertaken.

In the present study, BITRE grouped channelisation with rarely-occurring treatments in the 'upspecified' category. Obtaining more detail on the treatments was not possible because many jurisdictions were unable to locate their site records, especially where the work was completed more than some five years prior to the time the data were requested.

Ideally, the channelisation category would not be used at all. Instead, treatments or component treatments of multiple-treatment projects would be classified under more specific categories in the DCT table.

It is noted that the term channelisation appears in the Austroads 'Guides to Traffic Engineering Practice' series and is a widely used in traffic engineering circles. It may therefore be difficult to motivate applicants for black spot program funding to describe their treatments in the level of detail that will be most helpful for black spot program evaluation.

T29 Other

The 'other' treatment category is a category used in the National Black Spot Program database for treatments that did not fit into any of the categories of the old treatment classification system or where the applicant was unable to, or failed to, specify a treatment code.

Multiple treatment projects

Projects that combine multiple treatments of different types are becoming more common. Yet, due to lack of data from large numbers of sites over long periods, there is limited knowledge about how treatments of different types interact together to reduce crashes.

Future research into interactions between treatments will be assisted if all component treatments of multiple treatment projects are correctly recorded. The primary treatment should be indicated if possible. Otherwise, some indication of the relative safety values of each treatment would be helpful. Correct and complete categorisation of multiple treatment projects will eventually enable researchers to provide guidance about which combinations of measures work well and otherwise.

Examples

The following examples illustrate how to code multiple treatments using the DCT table.

If a sealed shoulder of less than one metre was added to an existing paved road that had no shoulder at all, two treatments would have been implemented — first, T12.3.1 (add a shoulder/s to a road where no shoulder previously existed and the shoulder is 1.0m or less (≤ 1.0m)) and second, because the new shoulder is sealed, T10.2 (seal surface of unsealed shoulders only on a paved road [shoulder width not specified]). The second treatment could have been coded as T10.2.1 (… & shoulder is 1.0m or less (≤ 1.0m) wide), however, this does not provide any additional information since the width has already been accounted for by using the T12.3.1 sub-code.

Sealing an unpaved road with a shoulder of width of 1.8m without changing the shoulder width would be coded as T10.3.2 only (seal surface of unpaved road lanes and unpaved shoulders … where shoulder between 1.0m and no more than 2.5m wide (>1.0m ≤ 2.5m)), because no change was made to the shoulder width.

Sealing of the road and shoulders in the previous example, but this time increasing the shoulder width to >2.5m, would be coded as T12.4.3 (widen existing road shoulder to greater than 2.5m (> 2.5m)) and T10.3 (seal surface of unpaved road lanes and unpaved shoulders [shoulder width not specified]). The sub-code T10.3.3 (where shoulder greater than 2.5m wide (> 2.5m)) could have been used, however, it does not provide any additional information because the T12.4.3 code indicates the shoulders were widened to >2.5m.

The DCT table could include sub-codes in T12 that would distinguish between sealed and unsealed roads that are being widened. However, in designing the table, there was an intention to avoid redundancy and duplication for coding multiple treatment projects. This however raises the question of how one knows from the DCT codes whether a road that has undergone a widening treatment is sealed or unsealed when no change in surface type has occurred. This information would be contained in the description of the road condition prior to the project. If no code is used to indicate a 'surface type' change then it is recognised that the road surface remained unchanged.

Knowledge of the pre-treatment surface type would be important to test whether widening treatments have different effects on unsealed and sealed roads.

Glossary

Acceleration lane

An acceleration lane allows traffic entering a road to match their speed with, and to safely merge into the main flow of traffic along the road into which they are entering. This is a specific type of 'auxiliary lane' (see below).

At grade

To describe something as being 'at grade' with something else is to imply they are on the same level. For example, a railway crossing is said to be at grade with a road or highway, when they are on the same level at the point where they cross — as opposed to where one passes over or under the other.

Attenuation device

An attenuation device absorbs the energy of impact when a vehicle collides with the device. Examples of crash attenuation devices include cushioning devices such as sand or water filled containers, plus crumple zones placed at the terminus of a dividing fence or median. Attenuation devices crush under the impact load, reducing the severity of damage to the vehicle and its occupants.

Auxiliary lane

An auxiliary lane is a separate lane placed alongside the direction of travel that allows a vehicle to move into, or out of, a side road.

Barriers

Barriers, including guardrails, can be of three types: rigid, semi-rigid or flexible. Examples include rigid concrete median or kerbside barriers, semi-rigid 'W-Beam' type metal fencing, which has some energy absorption properties, or flexible rope wire type of fencing, which has very good energy absorption properties.

Blister

Also known as a curb extension, a blister is a traffic calming measure intended to slow the speed of traffic and increase driver awareness, particularly in built-up and residential neighbourhoods. They also allow pedestrians and vehicle drivers to see each other when vehicles parked in a parking lane would otherwise block visibility.

Crossfall

Crossfall is a measure of the transverse slope of the road, that is the slope, measured at right angles to the alignment of the surface of any part of a carriageway.

Deceleration lane

A deceleration lane allows vehicles approaching a turn at an intersection to move out of the flow of through traffic and slow down prior to initiating the turn onto the side road. This is a specific type of 'auxiliary lane' (see above).

Grade

The gradient of a slope or road surface is the rate of ascent or descent. It describes the amount of deviation in vertical alignment from a perfectly level or horizontal surface to the inclined plane of the road in question.

Intersection treatments

See 'spot'.

Length

See 'mid-block'.

Mid-block

Mid-block treatments are conducted along a road length, also called 'route treatments'.

Route treatments

See 'mid-block'.

Slip lane

A slip lane allows vehicles to turn at an intersection without actually entering the intersection and interfering with through traffic. There is usually a raised island separating the slip lane from the traffic flow that continues straight through the intersection.

Splitter island

A splitter island is an isolated, raised median at intersections that divides traffic travelling in opposite directions. These islands are referred to as 'medians' (T02) and are usually found on the approach and up to the intersection junction (T02.6). Splitter Islands can also be triangular in shape to prevent both through and right turn movements at an intersection.

Spot

Treatments undertaken at an intersection or at a single well defined site on a road.

Superelevation

Superelevation is also known as the 'cant' of a road or 'camber'. Appropriate superelevation of a road minimises the effect of centripetal force on driver and passenger comfort, but more importantly it maximises the adhesion of the tyre to the road when cornering.

A difference in elevation of the two road edges, that is, a cant not equal to zero results in a banked turn, allowing vehicles travelling through the turn to go at higher speeds than would normally be possible. Superelevation also helps rainwater drain from the road surface, which improves wet surface traction. Insufficient superelevation in a corner can result in high speed 'run-off-road' accidents where rainwater forms pools on the road surface. Superelevation is an important factor in the speed and safety of road corner design.

Two-way crossfall

Two-way crossfall is the negative slope of the lanes from either side of the centre on a road, which allows for water to drain off the road surface, thus reducing the likelihood of pooled water causing 'loss of traction' accidents (see also crossfall).

Acknowledgements

BITRE acknowledges the input from road safety experts from ARRB Group in developing its treatment classification system.

Austroads guides (2004a, 2004b and 2005b) were consulted extensively in the preparation of the system. The *Guides to Traffic Engineering Practice* series were important sources for the engineering treatments and terminology used, in particular parts 4 'Treatment of Crash Locations', 5 'Intersections at Grade' and 12 'Roadway Lighting'. The 1993 Federal Office of Road Safety manual *Towards Traffic Calming: A Practitioners Manual of Implemented Local Area Traffic Management and Blackspot Devices* was a valuable source on local area traffic management.

APPENDIX B
Valuation of crash costs

Of the various ways to cost road crashes, two receive serious consideration: the human capital and the willingness-to-pay approaches.

The human capital approach attempts to measure the impacts of death or injury on current and future national output. The primary component is the present value of expected future before-tax earnings. Vehicle damage, medical and other costs are added in. In some cases, estimates are incorporated of the costs of pain, suffering and grief by using insurance payments or court compensation payments.

The willingness-to-pay approach attempts to measure the amount individuals are willing to pay to reduce the probability of death or injury. Estimates are obtained from either 'revealed preferences' as evidenced in situations where individuals trade off costs against risk of death or injury, or 'stated preferences' whereby people are asked how much they would be willing to spend to reduce the risk of death or injury in hypothetical situations.

Each approach has its pros and cons. The main advantage of the willingness-to-pay approach over the human capital approach is that it offers a more complete coverage of impacts on society. The human capital approach fails to capture the value individuals place on their own lives and those of others over and above current and future earnings. The willingness-to-pay approach is therefore more desirable for cost–benefit analysis where the aim is to gauge, as far as possible, the full value that members of society place on road safety impacts of projects. The greater degree of comprehensiveness explains why willingness-to-pay estimates of crash costs are normally well above human capital estimates.

The main advantages of the human capital approach over the willingness-to-pay approach are that the resultant crash costs are comparatively simple to estimate and use, and that the estimates are far less imprecise.

Widely differing values of willingness-to-pay are obtained depending on the circumstances in which people pay to reduce risk and the methods used to collect and analyse the data. According to BTCE (1996, pp. 6 and 12), the human-capital-based statistical value of life in Australia in 1992 dollars was $616 000. This compares with estimates from the US of willingness-to-pay-based values ranging between $1.3m and $10.2m in 1991 Australian dollars.

The Austroads unit costs used for the cost–benefit analysis in chapter 9 were derived from BTE (2000), which followed a modified human capital approach. A similar approach was followed to obtain the BITRE's most recent cost of crashes estimate, BITRE (2009).

The 'modified' approach includes 'non-pecuniary losses', which covers loss of quality of life resulting from injuries, and pain, grief and suffering of families and relatives as a result of fatalities. The values were obtained from statutorily-determined lump-sum compensation payments (BITRE 2009, p. 28).

APPENDIX C

Effect of non-target crashes in the data

This appendix explores the impact non-target crashes on treatment effectiveness estimated via Poisson regression. The formulas also show the relationship between the data and the results derived from the Poisson regression model.

Notation

Much of the notation has been adapted from Hauer (1997).

J = total number of sites with projects

K_i = count of pre-treatment crashes at site i

Y_i = observed years (or more generally, time periods) of crash data pre-treatment for site i, numbered $1, 2, 3, \ldots, y, \ldots, Y_i$

k_{iy} = count of pre-treatment crashes at site i during year y, $K_i = \sum_{y=1}^{Y_i} k_{iy}$.

L_i = count of post-treatment crashes at site i

Z_i = observed years (or more generally, time periods) of crash data post-treatment for site i, numbered $1, 2, 3, \ldots, z, \ldots, Z_i$

l_{iz} = count of pre-treatment crashes at site i during year z, $L_i = \sum_{z=1}^{Z_i} l_{iz}$.

θ = treatment effectiveness index (TEI), the count of post-treatment crashes as a proportion of the count of pre-treatment crashes. $1 - \theta$ is the 'crash reduction factor'.

Maximum likelihood estimation of treatment effectiveness index

The Poisson distribution with mean m is $p(N=n)=\frac{e^{-m}m^{n}}{n!}$, with the log of the probability $n\,ln(m) - m - ln(n!)$.

For an individual site, *i*, with mean annual crashes m_i before treatment and θm_i after treatment, and with crash counts extending over Y_i years before treatment and Z_i years after treatment, the log-likelihood function is

$$\mathcal{L}_i = ln(m_i)\sum_{y=1}^{Y_i} k_{iy} - Y_i m_i - \sum_{y=1}^{Y_i} ln(k_{iy}!) + ln(\theta m_i)\sum_{z=1}^{Z_i} l_{iz} - \theta Z_i m_i - \sum_{z=1}^{Z_i} ln(l_{iz}!)$$

Summing the log-likelihoods for all sites

$$\mathcal{L} = \sum_{i=1}^{J}\left[ln(m_i)\sum_{y-1}^{Y_i} k_{iy}\right] - \sum_{i=1}^{J} Y_i m_i - \sum_{i=1}^{J}\sum_{y=1}^{Y_i} ln(k_{iy}!) +$$
$$\sum_{i=1}^{J}\left[ln(\theta m_i)\sum_{z=1}^{Z_i} l_{iz}\right] - \theta\sum_{i=1}^{J} Z_i m_i - \sum_{i=1}^{J}\sum_{z=1}^{Z_i} ln(l_{iz}!)$$

To find the most likely values of θ and m_i given the data, the partial derivatives are set equal to zero.

$$\frac{\partial\mathcal{L}}{\partial\theta} = \frac{\Sigma_{i=1}^{J}\Sigma_{z=1}^{Z_i} l_{iz}}{\theta} - \sum_{i=1}^{J} Z_i m_i = \frac{\Sigma_{i=1}^{J} L_i}{\theta} - \sum_{i=1}^{J} Z_i m_i = 0$$

The estimated TEI is given by

$$\theta = \frac{\Sigma_{i=1}^{J} L_i}{\Sigma_{i=1}^{J} Z_i m_i} \qquad (1)$$

which is:

- the total number of post-treatment crashes at all sites in the data, divided by
- the expected number of crashes in all observed post-treatment years at all sites in the absence of treatment.

$$\frac{\partial\mathcal{L}}{\partial m_i} = \frac{\Sigma_{y=1}^{Y_i} k_{iy}}{m_i} - Y_i + \frac{\Sigma_{z=1}^{Z_i} l_{iz}}{m_i} - \theta Z_i = \frac{K_i + L_i}{m_i} - (Y_i + \theta Z_i) = 0$$

for all i.

The estimated pre-treatment mean for site i is given by

$$m_i = \frac{K_i + L_i}{Y_i + \theta Z_i} \tag{2}$$

which is:

- the total number of observed crashes for site i in the data (post- and pre-treatment combined), divided by
- the total number of observation periods (post- and pre-treatment combined), with the post-treatment number of periods weighted to account for the expected lower post-treatment crash rate.

The system of $J+1$ simultaneous equations (equation (1) plus J equation (2)s, one for each site i) can be solved to obtain values for θ and the $m_i s$.

If only the value of θ is required, the solution can be found by iteration of

$$\theta = \sum L_i \Big/ \left[\frac{Z_i\left(K_i + L_i\right)}{Y_i + \theta Z_i}\right]$$

(All sigma signs in the previous equation and hereafter are over i and sum to J.)

In the special case where the number of observation periods is the same for all sites, that is, $Y_i = Y$ and $Zi = Z$ for all i, the J equation (2)s can be summed to give

$$\sum m_i = \frac{\Sigma K_i + \Sigma L_i}{Y + Z} \tag{3}$$

which when substituted into equation (1) gives

$$\theta = \frac{\Sigma L_i}{Z} \Big/ \frac{\Sigma K_i}{Y} \tag{4}$$

Hence, the estimated TEI is

- the post-treatment average annual crash rate for all sites combined, divided by
- the pre-treatment average annual crash rate for all sites combined.

Substituting equation (4) into equation (3), the estimated value for each m_i is

$$m_i = \frac{\Sigma K_i}{Y\left(\Sigma K_i + \Sigma K_i\right)}\left(K_i + L_i\right)$$

The equations derived in this section provide simple ways to estimate TEIs from crash data where the treatment is the only explanatory variable. Poisson regression is required where there are additional explanatory variables.

Statistical significance of treatment effectiveness index estimate

To test the statistical significance of the estimated TEI, the variance of the estimate is required. The variance–covariance matrix for a maximum-likelihood estimation of a model is the inverse of the 'Fisher information matrix'. The Fisher information matrix is negative the Hessian matrix (the matrix of partial derivatives) of the log–likelihood function.

For the log–likelihood function derived above, the Fisher information matrix is

$$-\begin{pmatrix} \frac{\partial^2 \mathcal{L}}{\partial \theta^2} & \frac{\partial^2 \mathcal{L}}{\partial \theta\, \partial m_1} & \frac{\partial^2 \mathcal{L}}{\partial \theta\, \partial m_2} & \cdots & \frac{\partial^2 \mathcal{L}}{\partial \theta\, \partial m_J} \\ \frac{\partial^2 \mathcal{L}}{\partial m_1\, \partial \theta} & \frac{\partial^2 \mathcal{L}}{\partial m_1^2} & \frac{\partial^2 \mathcal{L}}{\partial m_1\, \partial m_2} & \cdots & \frac{\partial^2 \mathcal{L}}{\partial m_1\, \partial m_J} \\ \frac{\partial^2 \mathcal{L}}{\partial m_2\, \partial \theta} & \frac{\partial^2 \mathcal{L}}{\partial m_2\, \partial m_1} & \frac{\partial^2 \mathcal{L}}{\partial m_2^2} & \cdots & \frac{\partial^2 \mathcal{L}}{\partial m_2\, \partial m_J} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 \mathcal{L}}{\partial m_J\, \partial \theta} & \frac{\partial^2 \mathcal{L}}{\partial m_J\, \partial m_1} & \frac{\partial^2 \mathcal{L}}{\partial m_J\, \partial m_2} & \cdots & \frac{\partial^2 \mathcal{L}}{\partial m_J^2} \end{pmatrix} = \begin{pmatrix} \frac{\Sigma L_i}{\theta^2} & Z_1 & Z_2 & \cdots & Z_J \\ Z_1 & \frac{K_1 + L_1}{m_1^2} & 0 & \cdots & 0 \\ Z_2 & 0 & \frac{K_2 + L_2}{m_2^2} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Z_J & 0 & 0 & \cdots & \frac{K_J + L_J}{m_J^2} \end{pmatrix}$$

The variance of θ is the top left element of the inverse of this matrix. It can be obtained as follows

$$Var(\theta) = 1 \Big/ \left[\frac{\Sigma L_i}{\theta^2} - \sum \left(\frac{Z_i^2 m_i^2}{K_i + L_i} \right) \right]$$

After some substitutions, this simplifies to

$$Var(\theta) = \theta \Big/ \sum \left(\frac{Y_i Z_i m_i}{Y_i + \theta Z_i} \right) \tag{5}$$

If a treatment has no effect, θ will equal one. The statistical significance of an estimate for θ is determined by testing whether the estimate of $\ln(\theta)$ is significantly different from zero.

With the estimate of θ log-normally distributed, the standard error of the estimate of $ln(\theta)$ is $\sqrt{var(\theta)}/\theta$.

The z-statistic is therefore $\theta ln(\theta)/\sqrt{var(\theta)}$.

Non-target crashes

Target crashes were defined in chapter 7 as crashes the occurrence of which can be materially affected by the treatment. For the purposes of the following analysis, non-target crashes are defined strictly as crashes upon which the treatment has no effect whatsoever.

The expected occurrence rate for non-target crashes at site i, is $\rho_i m_i$ where m_i is the expected pre-treatment rate for target crashes and $\rho_i \geq 0$ is a site-specific proportionality factor. The non-target crash rate is the same before and after treatment. It is assumed the number of non-target crashes during the pre-treatment observation period at each site totals exactly $Y_i \rho_i m_i$ and the number during the post-treatment period sums to totals exactly $Z_i \rho_i m_i$. The effects of random variations in non-target crash rates have not been considered.

The superscript * is used to indicate the estimated values of θ and the m_is with non-target crashes added to the data.

Effect on estimated treatment effectiveness index

With non-target crashes in the data the maximum-likelihood estimates of the TEI and pre-treatment crash rates respectively are, from equation (1)

$$\theta^* = \frac{\Sigma L_i + \Sigma Z_i \rho_i m_i}{\Sigma Z_i m_i^*} \tag{6}$$

and from equation (2)

$$m_i^* = \frac{K_i + L_i + (Y_i + Z_i)\rho_i m_i}{Y_i + \theta^* Z_i} \tag{7}$$

Substituting $\sum L_i = \theta \sum Z_i m_i$ from equation (1) into equation (6) and $K_i + L_i = m_i(Y_i + \theta Z_i)$ from equation (2) into equation (7)

$$\theta^* = \frac{\theta \sum Z_i m_i + \sum Z_i \rho_i m_i}{\sum Z_i m_i^*} \tag{8}$$

$$m_i^* = \frac{m_i \left[(1+\rho_i)Y_i + (\theta + \rho_i)Z_i\right]}{Y_i + \theta^* Z_i} \tag{9}$$

With the m_i□s, θ and the ρ_i□s given, there are $J+1$ equations with $J+1$ unknowns, the values of θ^* and the m_i^*□s. The solution is given by

$$\theta^* = \frac{\Sigma(\theta + \rho_i)Z_i m_i}{\Sigma(1 + \rho_i)Z_i m_i} \tag{10}$$

and

$$\sum m_i^* = \sum (1 + \rho_i) m_i \tag{11}$$

This can be demonstrated by substituting equations (10) and (11) into equation (8) and by substituting equation (10) and $m_i^* = (1 + \rho_i)m_i$ into equation (9) and summing over i. Note that $m_i^* = (1 + \rho_i)m_i$ does not necessarily hold for individual sites. Equation (11) holds for all sites combined.

If ρ_i is the same for all sites, equation (10) reduces to the formula given in chapter 7, $\theta^* = (\theta + \rho)/(1 + \rho)$.

Effect on estimated crashes avoided per annum

The estimated number of crashes avoided per annum is $(1 - \theta)\sum m_i$ in the absence of non-target crashes, and $(1 - \theta^*)\sum m_i^*$ with non-target crashes included. The error in the estimate caused by non-target crashes, E, is

$$E = (1 - \theta^*)\sum m_i^* - (1 - \theta)\sum m_i$$

Substituting equations (10) and (11) and rearranging

$$E = (1 - \theta^*)\left[\frac{\Sigma Z_i m_i \Sigma(1 + \rho_i)m_i}{\Sigma(1 + \rho_i)Z_i m_i} - \sum m_i\right]$$

This expression will equal zero when

$$\frac{\Sigma(1 + \rho_i)m_i}{\Sigma m_i} = \frac{\Sigma(1 + \rho_i)Z_i m_i}{\Sigma Z_i m_i}$$

These two ratios will be equal and the error zero if one of the following three conditions holds.

1. ρ_i is the same for all sites. The non-target crash rate as a proportion of the pre-treatment target crash rate is the same for all sites.
2. Z_i is the same for all sites. All sites have the same number of post-treatment observation periods.
3. ρ_i and Z_i differ between sites but the values are such that the two ratios are equal.

In practice, it may be reasonable to assume that condition 1 holds approximately. Condition 2 is unlikely to hold because sites with more recently completed projects will have fewer years of data and hence lower values of Z_i. However, as long as the Z_is are randomly distributed across the different values of the m_is and the ρ_is, the ratios should be similar.

The ratios might differ significantly if more recently treated sites had, on average, significantly different target crash rates from sites with older projects, for example, due to the program concentrating on more highly or less highly trafficked sites, or different proportions of non-target crashes, for example, due a change in the way crashes are assigned to sites.

Effect on the variance and z-statistic of the estimate

The effect of non-target crashes on the variance of the estimate of θ is not obvious because the two variables in equation (5) that change — θ and the m_i's — both increase with offsetting impacts.

Provided the variance increases or reduces by only a small amount, the z-statistic becomes closer to zero because the addition of non-target crashes raises the TEI estimate closer to one, and the numerator of the z-statistic, $\theta\ ln(\theta) < 0$, closer to zero (for values of θ between 0.368 and 1.0). The presence of non-target crashes in the data therefore is most likely to reduce the statistical significance of TEI estimates.

Abbreviations

ABS	Australian Bureau of Statistics
ADVF	Average Daily Vehicle Flow
AIC	Akaike's Information Criterion
ANAO	Australian National Audit Office
ATC	Australian Transport Council
BCR	Benefit–Cost Ratio
BIC	Bayesian Information Criterion
BITRE	Bureau of Infrastructure, Transport and Regional Economics
BTCE	Bureau of Transport and Communications Economics
BTE	Bureau of Transport Economics
CBA	Cost–Benefit Analysis
CPI	Consumer Price Index
CRF	Crash Reduction Factor
DAA	Data Analysis Australia
DCA	Definitions for Classifying Accidents
DCT	Definitions for Classifying Treatments
DIT	Department of Infrastructure and Transport
NBSP	National Black Spot Program
NPV	Net Present Value
PDO	Property Damage Only
RCMPI	Road Construction and Maintenance Price Index
RSA	Road Safety Audit
RUM	Road User Movement
TEI	Treatment Effectiveness Index

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